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Function revisited: How infants construe functional features in their representation of objects

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I. Introduction

“...prior to operatory classifications based on...objective equivalences...there exists a mode of classification based on the relationship between actions which are functional...” (Piaget, Grize, Szeminsk, & Bang, 1977, p. 15)

“...an object is first identified as having important functional relations...and...perceptual analysis is derivative of the functional concept, not a priori essential to it.” (Nelson, 1974, p. 284)

“Affordances relate the utility of things, events, and places to the needs of animals and their actions in fulfilling them...Affordances themselves are perceived and, in fact, are the essence of what we perceive.” (Gibson, 1982, p. 60)

These quotations make clear that object function (or *affordance*, in Gibson’s terms) has long been believed to play a major role in infants’ conceptual development. Function has been argued to be central to some concepts (Nelson, 1972, 1973) and may be at the core of infants’ and young children’s conceptions of objects and artifacts (Keil, 1989). Functional commonalities can be more compelling in children’s forming of concepts and learning of words than other types of commonalities such as color or other aspects of perceptual similarity (Horst, Oakes, & Madole, 2005; Kemler Nelson, Russell, Duke, & Jones, 2000). Moreover, the importance of function may have an underlying neurophysiological basis. For example, apraxic patients have deficits specific to their knowledge of object *function*, defined as the intended use of those objects (Buxbaum & Saffran, 2002).

It is somewhat surprising, given its importance, that researchers have not adopted a single, unified operational definition of object function. For example, in psychological research function sometimes refers to the *goal* of acting on an object (e.g., to sharpen pencils, Buxbaum & Saffran, 2002), sometimes refers to the *characteristic actions of the objects themselves* (e.g., an object swings when hung from a hook, Booth & Waxman, 2002), and sometimes refers to the *consequences* of acting in a particular way on an object (e.g., a squeaking sound is produced when an object is squeezed, Perone & Oakes, 2006). In other words, function is not uniformly defined as why one acts on objects, how an object reacts to actions, or the consequence of actions on objects. For example, a shoe can protect the foot (why you use it), soar across the yard when thrown (the reaction when acted on), and make a loud noise (the consequence of banging it on the table). Should such different kinds of

function be considered interchangeable in designing studies probing infants' emerging understanding of function?

This lack of a clear definition is perhaps even more surprising because function has often been considered a conceptual property of objects. For example, in her seminal work on children's developing semantic knowledge, Nelson (1973; 1974; 1979) argued that children's first categories are based on function. That is, children have a conceptual basis for extending labels, rather than merely extending labels to objects that simply look alike. Perceptual similarities are used to extend labels only if they predict function—such as the ability of a bowl-shaped object to be put on the head like a *hat*. In subsequent work, function is at least partly equated with a deep, conceptual knowledge that goes beyond attention to appearance, physical structure, or idiosyncratic uses of an object. For example, according to Bloom (1996), the intended use of the designer of an object is the *essence*, or core, of artifact categories, even when an actor uses the object for a different purpose (for similar arguments see Casler & Kelemen, 2005; Keil, 1989; Matan & Carey, 2001). The results of several studies have been taken as evidence that even very young children's understanding of function reflects a “design stance,” or the understanding that function is related to the intention of the designer (e.g., Jaswal, 2006). That is, functions are seen as intentional properties of objects, and evidence that infants recognize functions as intentional indicates that they are recognizing deep, conceptual properties of objects, as opposed to superficial, perceptual properties.

Similarly, arguments about the shape-bias in early language development often pit apparently superficial shape similarities against deeper similarities in function. Researchers have examined whether shape itself is the salient feature—the assumption being that shape is a less sophisticated way of extending a label—or whether children consider shape and function together, which would suggest an understanding that structural features constrain functional features (Diesendruck, Hammer, & Catz, 2003; Diesendruck, Markson, & Bloom, 2003; Kemler Nelson, Frankenfield, Morris, & Blair, 2000), and can be a cue to hidden functional features (Welder & Graham, 2001). As a result of this general conception of function, in infant studies function is often pitted against appearance in an effort to show the conceptual basis of infants' categorization (e.g., Trauble & Pauen, in press).

However, we previously argued that the distinction between conceptual and perceptual categorization is not clear-cut (Madole & Oakes, 1999; Oakes & Madole, 2003). That is, it is not always clear that “conceptual” properties differ fundamentally from “perceptual” properties. Instead, properties may vary along a continuum in terms of how heavily they are specified by perceptual aspects (hue, contours, and so on) versus conceptual aspects (breathes, self-produced motion, and so on). Function, in fact, provides a particularly compelling example of a property that has both “conceptual” and “perceptual” aspects. Like many structural or appearance-based features, function can often be observed by looking at an object—perhaps as someone else interacts with it. Function, like many object characteristics, emerges from other properties or pieces of information available—such as whether the object is acted on, whether there is an outcome, the characteristics of the actor, the way the actor performs the action, and the individual's past experience with the object. Although some researchers might interpret this complexity as evidence that function is conceptual in nature, in reality appearance-based features are characterized by similar complexity. Our perception of an object's color, for example, is the combination of hue, saturation and brightness. Moreover, an object's perceived color changes with changes in the lighting conditions and as the object is moved or manipulated. Similarly, we recognize an object's shape only by considering its boundaries, shading, how parts are organized, and so on. Like color, the apparent shape of an object changes as the object is seen from different views or as the object is manipulated. Thus, both appearance and function are

complexly determined by multiple factors, and perceiving and representing either type of feature involves the integration of multiple sources of information. The distinction between obvious and non-obvious or conceptual and perceptual, therefore, is misleading, and leads to an incomplete understanding of how infants use many different features in their categorization.

In this chapter we examine the issue of object function and propose a new way of thinking about function as it relates to early conceptual development. Our view of function is similar, in many ways, to Barsalou and colleagues' HIPE model of function (Barsalou, Sloman, & Chaigneau, 2005; Chaigneau, Barsalou, & Sloman, 2004). In this model, object functions are dynamically constructed using knowledge about *how* an object has been or was designed to be used (H), an actor's *intentions* while interacting with the object (I), aspects of the *physical environment* that determine how an object can be used (P) and finally, the *event sequence* (E) which involves the object's behavior and any outcomes that occur during the interaction. As in that model, we do not see function as an independent, unitary property of objects. Instead, function is a mental model or construct that emerges as an actor interacts with an object and the state of the object changes over time.

We did not think about function this way when we began studying the role of function in infants' learning about, identifying, and categorization of novel objects nearly 20 years ago. Over the years our thinking about function has changed—from an intuitive conception of function (which we argue characterizes much of the work on object function in infancy) to a consideration of the features that comprise object function and how infants represent that collection of features. This chapter is the product of this nearly two decades of thinking about these issues.

This chapter is divided into three major sections. In the first section, we provide background information and an overview of the issues surrounding the study of object function. Here we discuss how function has (and has not) been defined in the literature as well as the nature of function as a property of objects. In the second section, we elaborate our conception of function as an emergent property of an object or event given other features or properties. In the context of this discussion we identify what we believe are the important features that typically comprise "function," and we discuss evidence from developmental and cognitive science, as well as neuroscience, about how such features are represented.

Finally, in the third section we describe our own program of work examining infants' sensitivity to, representation of, and categorization using object function. This work began before much of the empirical and theoretical work described in the first parts of the paper was conducted. Thus, some of our original assumptions were naïve with respect to how function should be defined or construed. However, this work provided an important starting point for our current understanding of object function and the future direction of our work in this area.

II. The construct of object function

It has been widely demonstrated that functional properties play a central role in object recognition and categorization (Keil, 1989; Rips, 1989). Although researchers have disagreed about whether young children's categories depend on superficial, "perceptual" similarities or deeper, "conceptual" functional similarities (Diesendruck, Hammer et al., 2003; Nelson, 1973), the features considered the "functions" of objects clearly have a powerful influence on how infants understand and learn about objects. For example, observing how objects are used (and perhaps the resulting effect) can increase infants' attention to a dimension that predicts that feature. Wilcox and Chapa (2004) for example, showed that demonstrating the different functions of two objects that differed in color

appeared to highlight the significance of color: The function demonstration induced 7- and 9-month-old infants to use the colors of a different set of object in a subsequent object individuation task; infant who did not see the function demonstration did not use color to individuate objects. Booth and Waxman (2002) observed a similar effect when testing 14-month-old infants' attention to the surface similarity of a collection of objects. Infants only seemed to recognize those commonalities when the objects' functions were demonstrated during learning.

Function may also be important in infants' mapping of names onto objects. Generally, children use object shape to extend the names of novel objects (e.g., Landau, Smith, & Jones, 1988). However, when the *function* of objects is demonstrated, children as young as two years of age will generalize the names of those objects to other new objects with the same function. (Kemler Nelson, Russell et al., 2000). Thus, ample evidence across many different kinds of studies indicates that functional properties play a central role in the identification and categorization of objects.

A. Defining function

Despite its significance in young children's (and adults') object concepts, function has rarely been clearly, uniformly, or explicitly defined. Consider the following definitions that come from research on infant conceptual development, adult language, and neuropsychological work with aphasic patients. Function is

“what an object is used for” (Kellenbach, Brett, & Patterson, 2003, p. 30)

“the action an object affords and is specifically fitted for” (Wilcox & Chapa, 2004, p. 279)

“the use of a thing” (Booth, 2006, p. 146)

“the purpose for which a particular object is conventionally used” (Regier, Carlson, & Corrigan, 2005, p. 191).

“...capacities of an object to act or be acted upon in a specific manner...” (Prasada, 2005, p. 206).

This list shows that there is no single, clear definition of function used in the literature. Moreover, many studies claim to manipulate function or probe knowledge of object function without providing any definition at all (e.g., Buxbaum & Saffran, 2002; Trauble & Pauen, in press). Often, function is defined intuitively—researchers create stimulus objects that have a particular “function,” but that function is based on the researchers' intuition of what a function is. Some researchers simply state that function is the “use” of the object without clearly indicating whether it is the intended use by the creator, how the object is typically used, or the possible uses of the object (e.g., Booth, 2006). In part, function may not be explicitly defined because researchers have a belief that object function is self-evident—we recognize it when we see it.

An additional problem arises because definitions of function vary depending on the researcher's goals in studying function. For some, functions are the uses intended by the creator of the object, and thus the primary research goal is to determine when children adopt this “design stance” (Jaswal, 2006; Matan & Carey, 2001). How structural properties constrain what can be done with an object is sometimes important in the functions used (Kemler Nelson, 1999), although it is not always clear whether those structural constraints are imposed by the potential actions by the subject (and thus would change with development) or constraints imposed by the design of the maker, or both. For others, functions are actions on objects that produce outcomes (e.g., Wilcox & Chapa, 2004), and can be arbitrarily related to the object structure or the intention of the designer. Clearly, all

these features, along with many others (the physical limitations of the actor, the consequence of acting on the object, how the object has been used in the past, and so on) can be considered aspects of function.

Such differing definitions may not reflect the same underlying construct. Features or properties that are labeled “object function” in different studies may not actually reflect the same type of feature or property, and thus they may not be processed in the same way. For example, Trauble and Pauen (in press) operationalized function by creating complex novel objects with parts that allowed them to be used with another device to produce some outcome—for example, a protrusion on the object could be inserted in an opening of an apparatus to produce a sound. Is such a function equivalent to squeezing an object to produce a squeak (Horst et al., 2005) using a scoop to pour salt (Wilcox & Chapa, 2004), or hanging a bag by its handle so it would swing (Booth & Waxman, 2002)?

Although such functions are treated interchangeably, the fact that researchers have adopted different criteria for considering a feature as part of the object’s function makes it difficult to compare the results of their work. For example, Trauble and Pauen (in press) and Madole, Oakes, and Cohen (1993) both used object examining tasks to investigate infants’ attention to object function. However, Trauble and Pauen (in press) found that 11-month-old infants were sensitive to object function, whereas Madole, Oakes, and Cohen found that 14-month-old infants, but not 10-month-old infants, were sensitive to function. Such discrepant findings may reflect differences in how the researchers defined function (and instantiated function in their stimuli). The lack of consensus in what constitutes an object’s *function* limits comparisons across investigations and weakens converging evidence about the importance of function.

Despite the lack of a single, agreed-upon operational definition of object function, most conceptions of function include the same type of features, at least in the context of infant conceptual development. Functions generally involve an action and an outcome. An object’s function is that it bangs on a peg and makes a sound (Wilcox & Chapa, 2004), swings to hit chimes, making them ring (Booth, 2006), or clicks when rolled (Horst et al., 2005; Perone & Oakes, 2006). Functions also appear to include actions performed by a human agent. In virtually all studies examining infants’ attention to function, human agents (or at least human hands) demonstrate object functions such as pouring salt (Wilcox & Chapa, 2004) or pushing an object which then clicks (Horst et al., 2005; Perone & Oakes, 2006).

Researchers differ, however, in how they emphasize these properties. For example, for some, functions require that actions on objects produce an outcome. Scooping actions result in the pouring of salt. Swinging an object causes chimes to ring. Squeezing an object causes a squeaking sound to be heard. Moreover, the presence of an outcome may have particular significance when learning about objects. Wilcox and Chapa (2004), for example, found that although demonstrating the different functions of differently colored objects enhanced attention to color, demonstrating “non-functional” actions (i.e., moving the object without any obvious outcome) did not enhance infants’ responding to color. The power of function to enhance attention to predictive features lies, at least partly, in the presence of an outcome.

However, most instantiations of function in the infant literature conflate the action and the outcome. This is a problem because we still know relatively little about how these different aspects of function are perceived by infants—that is, we do not know whether infants represent the action and outcome as a unified, single feature of *function*. Moreover, conflating action and outcome does not acknowledge the contribution of each dimension in infants’ attention to, processing of, and representation of the events. Consider the outcomes in the previous examples: salt moves from one location (the scoop) to another (the table)

during a few seconds of the event, a chime rings for a short time when the object strikes it, squeaking is heard intermittently during the action on the object. These outcomes are intermittent, dynamic, and often involve a sound. Thus, the *outcomes* may attract infants' attention and their representation of *function* may be a result of their attention to the outcome. For example, the difference between the functional and non-functional manipulation observed by Wilcox and Chapa's (2004) may not reflect the fact that one condition involved function and the other did not; rather, the difference may reflect the fact that one condition involved an outcome and the other did not, and the effects may solely have been due to infants' attending to the outcomes. There is no evidence that infants attended to the action (or associated the action with a particular outcome) in either context.

Another functional feature emphasized by researchers is the presence of an actor. Properties of objects that could be construed as relevant to function—for example, their characteristic movement trajectories—but that do not involve a human agent typically are not described in terms of *function*. Rakison (2004; Rakison & Poulin-Dubois, 2002), for example, does not use the label “function” when studying infants' representations of the distinctive movement trajectories of objects. Booth (2000) made her actions “non-functional” by having them occur in the absence of an actor. Clearly, therefore, researchers assume that functions involve the relationship between an actor and an object. Interestingly, infants' learning of non-functional features—such as movement trajectories—does parallel the development of infants' learning of functions in some ways. Although infants, like adults, may assume that functions are actions performed on an object by an *agent*, this hypothesis has not been adequately tested. We have not yet systematically studied whether the presence or absence of an agent (human or non-human) changes infants' understanding of a collection of actions that might be described as the object's function.

Note, however, that in the context of animate objects *function* is meaningful even in the absence of an agent. For example, Rakison and Cohen (1999) referred to the *functions* of the legs of cows (walking), and observe that in the second year infants interacted with objects with legs in functionally appropriate ways (i.e., they made them hop or walk). This example illustrates the many uses of the term *function*. When referring to an inanimate object, the function may require actions performed by an agent. But, when referring to parts of an animate object, a more teleological referent may be appropriate. That is, for animate objects, the *functions* of parts may refer to what those parts allow the animate being to do—or what those parts are *for* (Kelemen, Widdowson, Posner, Brown, & Casler, 2003).

A final aspect of function that is critical according to many theorists is the intention of the creator (Bloom, 1996; Casler & Kelemen, in press). Significant research has been aimed at attempting to understand when children adopt this view of function. For example, Casler and Kelemen (2005) observed that children as young as 2 years of age can learn after only one episode what a tool is “for.” They suggest that this finding reveals that very young children are biased to categorize tools by their intentional design, and have the foundation of the design stance (but see Truxaw, Krasnow, Woods, & German, 2006, for an alternative view).

These features—actions that produce outcomes, the intentional action of a human actor—are important for the *researchers'* definitions of function. We know little about how *infants* characterize function. For example, infants might well consider *self-produced movement*, *agent-produced movements* and *agent-produced movements leading to an outcome* all as “functional.” Although we know that older children are sensitive to the causal relation between functional and perceptual features (Kemler Nelson, Russell et al., 2000) and to the conventional and intended uses of objects (Diesendruck, Markson et al., 2003; Kemler Nelson, Herron, & Holt, 2003) little is known about what features are important for infants' construal of a feature (or set of features) as functional.

A truly general definition of function, in the context of conceptual development, may be impossible. Still, we need to be more precise about the use of the term “function” for at least two reasons. First, different findings with regard to the use of functional properties in identifying and categorizing objects may stem, in part, from differing definitions of function. Resolving these different results may be possible only through careful clarification of the relevant terms. Second, attention to functional properties is likely a gradually developing achievement that proceeds from attention to simpler features. Understanding how these different features come together to produce an understanding of function may be critical to fully understanding conceptual development.

B. What kind of property is *function*?

A potentially more serious issue than a lack of a definition for function is with the fundamental way that function has typically been conceptualized. Function has, at least implicitly, been characterized as a property of *objects*. In other words, function is considered to be inherent in objects and is one of many separable properties or features that together allow us to categorize objects. This way of thinking about function in the study of infant cognition can be traced to the seminal work of Katherine Nelson (1972; 1973; 1974). According to Nelson, what an individual can do with an object or what objects themselves do is at the core of children’s concepts of objects; the surface feature properties that help define the category are constrained by this function. For example, a child’s first category of “hat” denotes objects (of a general shape) that can be put on one’s head. Similarly, Mervis (1985), in describing one child’s *horn* category, argued that although the child used form to infer the function of the items, all the items in the horn category had the same function—they could be blown.

Interestingly, Nelson (1974) argued that early concept formation is based on an unanalyzed representation of a whole object, rather than on individual features or attributes. However, subsequent research often treated function as though it is in fact, an individual feature or attribute that can be manipulated in much the same way that one manipulates a feature like color or shape. One approach has been to consider the appearance and function as two separate features that can be crossed to produce novel objects. In a classic study, Gentner (1978), for example, presented children with two objects, each with a distinct function and a distinct appearance. Children’s label extensions were tested by presenting them with a hybrid object—an object with the appearance of one object but the function of the other. In a different design that similarly considers surface features and function as properties of objects, Landau, Smith and Jones (1998) taught children the names of objects and then asked them to extend those names to new objects that either were the same as the familiar object in terms of shape or a material-based function. This design similarly pits the two types of properties against one another, treating them as somewhat equivalently good object features. Indeed, in these and other studies of infants’ attention to object function, the researchers’ goal was to determine whether function or some alternate object property was the driving factor in categorizing or naming an object.

This conceptualization of function derives, in part, from a particular view of object concepts. Concepts are often referred to as the *mental representation* of things—for example, a category of objects (Murphy, 2002). This definition is useful for pointing out that concepts are (in a sense) “in the head” and are not the same as the “real” object. For example, one’s concept of *dog* is not the same as the category of real dogs that exist in the world. Traditionally, theorists have viewed these mental representations as stable and symbolic (e.g. Mandler, 2004). This relatively static view of concepts has led researchers to view the features that comprise those concepts as stable as well. It is, therefore, not surprising that much work on object function has focused on function as an intrinsic property of objects that has its own correspondingly stable mental representation. For example, if our concept of

fork is characterized by a stable, symbolic mental representation, then our representation of this object's function, *to eat with*, is also stable and symbolic. The notion that *function* is a separable feature of objects that can be manipulated arose from this tradition. However, subsequent research and thinking has revealed that function—like many object features—is not a static, separable feature of objects. Instead, function, and indeed objects concepts more generally, are dynamic and changing depending on the context.

III. A new conception of function

A. Function as an emergent feature of objects and events

We believe that the prevalent way of thinking about function is misleading. The very idea that function is a unitary feature that is inherent in a particular object, or set of objects, may have contributed to the imprecision in how function is instantiated in the literature. It is not at all obvious that function is always (or ever) a feature of objects in the same way as is color or shape. That is, although color, shape, and function all may be multiply determined, only function requires the interaction between the object and some actor—either the creator of the object (who presumably had an intended use of the object) or an individual currently interacting with the object (presumably for some purpose). In fact, function may never be fundamentally intrinsic to an object. Instead function is intrinsic to the relation between an object and an actor. Thus, function may be emergent in a different way than are other object properties that are attended to, encoded, and used as a basis of categorization.

Our view of function has many similarities to Barsalou and colleagues' (Barsalou et al., 2005; Chaigneau et al., 2004) HIPE model. Recall that in this model different pieces of knowledge about an object's use, the actors intentions, the physical limitations of an object's use, and the sequence of events when using an object are joined together in a causal model that determines one's "functional sense" about a particular object. Thus, function is a relational construct that involves all of the aspects we described in the previous section. Unlike the views described earlier, however, Barsalou does not argue that function is a single property that reflects any one of those features—for example, it is not solely the designer's intended use or the uses that are afforded by the physical structure. Rather, function emerges from many aspects of the object, the agent, and the context. According to this perspective, therefore, construing function as a property of objects that can be manipulated is misleading—what can be manipulated is a person's experience with an object, their knowledge of the intentions of the designer, their understanding of how it can be acted on, and so on.

This conception of function derives from the tradition of embodied cognition, which has a very different notion of *concept* from the view described earlier. Rather than focusing on concepts as mental states that refer to things outside the mind, the focus is on mechanisms that produce conceptual processing (Barsalou, Simmons, Barbey, & Wilson, 2003). For example, Smith (2005) argues for a dynamic systems view of cognition in which concepts are not "constants in the head," but rather emerge in real-time controlled by a number of variables. Smith points out that concepts are not constant, but change with the context, our knowledge, goals, etc. Relative stability emerges, according to this view, because of the stability of such factors, not because of an underlying stable concept. Thus, no features are stable—even features such as color and shape depend on the viewing conditions and one's goal and motivation at the moment. Our position is that infants' concept of function is not an independent, unitary property of an object that can be manipulated (although we have defined function in that way in the past), but emerges from the interaction of many factors and is stable to the extent that the context highlights the same features of the object, the context, and the interaction between the agent and the object.

Although the HIPE theory is not developmental in focus, it provides a starting point for a theory of how attention to function, as an emergent property, might develop, particularly during infancy when conceptual understanding is emerging. That is, under the view that function is a property of an *object* (presumably the use intended by the designer), the function of the object does not change (it is to sharpen pencils, provide light, etc.) unless the object undergoes radical changes in structure. Indeed, researchers have asked whether children believe the function of objects change with changes in how the object is used (e.g., using a teapot as a vase) or changes in superficial features (e.g., changing the color) (Gutheil, Bloom, Valderrama, & Freedman, 2004; Matan & Carey, 2001). However, if function is property of the relationship between an actor and an object, the function can change if the *actor* undergoes critical change (such as developing new motor, cognitive, or linguistic skills) even if the object remains the same over time. For example, a wooden block may have the function of *banging* before developing the manual dexterity to stack objects, but the function of *stacking* once such dexterity has developed.

Consider some of the factors that can impact infants' interactions with object, potentially changing the function of those objects: 1) infants' previous experience with that and similar objects, 2) infants' ability to recall and apply that previous experience, 3) infants' ability to act on the objects, 4) the salience of different features of the objects and the actor, 5) infants' ability or inability to connect different parts of the event (e.g., the action and the outcome), and 6) contextual factors that may reduce or increase the information processing demand placed on the infant. This list is not exhaustive, but serves as a starting point for illustrating the fact that *function* is, to a large extent, a moving target. No single feature that we can indisputably call *function* will be developmentally primary; instead, how infants conceptualize function—and whether the function they attend to, perceive, and encode corresponds to an adult-defined function—will be determined by features of the context and the infants' developmental level (Madole & Oakes, 1999; Oakes & Madole, 2000, 2003).

Nelson's (1979) classic account of object function reveals a sensitivity to the fact that function is not stable and unchanging. She described four ways function could be defined: 1) actions on things, 2) the independent activity of a thing, 3) the reaction of a thing to an action on it, and 4) the use, or utility of a thing. Note that this classic view of function separates the key elements of the factors in the HIPE model: actions performed on objects, how objects react, either on their own or in reaction to those actions, and the intention of the actor or creator of the object. Unlike Barsalou, however, Nelson describes these as different ways of defining function, not as elements of any function.

These definitions of function appear to represent a rough progression in terms of the cognitive skills required. To recognize and represent the actions on things and the independent activity of things (1 and 2 above) requires only that one recognize and represent observable properties. An infant can directly observe whether an object is squeezed or whether it jumps. Indeed, by 4 or 5 months infants have these skills—they detect changes in action and how objects behave (for a review, see Kellman & Arterberry, 1998). Thus from a young age infants have the ability to detect the most primitive aspects of function. However, if such features do form the foundation of a primitive recognition of function, this represents a very immature understanding of function relative to the way such properties have been operationalized in studies with older children and adults.

The third definition—the reaction of a thing to an action on it—requires integrating two distinct events. For example, learning that an object squeaks when an actor squeezes it requires that the infant detect and encode the squeezing, squeaking, and the contingency between them. The ability to detect and learn such associations seems to emerge later than the ability to attend to and encode the individual features (Madole et al., 1993; Rakison,

2004; Younger & Cohen, 1986). Thus, we would expect that associating actions performed on objects and the outcomes of those actions would emerge relatively late in infancy.

Finally, the fourth definition—function as the use or utility of a thing—seems to require abilities acquired beyond infancy. Specifically, if this aspect of function refers to the *intended* use of a thing—either intended by the designer or the actor—it seems unlikely that infants have access to this information. Infants can observe an object being used, but they cannot be told why the object was made or that, although we are currently using the object as a hammer, it is actually a shoe. As described earlier, a large number of investigators have been examining the developmental origins of the design stance, or the belief that artifacts are defined centrally by the use intended by the designer (Bloom, 1996; Matan & Carey, 2001). Although some evidence indicates that by age 2 children may be sensitive to this kind of information (Casler & Kelemen, 2005), infants may not use such information to determine the functions of objects. Nonetheless, infants may have a primitive understanding of the intended use of objects. Even if they do not have access to information about the intention of the designer or the actors' goals, infants may be able to differentiate intentional from accidental actions (Carpenter, Call, & Tomasello, 2005). In addition, infants almost certainly do have access to information about objects' typical uses. Because the designer's *intended* use is often highly confounded with how objects are *typically* used, infants' recognition of the typical use of objects may bootstrap an eventual understanding of the intended use.

Thus, there may be a rough developmental progression from function as “identifying actions on an object” or “recognizing action” to function as “understanding how an object is intended to be used.” This proposed developmental progression, however, highlights a clear gap in how the latter form of function can be derived from the former. This gap may be at least partially filled by considering the third notion of function: The reaction of a thing to an action upon it. This idea of function brings together the first two definitions via an emerging understanding of the causal relations that join them. Moreover, it might provide the groundwork for an understanding of the conventional or intended use of an object. Although the remote control could be used for banging on the table, the fact that an interesting reaction occurs when the buttons are pressed might provide a basis for understanding that the buttons exist for just this purpose.

Thus, we propose the following conceptualization of how attention to and representation of function emerges over infancy and early childhood. Because we argue that the perception of object function actually involves integrating several different aspects of events and contexts, we believe that there is no single point at which infants recognize *function* as a property of objects. Rather, across development infants come to recognize and represent new kinds of features of objects and events, and these features comprise their conception of function. Function, therefore, is not (by this view) a single, coherent property of objects, but rather function is an emergent property of objects, events, or situations given the presence of several component features. Obviously, this conceptualization makes it difficult to ask questions such as “is function more or less salient with development” and “when do infants first categorize on the basis of function.” However, we argue that by considering the shifting ways in which infants might construe object function, we can get a deeper understanding how their developmentally appropriate understanding of function is incorporated into their object representations.

B. Infants' sensitivity to the components of function

An important step in understanding how infants conceptualize object function is to consider whether infants are sensitive to the components of function described earlier, as well as when infants integrate such pieces of information. Although studies have examined infants' sensitivity to features of events that may contribute to their understanding of function, little

work has been directed at addressing such questions in the context of infants' understanding of object function itself. To further our understanding of infants' developing conceptions of object function, in this section we review what we know from the literature about infants' developing sensitivity to aspects of events that relate to object function. We use Barsalou and colleagues' (Barsalou et al., 2005; Chaigneau et al., 2004) HIPE model as a framework for thinking about the primary aspects of function. In particular, we examine whether infants are sensitive to 1) the history of objects' uses, 2) the intentions of the actor or designer, 3) the physical features that constrain objects' uses, and 4) the event sequences in which the objects participate. Currently, our understanding of infants' sensitivity to each of these aspects is incomplete—particularly as it relates to infants' perception of function. However, by identifying gaps in the literature, we also identify important avenues for future research.

1. History of how objects have been used. Our knowledge about infants' understanding of artifact history is limited. Certainly, infants learn about actions performed on objects from observing the history of their uses. They imitate actions they have seen performed on objects (e.g., Meltzoff, 1988) and they dishabituate when they see objects acted on in new ways (Perone & Oakes, 2006). But the nature of this behavior and its relation to infants' underlying knowledge about objects is unclear. Infants' imitative ability as well as their ability to recognize when an object is acted on in a novel way might simply reflect the ability to form associations between an action and some other property of the object. We do not know whether infants expect that how an object has been used historically is how the object *should* be used, or whether they expect that objects can be acted on in multiple ways. Moreover, for infants, the historical use of objects might be irrelevant to considering the object's function. Indeed, several studies have shown that, with development, an object's history or the creator's intent becomes more important in children's judgments about an object's function (German & Johnson, 2002; Matan & Carey, 2001). Thus, although we know that infants attend to and recognize the history of an object's use, we do not know how such information is integrated into their representation of the object's function.
2. Intended use by the designer or the actor. Infants may have a primitive understanding of the "use" or "utility" of an object. Perceiving an actor's behavior as intentional toward an object (even if one does not know what those intentions are) or expecting that actions produce outcomes (even if one does not have expectations about what outcomes should be produced) can be thought of as the foundations of understanding the objects have uses. For example, Buresh and Woodward (2007) reported that infants recognize a single actor's behavior (consistently reaching toward a particular object on several trials) and use this information to anticipate that actor's future behavior, but not the future behavior of another actor. They interpreted this finding as suggesting that by 13 months, infants restrict goals to specific actors. Other findings have been taken as evidence that even younger infants are sensitive to the intentions of an actor (e.g., Song, Baillargeon, & Fisher, 2005). When imitating the actions of an adult model, infants in the second year perform actions that produce the intended goal of an actor rather than exactly mimicking his or her precise actions (Carpenter et al., 2005; Gergely, Bekkering, & Kiraldy, 2002).

Although this evidence may reflect sensitivity to the goals of the actor, how infants use such information in their conceptualization of function is uncertain. Certainly, performing an action that reproduces the agent's goal (if not his or her actions) reveals that infants must have associated that goal with the object (otherwise, they would not have been able to reproduce the goal). However, this pattern may reflect infants' selective attention to the *result* of the action, rather than to the details of the

action itself. Infants do seem to have some of the skills required for at least a primitive understanding the intensions of how objects are used—perhaps an expectation for how a particular actor will behave based on past experience or perhaps selective attention to the end result of an action (as opposed to detailed understanding of the action itself). What is unknown, however, is when infants integrate these expectations or perceptions into their conceptions of the functions of objects (e.g., it can illuminate, it can roll). It is one thing to be sensitive to actions as intentional; it is quite another to incorporate the knowledge into understanding the intentional use of an object.

3. How physical structure constrains the use of an object. Clearly, infants detect and encode the physical structure of objects—they detect changes in features such as object shape, color and pattern (see Kellman & Arterberry, 1998, for a review). However, we know little about how infants' sensitivity to such features influences their understanding of object function. Indeed, researchers often assume that infants are insensitive to such constraints, presenting infants with arbitrary structure-function combinations. In many studies, objects with identical structures but that differ in some superficial property (such as color) perform different functions. Thus, a non-structural feature (in this case color) is predictive of function, and the structural constraints on the functions of the objects are the same. In such cases, structural information is not useful for determining the functions of the objects. For example, in Wilcox and Chapa's (2004) study, the structure that afforded banging or pouring was identical in the two objects; the surface feature that predicted function was color. Color is not a feature of objects that would constrain the ability of that object to bang or pour. Similarly, in our own studies, the same objects can be shaken, rolled, inverted, squeezed (Horst et al., 2005; Madole et al., 1993; Perone & Oakes, 2006). In our studies the objects have the structural support to allow any function—they have wheels, they can (presumably) have rattling objects inside, and so on.

A sophisticated conceptualization of function, however, may require noting the correspondence between the structural feature that affords particular actions or uses and those actions or uses. Because humans can perform so many different actions on objects, acting on and recognizing actions on objects requires linking specific actions with specific objects. Forming such representations is likely difficult because they involve the integration of information processed by both the dorsal and ventral streams (Buxbaum, Kyle, & Menon, 2005; Chao & Martin, 2000; Wolk, Coslett, & Glosser, 2005), two visual streams that in primates process different information. The ventral stream is used for recognizing and identifying objects, and the dorsal stream is used for recognizing and controlling actions (Goodale & Milner, 1992). Recognizing that particular objects can be acted on in specific ways, therefore, may require integration of information processed by these two different streams.

We know very little about how infants represent these different kinds of information, or how they represent information processed by the two streams. However, at least in the context of short-term or working memory, there has been considerable interest in this kind of integration, which is assumed to develop between 6 and 12 months of age (Kaldy & Leslie, 2005; Oakes, Ross-Sheehy, & Luck, 2006). Unlike the kinds of contexts in which infants' attention to function is typically assessed, in short-term or working memory tasks infants are given only brief exposures to stimuli and their ability to remember features (or combinations of features) over the very short term (sometimes less than 1 s) is assessed. Thus, although integration on this time-scale certainly contributes to how infants encode

features of complex objects and events, the kind of integration of information processed by the dorsal and ventral streams in such tasks may or may not be central to the kind of integration required for acting on and perceiving actions on objects.

4. The event sequence. We perhaps know the most about the skills infants possess for representing this last component. Infants develop the ability to link actions and outcomes (the components of the event sequence) in the first year. At 6 months, infants perceive causal relations of launching events (Leslie, 1984). Later in infancy, spatiotemporal cues help infants parse causal chains (Cohen, Rundell, Spellman, & Cashon, 1999). By 9 months, infants segment human action into meaningful components related to actions and goals (e.g., picking up a towel from the floor) (Baldwin, Baird, Saylor, & Clark, 2001). Thus, infants have the prerequisite ability to link action and outcomes when observing demonstrations of object function and as described previously, infants might respond differently to actions that produce an outcome than to those that do not (Wilcox & Chapa, 2004).

Understanding how infants integrate actions and the outcomes is important because researchers often conflate these, assuming that a function is an action that produces an outcome, such as squeezing an object to make it squeak, inserting a part to make a sound, or swinging an object to make chimes ring (Booth, 2006; Horst et al., 2005; Trauble & Pauen, in press). Barsalou and colleagues' (Barsalou et al., 2005; Chaigneau et al., 2004) conception of the event sequence also reflects this assumption—in their model, the action and outcome are parts of a single component, the event sequence.

However, actions and outcomes may in fact be distinct features of function. Specifically, the human adult brain represents *action* (the characteristic ways of moving an object, such as the circular motion used when operating the pencil sharpener) separately from the goal or the outcome of acting on an object (e.g., using a pencil sharpener to sharpen a pencil) (e.g., Kellenbach et al., 2003). For example, Buxbaum and Saffran (2002) found that apraxic patients had deficits in their knowledge of how objects were manipulated, but not their knowledge of the intended function (i.e., the consequence of that manipulation). In a PET study of normal adults, Kellenbach et al. (2003) found brain regions that responded specifically when identifying the actions performed on objects but not the functions of those objects. Moreover, *action*, and not *function*, is central to how people represent manipulable objects (e.g., Yoon & Humphreys, 2005).

In summary, infants clearly develop sensitivity to many of the components involved in function, and thus they have the tools required for conceptualizing function, at least in a primitive way. In the following section, we review our work on infants' sensitivity to object function. This work provides a foundation for understanding how infants' conceptualize function, and how the components discussed previously influence infants' responding to features adults would label as an object's "function."

IV. Our research on infants' attention to and representation of function

Our work examining infants' attention to, representation of, and categorization based on object function began almost two decades ago. We were motivated by an interest in infants' use of "non-obvious" features in categorization (for reviews of these issues and our perspective see Madole & Oakes, 1999; Oakes & Madole, 1999, 2000, 2003). When we designed our first studies examining these issues in the late 1980s, much of the work described in previous sections had not yet been conducted. Subsequent work has refined our thinking about function. Not surprisingly, therefore, in our early work function was intuitively, and often imprecisely, defined and how function in one study is related to function in other studies is not always clear.

However, despite these limitations, our program of research illustrates how we can begin to go beyond our initial question—when do infants categorize using function—and answer questions about how infants conceptualize object function. Specifically, we can ask how function is related to other properties, what kinds of functions infants detect and represent, and the relative importance of function versus other types of features when identifying and categorizing objects. Moreover, we believe this work reveals that function is similar to other properties that are often regarded as more perceptual. Function is not always the most salient feature; whether infants seem to treat function as more important than other features depends on the context. No single functional feature seems to have a special status; instead the particular feature or combination of features to which infants attend is determined by multiple factors including infant age, how the stimuli are presented, and whether items are presented in isolation or in the context of other items. Function does not necessarily reflect the infants' deep, theoretical understanding of the object or the connections among objects—any more than do features such as perceptual similarity, shape, and the like. Of course, infants' developing understanding of the world—particularly of physical mechanisms of causality—will constrain their understanding of object function (as well as other properties such as shape). Thus, infants' use of object function is not unrelated to their emerging conceptual understanding of objects, categories, and causality. However, early attention to object function may not be sufficient evidence that infants have a deep, conceptual understanding of manipulable objects or artifacts. In line with this “constructivist” view, our research has focused on how infants' attention to and understanding of function changes with increasing information-processing skills, motor abilities, “theories” (i.e., expectations for how objects are constructed), history with objects, and so on.

A. Infants' shifting attention to function and appearance

When we began our studies, a large body of research had established that infants perceive and represent the surface features of objects. Less was known about infants' perception and representation of object function. Thus, our first question was simply “Can infants learn both the surface features and functions of objects?”

Initially, we assumed, on the basis of a general understanding of infants' cognitive and perceptual development, that function would be more difficult to perceive because of greater demands on the information-processing system. More challenging stimuli (e.g., images with more elements) take more time for infants to learn, and are more difficult for younger infants to perceive and remember (Cohen, 1988). Surface features are relatively static and unchanging; the color, presence of particular parts, and overall shape, for example, are available most of the time that objects are visible, although some actions on objects may temporarily transform the objects' shape (e.g., squeezing) or obscure some features momentarily (e.g., grabbing an object). Functional features present greater demands on infants' perceptual, attentional, and memory processes—for example they involve an action that unfolds over time and an outcome that occurs only at specific points during the action. Thus, accurately perceiving those features requires tracking them over changes in space and time—perhaps recognizing commonalities across transformations, changes in lighting conditions, and occlusion. Selectively attending to relevant features, and ignoring irrelevant ones, may be particularly difficult in contexts involving changes in luminance and abrupt onsets, features that effectively capture attention. Linking actions and outcomes requires detecting the spatial and temporal contingency between different parts of events and integrating that information. Thus, we predicted that, in general, infants would attend to surface features earlier in development than they would attend to functional features.

Our first study revealed exactly this developmental pattern (Madole et al., 1993). We defined function as an action that can be performed on the object resulting in some outcome—*shaking* resulted in *rattling* and *pushing* resulted in the *wheels rolling*. We employed an

object-examining task in which the actual objects are presented to the infant and the infant is allowed to manipulate and explore the object for a fixed period of time. Each trial began with the experimenter demonstrating the function of the toy (i.e., either rolling or shaking it), and then the infant was given the toy to explore for 30 s. Thus, the function was only available to the infant during the first few seconds of the trial unless the infant him or herself reproduced that function during that trial.

The design of this experiment is presented in Figure 1. During an initial pretest, infants received trials with the two items to be presented during test. This pretest provided a baseline for infants' preference for one object over the other. Next, infants were presented with one of those items on each of eight familiarization trials. Finally, the two test items were presented once again. We asked whether infants' preference for the "novel" item (i.e., the item that was not presented during familiarization) changed from pretest to test.

Infants were randomly assigned to one of three conditions: In the *appearance novel* condition the two objects differed in appearance but had the same function (e.g., the tall yellow and red round objects both rolled when pushed), in the *function novel* condition, the two objects had the same appearance but performed different functions (one rattled when shaken and the other's wheels rolled when it was pushed), and in the *appearance and function novel* condition, the two objects differed in both appearance and function (e.g., a tall yellow object that rolled when pushed and a round red object that rattled when shaken).

The preference scores are in Figure 2. For the purposes of presentation here, novelty preference scores are shown: For both the pretest and test, we calculated infants' preference for the novel item by dividing their attention (as measured by the duration of *examining*) to that item by their attention to both the novel and familiar items. Thus, a novelty preference score of .50 represents equal attention to both items, and a score above .50 represents greater attention to the novel item. All infants looked about equally to the two items during the pretest (the white bars). After familiarization (the black bars), in contrast, every group except one had novelty preference scores that were well above chance during test, and they clearly increased their novelty preference from pre-test to test.

The one group who failed to show this novelty preference was the 10-month-old infants who were shown two items that differed only in function. These infants had novelty preference scores near chance both before and after familiarization. Familiarization trials with a rattling object, for example, did not induce a preference for rolling during test, if those two objects had the same appearance. We therefore concluded that younger infants were more attentive to the static appearance features, and older infants were attentive to both those features and the more dynamic functional features, consistent with our prediction that information-processing demands underlie infants' selective attention to appearance or function (Madole & Oakes, 2005; Madole et al., 1993).

However, subsequent research and theorizing leads to different predictions for how infants' should allocate their attentional resources to functional versus surface features of objects. Specifically, low-level perceptual features of the stimuli associated with function may result in function having priority over appearance. For example, auditory features may be selectively attended to over visual ones (Robinson & Sloutsky, 2004). Moving stimuli are often preferred over static stimuli (Shaddy & Colombo, 2004). Stimuli that abruptly appear may more effectively recruit attention than stimuli that are constantly available or that appear in other ways (Yantis & Jonides, 1990). Such results lead to the prediction that infants should prefer and selectively attend to dynamic, changing features that have an auditory component (such as function) over static, unchanging features that are solely visual (such as appearance).

Indeed, increasing evidence shows such selective attention for relatively dynamic over relatively static features. Bahrick, Gogate, and Ruiz (2002), for example, found that 5½-month-old infants learned the actions performed by an actor (e.g., brushing her hair) but failed to remember the details of her face or the object she used in those actions. For these infants, therefore, the dynamic actions were more salient than the relatively static surface features of the actress's face or the object she used. When presented with competing static and dynamic information, young infants apparently selectively attend to dynamic features, at least under these circumstances.

We observed this pattern for infants' attention to appearance versus function in a visual habituation task in which, in contrast to our object-examining task described earlier, infants are shown movies of events in which the function is demonstrated several times during the course of a trial and they simply sit and watch those movies. Using such a task, we examined infants' attention to appearance and to function, defined as an action performed on an object and a resulting outcome. The stimuli were always movies in which a hand acted on an object and the outcome of that action was a sound (see Figure 3). In each experiment, infants were familiarized with one event (e.g., a hand rolling a yellow object accompanied by clicking) and then were tested with a change in appearance (e.g., a hand rolling a purple object accompanied by clicking), a change in function (e.g., a hand pulling the top of the yellow object accompanied by whistling), and changes in both (e.g., a hand inverting a pink object accompanied by a mooing sound).

Perone, Madole, Ross-Sheehy, Carey, and Oakes (2006) observed that 6- to 7-month-old infants were more attentive to the *function* than the *appearance* in these events. The results of two experiments using the design just described are presented in Figure 4 (the 6- and 7-month-old infants in that figure). We have plotted infants' increases in looking to tests that involve a change in appearance or a change in function, relative to their looking to a familiar item. Specifically, we subtracted infants' looking during a trial with the familiar item from their during each test trial with a novel item; if infants increase their interest to a novel stimulus, this dishabituation score will be greater than zero. In general, infants in this age range robustly responded when the function changed, but they responded only weakly (or not at all) not when just appearance changed. Thus, the dynamic functional features were more salient than the static appearance features. Horst, Oakes, and Madole (2005) tested 10-month-old infants in essentially the same experiment. The data are also presented in Figure 4. In contrast to the 6- to 7-month old infants, these older infants attended to and represented *both* function and appearance. They significantly increased their looking to both a change in function and a change in appearance.

These results therefore, reveal the opposite developmental trajectory from that we observed in our previous study. Whereas Madole et al. (1993) reported that infants responded first to static appearance features, the subsequent studies suggested that dynamic functional features have developmental priority over the static appearance features. Moreover, the 10-month-old infants observed by Madole et al. failed to attend to function, whereas the 10-month-old infants observed by Horst et al. (2005) robustly attended to function. Clearly, these two sets of studies revealed different patterns and suggest that function and appearance were differentially effective at recruiting infants' attention in these two experimental contexts.

Why did we observe that infants found appearance more salient than function when using object examining, but observed the opposite pattern when using a visual habituation task? Object-examining, in which infants actively manipulate and explore objects, may tap different cognitive processes than does visual habituation and familiarization, and different developmental trajectories reveal that the two types of processes develop independently. Indeed, this is the view argued by Mandler (2004). However, our findings are the opposite

from what one would predict from Mandler's reasoning. She argues that object-examining elicits attention to more conceptual, non-obvious features, whereas visual tasks elicit responding to appearance features. In this case, attention to appearance should dominate in the visual task but not the object-examining task, and yet this is exactly the opposite of what we observed.

We believe that the apparent discrepancies reflect the fact that function is an emergent feature as described in Section III. Contextual factors, the infant's past experience, and characteristics of the different properties, all contribute to which features are most salient at a given point in development. Recall that dynamic features (such as hand moving and grabbing an object or an intermittently heard sound) might be more salient than static features (such as the color of the object) due to low-level perceptual factors such as movement, flicker and abrupt onset. In some contexts, function will have these properties. In our visual tasks, infants see a 7 s event sequence in which a hand is in motion most of the time and the object changes position and may change shape momentarily. Thus, movement, flicker, and abrupt onset characterize the action—and its associated outcome. Functional features in this task, therefore, may be highly salient. In object-examining, in contrast, the function is only demonstrated at the start of the trial. For the majority of the trial, the infant is free to explore and manipulate the object, and reproduce the function *if he or she chooses*. Thus, in this context, the surface features may be more salient because the infant can look at the object from a wider variety of angles and the function may be only minimally available (because the infant does not reproduce it).

Object-examining and visual-habituation tasks also differ in their general information-processing demands. We have argued elsewhere that infants may respond differently in visual tasks than in object-examining tasks because the former places fewer demands on the infants' information-processing resources (Oakes & Madole, 2003; see also Younger & Furrer, 2003). In object examining, infants have access to much more information—both relevant and irrelevant. In the study by Madole et al. (1993), for example, infants could view the object from multiple perspectives, gaining information about what each side, the top, and bottom looked like. They had access to what effect shaking *and* rolling had on the object (if they chose to produce both actions). They had information about the object's texture, weight, taste, and so on. Clearly this is much more information than that available in the studies by Perone et al. (2006) or Horst et al. (2005). In these studies, infants could see only the front of the object. On each trial they had information about the effect of only one action produced on the object (the one demonstrated by the agent). They did not have other views of the object, or information about the taste, texture, or weight of the object. Thus, the differences in attention to appearance and function may be related to differences in how much information is available to the infant and infants' inability to selectively attend to relevant information. Indeed, as we discuss subsequently, Horst et al. observed that 10-month-old infants attended to function over appearance in a more demanding visual habituation context.

The effects of the information-processing demands and low-level visual and auditory characteristics of the stimuli may not be independent of one another. Our view of function is that such factors should together determine how infants perceive the events and the objects in them. Indeed, variations in the information-processing load likely alter the effect of low-level sensory characteristics of the stimuli (e.g., loudness, luminance, movement). For adults, distractors are less likely to capture attention when the central task is demanding (e.g., Lavie & Cox, 1997). Similar interactions have been observed for control of infants' attention (Oakes, Tellinghuisen, & Tjebkes, 2000). Thus, to the extent that such processes are relevant for how infants deal with competing stimulus properties—such as appearance versus function—we predict that the effect of characteristics of function (e.g., flicker,

motion) would be determined, in part, by the information-processing demand (or “load”) of the task in general. Thus, it may be misleading to suggest that, developmentally, infants *always* initially attend to function or *always* initially attend to the surface features. Which features are attended to earlier in development may depend, critically, on the context. In some contexts, low-level features may draw attention to some aspects of the event (such as the function).

Do the varying results described here suggest that it is hopeless to try to derive some underlying principles about the development of attention to features like appearance and function? We are not this pessimistic. Despite the fact that we observed different developmental trajectories in the two tasks (and with different sets of stimuli), we can still attempt to understand the mechanisms of developmental change in infants’ attention to such features. In fact, the two developmental trajectories we have observed are not very different at the broadest level. In both contexts we observed that younger infants attended to and remembered a smaller subset of the information available than did older infants. One explanation for this finding is that because of more limited abilities to encode information in visual short-term memory (Ross-Sheehy, Oakes, & Luck, 2003) and control visual attention (Oakes, Kannass, & Shaddy, 2002), younger infants attended to only some of the features present and focused their attention and memory processing on those features. As infants become able to hold more information (perhaps for longer) in short-term memory and more effectively control their attention, they apparently become able to attend to and encode more features and a wider variety of features. The difference between the two experimental contexts is whether the youngest infants attended to appearance or function. Of course, at this point an information-processing explanation for these changes is speculative, but consistent with what we know about changes in infants’ encoding abilities, attention, and memory. Additional studies are needed to confirm whether developmental changes in infants’ attention to appearance and function are, in fact, the result of more changes in such information-processing abilities.

We can therefore begin to ask what factors influence infants’ ability to attend to more features in one or the other context. It has become increasingly apparent that changes in motor development influence infants’ perception of the surface features of objects in visual task. Needham (2000), for example, observed that 4-month-old infants who were more active during object exploration also were more sensitive to the surface features that defined object boundaries in a visual task. This relation is not surprising given the significance of object boundaries for effectively reaching for and grasping objects. Such findings do not show that object exploration induces changes in visual perception, but they do show that perception and action are related, and provide the background for asking how changes in infants’ ability to act on objects might bring about changes in their perception of appearance and function.

Therefore infants’ ability to attend to and encode object appearance *in addition to* object function in visual habituation is likely influenced by changes in motor skill. In a study with 6-month-old infants, Perone et al. (2006) found that not only were infants more responsive to changes in function than to changes in appearance, but also that infants’ emerging reaching and grasping skills were related to their responding to a change in appearance. In this experiment, we tested infants in an experiment with the design in Figure 3, *and* we assessed their skill at reaching for and retrieving objects (see Figure 5). We found that attention to a change in appearance, but not to a change in function, was related to infants’ skillful grasping and object exploration in this task. In particular infants who successfully grasped toys more frequently tended to look longer when appearance changed at test. Moreover, this relation held even when we controlled for infants’ sitting ability, age, and their general interest in novelty.

Obviously, this work is a first step in understanding how infants' attention to the features of the objects in this context develops. But, this step is critically important because it suggests a mechanism (the emergence of new motor skills) that may account for developmental changes in attention to appearance and function. Clearly there are intricate and complex relations between how infants integrate information about action and the surface features of objects.

The results of the studies described in this section underscore the fact that questions such as "when do infants perceive function?" or "is function or appearance more salient?" are not straightforward. Observing discrepancies like that described here led to our rethinking of function. Clearly, from our findings, function does not seem to be a single feature of objects that can be manipulated equivalently in different contexts—it is not simply what an object does or the reaction of an object to some action. Whether infants selectively attended to function or appearance seemed to be complexly determined by how those features were presented, the salience of different aspects of the features, and the information-processing demands of the task.

B. Infants' developing attention to appearance and function

It is important to keep in mind, however, that even though young infants may represent appearance and function separately, they are not independent. One explanation for Perone et al.'s (2006) finding that infants with more advanced motor skills were more attentive to object appearance is that these infants have begun the process of learning that appearance and function are related. Structural properties of objects are a component of function. Adults know that the structural properties of objects constrain the functions—or afford the actions that can be performed. Objects with wheels can be rolled. Compressible objects can be squeezed. Objects with beads (or rice or beans) in them rattle when shaken. Moreover, for adults, the visual perception of manipulable artifacts (such as tools) engages brain areas thought to be important in the representation of action on those objects (Martin, 2007). Thus, representing appearance and function together is an important step in developing a mature, sophisticated conception of function.

Integrating appearance and function, however, is critically related to integrating *what* information with *how* information—or information thought to be processed by the ventral and dorsal visual streams (Goodale & Milner, 1992). Integrating this kind of information—or even attending to both kinds of information simultaneously—may be particularly difficult for infants (Mareschal & Johnson, 2003). Thus, it would not be surprising to observe a protracted development of infants' integrated representation of function and appearance.

One of our experiments indeed revealed a relatively late emerging recognition of the relation between object appearance and object function (Madole et al., 1993). We familiarized 10-, 14- and 18-month-old infants with two objects in an object-examining task. The objects had different appearances and functions—for example, a tall, yellow object that rolled when pushed and a red round object that rattled when shaken. Thus, *function*, or the object-action correspondence, was correlated with appearance. We asked whether infants learned the combination of a particular function and a particular appearance—for example, that yellow objects roll and red objects rattle. If so, during test infants should prefer a red object that rolled to a red object that rattled.

Indeed, this is exactly what we observed in 18-month-old infants (see Figure 6). At this age, infants apparently could associate appearance with function (e.g., red objects rattle when you shake them) in object examining. Fourteen-month-old infants, in contrast, did not associate the appearance and function. They did not respond to a novel combination of the appearance and function, responding instead to novel individual features. They learned that

objects could be red or yellow and could shake or roll, but not that red objects rolled and yellow objects rattled.

Thus, attention to the combination of function and appearance—at least in object-examining—emerges relatively late in infancy. This understanding likely does not emerge full-blown at this age. In fact, the developmental achievements necessary for understanding the relation between appearance and function almost certainly begin to emerge much earlier, as infants begin exploring objects. Skillful object exploration requires (and may even induce) the recognition of a connection between the surface features of objects and how the object can be acted upon. With development, infants use visual information to adjust their manual actions on objects (Corbetta, Thelen, & Johnson, 2000). They adjust their exploratory activity in response to the material and texture of objects (Bourgeois, Khawar, Neal, & Lockman, 2005). Note however, that the appearance-function relation in the objects used here was arbitrary. Nothing about the structure of the objects immediately revealed their functions. Thus, there may be a delay before infants apply their knowledge about the relation between appearance and function to objects in which that relation is less transparent. The lack of transparency however, does not mean these relations lack ecological validity: Many real objects are characterized by a similar arbitrariness in terms of the relation between structure and function. One might have to learn, for example that the silver key starts the car, but the gold key opens the office, because the actual mechanism underlying this function is unobservable. An important achievement, then, is learning which appearance-based features are most predictive of function.

C. Infants' attention to the relation between appearance, action and outcome

Through the course of conducting this research, we realized that neither appearance nor function is a simple, unitary feature of objects. As our understanding of function has become more refined, our approach to considering the relation between object appearance and object function has also become more refined. In fact, the appearance of an object as a whole might be considerably less important than the appearance of relevant *parts* of that object. In a set of experiments that further clarified the nature of infants' attention to the association between appearance and function, Madole and Cohen (1995) asked whether 14- and 18-month-old infants could associate the function with the appearance of only a part of the object, and whether some associations are more easily learned than others. Using a visual habituation procedure, we familiarized infants with two events in which the appearances of an object's parts were correlated with different functions. In one condition, the appearance of the part predicted whether or not it was functional—for example small, black wheels rolled but large, red wheels did not roll. Both 14- and 18-month-old infants dishabituated to a new object in which the previously nonfunctional part now worked (see the *meaningful* panel in Figure 7). In the example just given, the large red wheels now rolled. In another condition the appearance of one part was associated with whether or not the *other* part was functional. So, for example, if the protrusion on the top of the object was a green tree, the wheels rolled—regardless of the appearance of those wheels. Interestingly, although 14-month-old infants also learned this relation, 18-month-old infants did not (see the *arbitrary* panel in Figure 7). Only the 14-month-old infants dishabituated to the uncorrelated event that violated the association presented in habituation. Thus, they learned that the appearance of one part was predictive of whether another part functioned.

What had developed between 14 and 18 months? During this time, at least for these kinds of objects, infants apparently become increasingly sensitive to the way in which appearance and function are actually related in real objects. Their learning of new associations is constrained by their developing theories of how objects are constructed or work, their understanding of action at a distance (i.e., that causes and outcomes are usually spatially contiguous), the extraction of statistical regularities they have observed about objects, or

some combination of these three. Thus, development proceeds beyond simply associating functions or actions with object appearance to understanding how function or actions and appearances are related.

But how do infants' conceptualize *function*? The studies described up to this point laid the groundwork for demonstrating that infants are sensitive to the object property that adults would label "function," and that they correlate such function with appearance. Now, if function is a complex, multiply determined property, it is important to identify exactly which of the features that might comprise function are detected and represented, as well how those features are combined. When infants represented *function* in our studies, did they represent a single, coherent feature—such as "squeaks when squeezed?" Our results can be equally well explained by infants' attention to a single component—for example, the same patterns would have emerged if infants attended to just the outcome. Even if infants do learn several components relevant to function, a full understanding of how infants conceive of function requires that we establish how they combine those components.

Subsequently, we examined infants' attention to the actions and outcomes relevant to function. Obviously, infants may be sensitive to other components of function such as the intentions of an actor or designer, how the object has been historically used, or how the object's structure constrains the function. However, central to any demonstration of function is an action on an object and some reaction (in our case the object apparently emitting a sound). Perhaps before one can detect intentional actions, learn patterns of how objects are used, and so on, one must be able to represent actions and outcomes, and link these features to other components. In other words, action and outcome may be components of the most primitive conceptions of object function. Indeed, according to Nelson (1974) infants' first concepts are focused on objects that can be acted on and that engage in dynamic changes (such as rolling).

To test whether 10-month-old infants responded to changes in both action and sound, Perone and Oakes (2006) habituated infants to a single event and then tested their responding when just the sound or just the action changed. Using essentially the same design as depicted in Figure 3, we habituated infants to a single event and then tested them with events that differed from the familiarization event only in sound or only in action. For example, infants habituated to the object that clicked when it rolled, might receive tests with an object that mooed when it rolled and an object that clicked when it was squeezed. Thus, if infants attended to and represented both the action and the sound they would dishabituate to both of these tests. As shown in Figure 8, infants did indeed respond to both changes. We replicated this finding in a second experiment when infants were habituated to four different object appearances, but a constant sound and action. Again, 10-month-old infants dishabituated if just the sound changed or if just the action changed. Together, these results show that 10-month-old infants attend to and represent both of these components of function.

We also examined 7-month-old infants' responding to these changes using a different experimental design (Perone & Oakes, 2007). In these experiments, infants were again habituated to a single event and then tested with two new events. However, whether infants responded to a change in action or sound was tested between-subjects. Infants received a test event that differed in only one property (e.g., sound) and a second test event that differed in two properties (e.g., action and appearance). Comparing these two tests allowed us to test the alternative possibility that infants at this age generally find multiple changes more compelling than fewer changes. One group of infants received a test event that had only a change in sound and one that had changes in both action and appearance; the other group received a test event that had only a change in action and one that had changes in both sound and appearance. Seven-month-old infants dishabituated when just the sound or just the

action changed, as well as when sound or action changed with appearance (see Figure 8). Thus, 7-month-old infants responded to changes in either feature, and did not respond more when two features changed. Together, all these results show that both 7- and 10-month-old infants represented action and sound.

At least by 7 months, therefore, infants learn about two critical components of function—actions and outcomes. Of course, these features in isolation are not functions—as described earlier, action without an outcome is not considered sufficient to be function (Wilcox & Chapa, 2004), and for older children and adults functions are, in part, actions constrained by the physical structure of objects (Kemler Nelson, Frankenfield et al., 2000). Thus, in the context of function, components such as action and outcome are important in combination with other components that help to define the relation between them.

It is not immediately obvious how infants might combine the various components of function. Researchers' intuitive definitions of function suggest that binding the action and outcome is critical. Functional demonstrations or objects are those in which an action produces an outcome (Welder & Graham, 2001; Wilcox & Chapa, 2004), and functions are made more salient by increasing the intensity of their outcomes (Booth, 2006). Clearly for researchers, then, actions and outcomes are bound. Thus, an important achievement for infants would be the development of this same intuition about function—that is, that actions produce a particular outcome, and function is acting in a particular way *in order to produce* a specific outcome—and they should represent the association between actions and their outcomes.

Indeed, by 7 months—and certainly by 10 months—infants have many of the skills necessary to link the action and the outcome. Our events are characterized by a clear contingency and evidence of a causal mechanism. The outcome is spatiotemporally contiguous with the action. The hand makes contact with the object and as it acts the sound is heard. Infants are sensitive to exactly these cues, at least for physical causality—that is, when one object makes contact with another object, launching it into motion (Leslie, 1984; Oakes, 1994; Oakes & Cohen, 1990). Thus, infants have the skills required to bind action and outcome. Moreover, such causal connections may be particularly compelling, and as a result infants find the binding of action and outcome salient.

As described earlier, however, the human adult brain represents separately actions on objects and the results or goals of those actions (e.g., Kellenbach et al., 2003), and *action*, not *function*, appears to be central to how people represent manipulable objects (e.g., Yoon & Humphreys, 2005). Despite researchers' intuitions, therefore, the binding of action and sound may not be the most salient to infants. Instead, actions may be more central to infants' object representations—at least when encoding and remembering manipulable objects. Indeed, Nelson (1972; 1973; 1974) argued that children's earliest concepts are based on similarities in the *actions* that they can perform on the objects (e.g., all balls can be rolled), and children must learn the features of objects that predict those actions (e.g., round shape predicts the ability to roll). Therefore, the most salient binding may be between object appearance (e.g., color, shape) and the actions that can be performed on objects. Madole and Cohen (1995) found that 14-month-old infants form such associations, although they are not constrained to link the appearances of specific parts with the functions of those parts—suggesting that they do not have an adult understanding of how the physical structure allows or inhibits some actions.

Linking actions and appearances may be difficult, however, because such links involve integrating information processed by both the ventral and dorsal streams (Buxbaum et al., 2005; Chao & Martin, 2000; Wolk et al., 2005). Mareschal and Johnson (2003) reported

evidence suggesting that at 4 months dorsal and ventral processing are quite distinct. In short-term or working memory, integration of such information occurs between 6 and 8 months (Kaldy & Leslie, 2005; Oakes et al., 2006). When object function is demonstrated, actions occur briefly and intermittently. In the studies described here, the resulting sound also occurred briefly and intermittently. Limitations in short-term or working-memory ability may contribute to infants younger than 8 months having difficulty linking such features with appearance. Moreover, recall that appearance is less salient for young infants than are the dynamic features of sound and action. Thus, despite the importance of the links between action and appearance, sensitivity to these combinations of components may not emerge until relatively late in infancy.

Finally, the combination of the outcome and the appearance may be the most salient. In the real world, the particular outcomes produced by acting on objects are determined, in part, by the structure of those objects. Objects with wheels can roll; objects without wheels cannot roll. Infants' history with different types of objects, therefore, may cause them to attend to such combinations. Although, as just mentioned, because appearance is generally less salient than the outcomes used here, these combinations may not be the first learned.

Thus, there are reasons to suspect that infants may attend to any one of the possible associations between object appearance, actions on objects, and outcomes of actions. Perone and Oakes (2006) tested among these three possible patterns in 10-month-old infants by familiarizing infants with two different events like those depicted in Figure 3. One feature was the same in both events—for example, the objects had the same appearance in both events, or the same action was performed in both events. The other two features were associated and were different in the two events. If the two objects looked the same, then the action and sound were associated (e.g., infants might see a purple object that squeaked when it was squeezed on half of the trials and that clicked when it was rolled on the other trials). In this way, infants could learn either the four independent features—rolling, squeezing, squeaking, and clicking—or two sets of bound features—rolling/clicking and squeezing/squeaking.

Infants then were tested with a switched or uncorrelated event—an event that had all the familiar features, but the features were recombined. For example, squeezing would produce clicking. We tested 10-month-old infants in one of three conditions—one that tested their learning of the association between sound and action, one that tested their learning of the association between appearance and action, or one that tested their learning of the association between appearance and sound. As can be seen in Figure 9, only infants familiarized with events in which the action and appearance were associated (e.g., purple objects are squeezed, yellow objects are rolled) looked longer to the uncorrelated (or switched) event than to the correlated (or familiar) event. The other infants all looked equivalently to the correlated event and the uncorrelated event. Thus, 10-month-old infants *only* learned the association between action and appearance.

Apparently at this age infants do not perceive function as a single feature unifying action and outcome. Putting these results in the framework of Barsalou and colleagues' (Barsalou et al., 2005; Chaigneau et al., 2004) model, infants at this age appear most sensitive to the P aspect of the HIPE model of function—they learned how the physical structure was associated with the actions performed on the object. Although in our stimuli this association was arbitrary (all of the objects could be rolled, squeezed, inverted) these 10 month-old infants may have already formed a bias to attend to this association from their experience in real life. That is, they had learned that the shape, size, and other features of objects determine what actions can be performed on them. In Gibson's (1988) terms, the appearance is related to the *affordances* of the objects.

Thus, we have begun to build an understanding of infants' perception and representation of object function as multiply determined by the factors described earlier. Although our work has uncovered some of the ways infants combine the information available in these events, several important questions remain. First, the effect of the outcome on infants' learning of function is unclear. Recall that actions without outcomes, or with less salient outcomes, are not processed the same as are actions with clear, salient outcomes (Booth, 2006; Wilcox & Chapa, 2004). However, we found 10-month-old infants fail to learn the association between the action and the outcome, instead focusing on the action and appearance. Despite the fact that infants fail to learn that particular outcomes are associated with particular actions, it may be critically important that the actions actually produced outcomes. That is, the effect of the action may have facilitated infants' learning of the association between the action performed on the object and the appearance of that object. For example, although models of category structure such as the causal status hypothesis (Ahn & Luhmann, 2005) argue for the priority of *causes* in categorization, properties may not be perceived as causes unless they are linked with an outcome. Thus, although infants do not link the action with the outcome, the fact that the actions produce outcomes may be key to their learning of object function.

In addition, questions remain about how attention to combinations of features develops. Madole and Cohen (1995) observed that younger infants responded to a broader range of associations among features than did older infants. If this pattern is general to different aspects of linking functional features, we may observe that younger infants detect and learn a broader range of feature bindings—for example, the binding between sound and action as well as the binding between action and appearance—and that only with experience with the real objects do they restrict their attention to only the action/appearance bindings. Indeed, unlike older children, our 10-month-old infants were sensitive to any structure-action combination (not just those in which the physical structure constrains what one can do with an object). Thus, even for their attention to the appearance/action links, infants may initially be sensitive to a broad range of associations—even those that adults find arbitrary—and only gradually come to recognize only the plausible associations, much like pattern observed by Madole and Cohen.

Alternatively, infants' developing understanding of the links between the components of function may take a different path. They may become increasingly sensitive to the associations among the features in these events and the action/appearance association is simply the first one learned. Older infants may show sensitivity to other relations that younger infants do not—such as the association between particular actions and particular outcomes. Only by testing older and younger infants can we answer these questions.

In summary, infants clearly do not perceive the functions used here as single, unified features of objects. Rather, they attend to the components and combine those components in non-obvious ways. Although we are only just beginning to understand the development of infants' attention to and integration of the components of object function, the work we have discussed here is enlightening. This work will serve as the foundation of future work examining how infants' perception and representation of function changes with increased sensitivity to the components of function and their ability to integrate and coordinate these difference pieces of information.

D. Object function in infants' categorization

Note that we have wandered quite far from the original focus of the study of function in the developmental literature. Nelson (1973; 1974) was concerned with children's conceptual development as it related to language acquisition. She was interested in understanding which concepts were first learned and labeled. Her empirical work examined young children's

vocabularies to establish the foundation of their first words. Mervis (1985) in her classic study used a functional definition for a non-verbal category. She argued that examining the assumptions infants make about the function of an object (from the actions they attempt to perform on that object) provided insight into the development of categorical knowledge.

None of the work we have described addresses these questions. Instead, our work has primarily focused on how infants identify and represent individual objects or learn the correlations or associations among features when familiarized with only two objects. These are critically important questions and inform us about infants' conceptual development. However, we also need to establish how infants use these features to form *categories*. Because we have focused on how function is construed, we have spent less time understanding how infants use commonalities in function as compared to appearance to group objects or events. Obviously, a complete understanding of how function forms the basis of a category of objects depends on a fuller understanding of how infants' conceptualize function itself. However, we have begun to examine how infants use commonalities in appearance and function to form categories.

Horst, Oakes, and Madole (2005) habituated 10-month-old infants with a series of events like those in Figure 3. Unlike the previous experiments described here, infants were familiarized with four different events that depicted a category of objects. For half of the infants, the objects all had the same appearance—for example, a purple, round object—but each object had a different function. On one trial, for example, the hand squeezed the object and it squeaked and on a different trial the hand inverted the object and it mooed. Infants in this condition saw the hand engaging in four different actions toward objects with the same appearance (presented one at a time on different trials), and each action was associated with a unique outcome (sound). In this context, infants could learn the single common appearance, the four different functions, or both.

For the other infants, the common feature across trials was the function. Infants saw objects with four different appearances—the purple object, a multi-colored pyramid shaped object, and so on—but the same function was demonstrated on each object (e.g., squeezing that produced a squeaking sound). In this context, infants could learn the single common function, four different appearances, or both.

Infants' responding during test revealed that when familiarized with four different items—whether those items shared a common function or a common appearance—the function was the most salient feature (see Figure 10). Infants who were familiarized with four different appearances and one function dishabituated when shown a new event involving a familiar appearance and a new function. Infants who were familiarized with four different functions and a single appearance dishabituated when shown a new event involving a familiar appearance and a new function.

Of course, we do not know whether infants perceive and conceptualize function in the same way in this context as they do when they are habituated to only one or two items. The representations we uncovered when we presented infants with only one or two events during familiarization may not generalize to the increased information-processing demands of seeing four different events during familiarization. For example, although 10-month-old infants have little difficulty attending to and encoding appearance when familiarized with a single event, they do not attend to and encode appearance as readily when familiarized with four different events. Therefore, in this categorization context, infants might detect other types of combinations of features and the salience of sound or action change. Obviously, our future research in this area will be informed by our findings on how infants perceive and conceptualize function more generally.

V. Conclusions

We have studied object function for nearly 20 years. During this time our thinking has gradually shifted from considering function as a single, coherent feature that can be manipulated (or treated as a single property of an object) to considering function as multiply determined and emerging from the confluence of many different factors. This shift is inspired, in part, by the movement in cognitive science away from thinking about concepts as static and symbolic, to the recognition of concepts as dynamic and embodied. Research on how infants conceptualize the particular function of an object provides an excellent context for exploring this new view of concepts. Infants' understanding of function in a given context may involve their recognition of the ways the object has been used, the intentions of the actor, the physical constraints of the object, and the relation between the action and an outcome, similar to Barsalou and colleagues' (Barsalou et al., 2005; Chaigneau et al., 2004) view of adults' understanding of function.

This view of infants' developing understanding of object function has much in common with contemporary dynamic systems views of cognitive development (Smith, 2005, forthcoming; Smith & Thelen, 2003). As in that approach, we argue that the conceptualization of the function of the object is created in the moment through the interactions of multiple factors. Consider the function of a *spoon* for an infant. At one point in time, the function of a spoon is for *mouthing*, for example, if the infant has sore gums, the spoon is cool to the touch, is sufficiently round to provide a comforting surface, and the infant can bring the spoon to her mouth. At another point in time, the spoon's function is *to make noise with*, if the infant is seated at a hard surface, the spoon is rigid and has good resonance qualities, and the infant has the motor coordination to bang the spoon. At still another moment the spoon's function is *to transfer food to one's mouth*, if the child has developed the fine motor skills to grasp the spoon properly, is interested in the available food, and the spoon's structure can provide the support needed. Thus, the spoon does not have a single, unchanging function that is part of the individual's stable concept for "spoon." Rather, the concept and the function of the spoon is emergent given these contextual factors, and these concepts and functions might then influence the actor's subsequent identification and categorization of the object. We do not mean to suggest that the spoon has no conventional function, or that the designer's intention is irrelevant. We do propose, however, that those factors work along with other contextual and developmental factors to create the object's function at any given moment.

The work we have presented illustrates how we developed this perspective. Our view of function derived from the traditional views of function described in the first section. These views have been useful for understanding the significant role object function plays in infant cognitive processing. However, further understanding of function requires a different approach. By examining the component aspects of function—and how infants represent both those component features and the links between them—we provide a foundation for deeper understanding of the role function plays in infants' understanding of the world, for example, by disentangling their representations of the actions performed on objects and their outcomes.

Our thinking about function also has been shaped by our perspective on conceptual development in infancy more generally. Function has been promoted as a non-obvious or deep-level conceptual property that members of category share (Keil, 1989). Indeed, our initial work in this area was motivated, in part, by a desire to understand how infants integrate non-obvious features into their categorization of objects. However, the conceptual ranking of function has been elevated to the "essential" status for artifact categories (Bloom, 1996). Infants' functional actions on objects—for example, making animals drink from cups

—have been used as evidence that their grouping of objects is not merely perceptual, but contains conceptual information (Mandler & McDonough, 1998).

We propose, in contrast, that infants' representation of function is not qualitatively different from their representation of other, more obvious features. Perceiving and representing function involves attending to and combining the components described earlier. Thus, although accurately representing function aids in making inferences about features of objects that are not immediately visible, recognition of such features may not involve different processes from those that are used when recognizing other types of features of objects.

The concept of object function is fuzzy, and is not easily characterized by a set of necessary and sufficient features. We hope that research programs like ours will provide a deeper understanding into how the human mind conceptualizes the collection of properties that together comprise *function*. Moreover, by studying the development of this conceptualization we gain understanding not only of how to think about function in general, but also how infants' understanding of object function changes. An *adult* conception of the function of an object may incorporate an understanding of the intentions of the actor or object's creator, the causal relation between the action and the outcome, the affordance of the surface features of the object to allow the action, and the mechanism hidden in the object that produces the outcome. The *infant* conception of the function of an object, in contrast, may incorporate only some of these features. An unresolved issue, of course, is whether such a primitive understanding of function actually constitutes object function (although this may be a philosophical rather than a psychological question).

Although some might interpret our perspective as begging the question as to whether infants actually represent object *function*, we think the study of infant conceptual development should move beyond this question. Instead of trying to identify the point at which infants have an adult conception of function, it will be more fruitful to explore the features infants do represent, and the broad range of developmental changes that allow infants to represent new features of objects in the world around them.

Specifically, although clearly beyond the scope of this paper, we believe that the components of functions (and their associations) are learned by detecting regularities in how objects are structured, how people interact with objects, how objects respond to such interactions, and so on. Indeed, results like those reported by Madole and Cohen (1995) show the powerful influence of such statistical regularities on infants' changing conceptualization of function. Our future work will be aimed at a deeper understanding of how such a mechanism can induce changes in infants' perception of, attention to, and encoding of function.

In summary, we have attempted to bring clarity to a feature of objects that is often not clearly defined, and we are making progress toward understanding how infants think about a feature that is fundamentally important to how a large class of objects is defined. By examining infants' changing understanding of object function, we gain a deeper and more general insight into infants' conceptual development.

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Figure 1.

The stimuli and design of Madole, Oakes, and Cohen (1993), Experiment 1. An object-examining task was used. Infants were given objects one at a time on 30-trials. The session was divided into a pretest (2 trials with the novel and familiar items), familiarization (8 trials with the familiar item), test (2 trials with the novel and familiar items). Infants were tested in one of three conditions: an *Appearance Novel* condition, in which the two items differed only in appearance, a *Function Novel* condition, in which the two items differed only in appearance, and an *Appearance and Function Novel* condition in which the two items differed in both appearance and function.

Figure 2. Novelty preference scores derived from the examining durations during pretest and test from Madole et al. (1993) Experiment 1 by condition. Novelty preference scores greater than chance (.50) indicate that infants preferred the novel item over the familiar item.

Figure 3. Stimuli and design for Perone, Madole, Ross-Sheehy, Carey, and Oakes (2006) and Horst, Oakes, and Madole (2005). Infants were familiarized with a single movie in which a hand reaches for, grasps, and acts on an object, and a sound is produced. Infants then were tested with two new events, one that differs from the familiar in appearance and one that differs from the familiar in function. On each trial, infants' looking time to the movie was assessed.

Figure 4.

Infants' dishabituation score (looking time to the novel item-looking time to the familiar item) for tests involving a change in appearance or a change in function for A. 6-month-old infants observed by Perone et al. (2006), B. 7-month-old infants observed by Perone et al. (2006), and C. 10-month-old infants observed by Horst et al. (2005). Error bars represent 95% confidence intervals.

Figure 5.
An infant in the object exploration task used by Perone et al. (2007). Infants were seated with their caregiver; four toys were arranged around their feet.

Figure 6.

Examining times (in s) to the correlated, uncorrelated, and completely novel tests by age for Madole, Oakes and Cohen (1993), Experiment 2. The correlated item was one of the two items presented during familiarization. The uncorrelated item was a new combination of the familiar function and appearance. The novel item had a new appearance and function. Error bars represent ± 1 SE.

Figure 7. Looking times (in s) to the correlated, uncorrelated, and novel tests for 14- and 18-month-old infants habituated to the arbitrary and meaningful correlations in Madole and Cohen (1995). In the arbitrary condition, the appearance of one part was correlated with the function of a different part. In the meaningful condition, the appearance of a part was correlated with the function of that part. Error bars represent ± 1 SE.

Figure 8. Dishabituation scores (in s) to (A) a change in sound and action by 10-month-old infants in Perone and Oakes (2006) who were habituated to a single object or four different objects, and (B) a change in sound and a change in action by 7-month-old infants in Perone et al. (2007). Error bars represent 95% confidence intervals.

Figure 9.

Looking time to the familiar, uncorrelated, and novel events by 10-month-old infants in Perone and Oakes (2006), by condition. In the sound/action combined condition, infants were familiarized with two events that instantiated a constant relation between the sound and the action (e.g., squeezing produced squeaking). In the sound/appearance combined condition, infants were familiarized with two events that instantiated a constant relation between sound and appearance (e.g., purple objects squeaked). In the action/appearance combined, infants were familiarized with two events that instantiated a constant relation between action and appearance (e.g., purple objects are squeezed). Error bars represent ± 1 SE.

Figure 10. Looking time (in s) to the novel appearance and novel function test by 10-month-old infants in Horst et al. (2005) who were habituated to four items that had the same appearance but different functions (*Appearance Constant* condition) or four items that had the same function but different appearances (*Function Constant* condition). Error bars represent ± 1 SE.