CHAPTER

26

The Development of Object Categories: What, When, and How?

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OUTLINE

Abstract

From birth, infants are exposed to a wealth of information from their surroundings. This makes early categorization abilities especially important for infants and children to process information and come to understand the world around them. As a result of several sophisticated experimental paradigms, it is well-established that early categorization abilities become refined over the developmental trajectory. Researchers have identified a global-to-basic shift in early categorical thinking, such that preverbal infants discriminate between global-level categories (i.e., dogs, cats,

Handbook of Categorization in Cognitive Science.
DOI: http://dx.doi.org/10.1016/B978-0-08-101107-2.00027-0

chairs, tables, etc.) before basic-level categories (i.e., different breeds of cats and dogs). However, differences in the literature regarding the *timing* of this shift emerge depending on the paradigm used to measure categorization. There is evidence to suggest that infants also use dynamic, causal, and functional information to guide their object categorization and discrimination. This chapter provides a comprehensive review of the research and theory on early categorization and concept development.

26.1 INTRODUCTION

In mainstream cognitive science, the literature on categorization rarely references the developmental research, although the reverse is not necessarily true. Thus, it becomes important to increase our understanding of how infants form categories as they are at the origins of adults' complex categories. Fortunately, a bridge between these two "solitudes" has been built over the last decade, as shown by the inclusion of a few chapters on development in a recent "state-of-the-art" book on the topic (Murphy, 2002). The content of the present handbook confirms the relevance of children's categorization abilities in cognitive science with the inclusion of five chapters dedicated to developmental issues. In this chapter, we focus on the development of nonlinguistic categories, more specifically entities such as animals, vehicles, dogs, chairs, etc. The main reason for this choice is that theorizing and research in this area have focused mainly on studying the development of physical objects, in part due to the fact that there is a noun bias in children's early vocabulary (Oakes & Rakison, 2003). However, here are many other types of categories that are formed early in development by children, including color categories, spatial relations, and linguistic units (Quinn, 2003).

As active information processors, infants must cope with a wealth of information and regrouping objects together is a way to avoid being overwhelmed and experiencing the world as a "blooming, buzzing confusion," as William James once described infants' perceptions. Over the last four decades, an explosion of research on concept formation, due in large part to new research paradigms, has greatly advanced our knowledge about the developmental origins of categorization skills and related psychological mechanisms. Despite these achievements, a number of unresolved issues remain: one major debate is whether categorization is highly determined because there is a natural discontinuity in the world that simply needs to be detected or whether categories are derived from language. Other important issues concern whether object categories proceed from a concrete form in infants and young children to an abstract form in adults and from an implicit to an explicit form. Some proposals revolve around the idea that language plays a pivotal role in transforming cognition at large, and concepts in particular (Keil & Newman, 2010). In the next section, we provide an overview of the recent research on the development of object categories, followed by a review of the current theoretical proposals about the nature of early categories (deep or shallow) and the psychological mechanisms (smart or dumb) that have been proposed to account for some surprising achievements early in life.

26.2 OBJECT CATEGORIZATION

Our human cognitive system has a tendency to group objects according to some kind of similarity. This helps us to structure our experiences and to make inferences (see previous chapters). Object categories rarely have clear-cut boundaries; most of them are defined by a correlated set of features, reflecting a family resemblance structure (Wittgenstein, Anscombe, & Anscombe, 2001). Within adult thinking, categories can be described at varying levels of abstraction (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), ranging from ontological categories at the top of this hierarchy (e.g., living vs. nonliving kinds), followed by superordinate- (e.g., animals, furniture, vehicles), basic- (e.g., dogs, chairs, cars), and subordinate categories (e.g., different breeds of dogs). The majority of object classes referred to in spoken language are basic-level categories (Rosch et al., 1976), presumably because within-category similarity is rather high and between-category similarity is rather low at this level. It should be noted, though, that the outcome of any comparison depends on the criteria considered. We can group objects according to static or dynamic features, or according to causal and functional properties. This raises two important questions: (1) How can we investigate the beginnings of human categorization? (2) How can we describe the development of categorization skills in early years? The following paragraphs will address these issues.

26.3 METHODS FOR STUDYING OBJECT CATEGORIZATION IN EARLY CHILDHOOD

The dominant paradigm to study categorization at a preverbal age first familiarizes the infant with a number of different-looking exemplars from the same category. In the following test phase, a new exemplar of the familiar category is contrasted with a new exemplar of a different category. If infants show a preference for the out-of-category exemplar, we assume that they can discriminate both categories. Many versions of this general procedure have been introduced, varying the number and duration of familiarization and test trials, the mode of presenting stimuli, as well as the dependent measure.

Visual familiarization-preference-for-novelty tasks have become popular since the late 1970s (e.g., Oakes, Coppage, & Dingel, 1997; Quinn & Eimas, 1986). They typically present different pairs of pictures from the same category for 10−15 seconds each, followed by multiple test pairs contrasting new same-category and different-category exemplars. Looking preferences to out-of-category exemplars at test indicate category discrimination. In addition to static stimuli, it is also possible to present dynamic displays (e.g., Arterberry & Bornstein, 2001).

In 2006, Quinn, Westerlund, and Nelson introduced *brain measures (event-related potentials, ERPs)* to study infant categorization. The authors familiarized infants with one category following the procedure of a classical visual fixation task, but then probed ERPs in response to exemplars from both contrasted categories. Recently, Pauen and her team developed a broad range of alternative paradigms that lack any familiarization phase, and present a mixed (random) sequence of exemplars from two contrasting categories. In a *semantic priming paradigm* (Jeschonek, Marinovic, Hoehl, Elsner, & Pauen, 2010), an equal number of exemplars from both categories are presented sequentially for 1 second each. ERP responses to individual stimuli reveal whether a given stimulus is processed differently when it follows a same-kind or a different-kind exemplar. Other methods refer to the so-called *oddball paradigm*. In one version, 80 exemplars from one category and 20 exemplars from a contrasting category (all different) are presented in mixed order, and ERPs to standard and oddball stimuli are compared (Marinović, Hoehl, & Pauen, 2014; Pauen, Wahl, & Hoehl, 2011; see Jeschonek et al., 2010 for a different approach). Finally, a very new paradigm called *rapid repetition ERP paradigm* presents sets of six different exemplars at a rate of 6 Hz, with five exemplars belonging to one category and the sixth representing an out-of-category exemplar. The out-of-category exemplar is always presented at the same position within each set to determine whether the infant brain detects this rhythm (e.g., Peykarjou, Pauen, & Hoehl, 2014).

Whereas all procedures mentioned so far present pictures, another behavioral paradigm uses 3D objects: In the *Object examination task*, stimuli are presented for rather long times (range: 15−30 seconds), usually one at a time, and infants of 6 months or older explore them visually as well as manually. First they get familiarized with one category, either by being exposed to only a limited number of exemplars presented twice (classical OET; see Mandler & McDonough, 1998 for an example), or to a larger number of stimuli presented only once (modified OET; see Pauen, 2000) before the start of the test-phase. In addition to looking time, examination duration (i.e., focused attention towards the object) serves as dependent variable. This measure has been shown to reflect deeper levels of cognitive processing than looking time (Elsner, Pauen, & Jeschonek, 2006).

Infants and toddlers beyond 1 year of age may also be tested with a *sequential touching task* (e.g., Mandler & Bauer, 1988). Here, different exemplars of two contrasting categories (usually four per category) are placed in random order on a tray, and children are allowed to play freely with them for 2 minutes. Off-line video coding reveals whether exemplars of the same category are touched in sequence more often than expected by chance. Further methods used to study infant categorization beyond 1 year of age are the *inductive generalization paradigm* (Mandler & McDonough, 1996; Rakison, 2007) or the *individuation paradigm* (Xu & Carey, 1996).

Taken together, we conclude that preverbal categorization can be investigated in multiple ways. Visual familiarization-preference-for-novelty studies opened the way for exploring the mental processes involved in category formation more than 40 years ago. ERP studies provide a very new approach, probing fast responses of the brain to categorical stimuli. Given the high time-resolution or ERPs, future studies using this method may help us to disentangle different stages of visual categorization in the infant brain, as recently suggested by studies of Peykarjou, Pauen, and Hoehl (2015). By developing paradigms that omit a familiarization phase prior to testing category discrimination, we improve the ecological validity of category learning in laboratory settings, and will eventually become able to separate processes of visual abstraction from processes involving the activation of previously developed representations. It should be noted, though, that the active involvement of participants in exploring stimuli gradually increases from ERP-paradigms over visual fixation procedures to object-examination, and sequential touching tasks. As will be discussed in the following section, this may have important implications for differences in empirical findings obtained with these methods.

26.4 THE DEVELOPMENT OF CATEGORIZATION IN EARLY CHILDHOOD

One important insight from existing work is that infants start forming natural categories at various levels of abstraction long before their first birthday. They quickly learn to attend to overall-similarity (Quinn, Eimas, & Rosenkrantz, 1993), or part similarity (e.g., Rakison & Butterworth, 1998; Rakison & Cohen, 1999; Träuble & Pauen, 2011), as well as to the correlated structure among the stimuli presented during familiarization (Younger, 1990, 2003).

Interestingly, global-level or superordinate-level categories (e.g., animals, furniture, vehicles, fruits) are typically discriminated before basic-level categories (i.e., dogs, cats, chairs, tables, etc.) and subordinate categories (different breeds of cats and dogs). The timing of this so-called *global-to-basic level shift* varies with the paradigm used to probe categorization performance. However, in *visual fixation studies*, first tentative evidence for global-level discrimination (i.e., mammals vs. nonmammals; mammals vs. furniture, mammals vs. vehicles) has been reported for 2- to 4-month-olds, whereas various basic-level categories (cats, dogs, rabbits, elephants) seem to emerge slightly later (Quinn & Johnson, 2000; 3 months; Behl-Chadha, 1996; 3–4 months, Younger & Fearing, 2000; 10 months). In general, visual familiarization-preference-for-novelty studies demonstrate highly developed skills of preverbal infants to discriminate a broad range of natural object categories at various levels of abstraction (see Quinn, 2011 for an overview).

So far, *ERP-studies* have only been conducted with infants of 4 months and older, but corresponding data suggests that the ability to discriminate objects at the global level emerges at a rather young age (animals vs. furniture: Jeschonek et al., 2010; Jeschonek, Pauen, & Babocsai, 2013; Pauen et al., 2011; Quinn & Johnson, 2000). By 7–9 months of age, corresponding evidence has also been reported for more fine-grained categorical distinctions (Grossmann, Gliga, Johnson, & Mareschal, 2009; Marinović et al., 2014; Quinn, Doran, Reiss, & Hoffman, 2009), including even subordinate-level categories (Quinn, Westerlund, & Nelson, 2006).

In *object examination studies*, the global-to-basic level shift has been observed during the second half of the first year of life (Mandler & McDonough, 1993, 1998; Pauen, 2002a), and in *sequential touching tasks* (e.g., Mandler & Bauer, 1988), as well as in *inductive generalization tasks* (e.g., Mandler & McDonough, 1996) or *object individuation tasks* (e.g., Xu & Carey, 1996), it seems to occur between the first and third year of life (Bornstein & Arterberry, 2010).

How can we explain the diversity of existing findings? Following one theory, infants start by forming visual abstractions based on appearance information (Oakes et al., 1997; Quinn & Eimas, 1997; Younger, 1985). In support of this view, computational models demonstrate that automatic category learning based on low-level perceptual features proceeds from rather broad to more fine-grained distinctions (Quinn & Johnson, 2000). According to the *one-process account*, other aspects (e.g., behavioral attributes) are associated with these primitive perceptual categories only later, thus creating more complex representations (e.g., Quinn & Eimas, 1997, 2000; Quinn, Johnson, Mareschal, Rakison, & Younger, 2000; Rakison, 2007). Following this line of argument, concepts are elaborated perceptions, a network of observable features that gradually become associated with other attributes over time. This form of perceptual reductionism assumes that conceptual representations, in the sense of an accessible knowledge store retrievable from limited and decontextualized cues, emerge out of correlation-based learning. For example, Madole and Cohen (1995) observed a shift in infants' ability to correlate the form of object parts and their function during the second year with learning becoming increasingly constrained by experience.

Authors following this line of argument attribute variations in the timing of the global- to-basic level shift to differences in task demands (e.g., Younger & Furrer, 2003). This would imply that looking time measures are more sensitive than examination or sequential touching measures when it comes to studying the very beginnings of category formation.

In contrast to this view, Mandler (1992, 2000, 2004) suggests a *dual-process-approach*, stating that perceptual and conceptual categories are qualitatively different from each other. Whereas perceptual categories are formed automatically by the perceptual system, conceptual categories are formed in a conscious act. Following up on pioneering work by Gelman and Spelke (1981), Mandler assumes that our cognitive system is prepared to distinguish between things that show self-propelled non-linear motion (i.e., animates) and those that show externally induced linear motion (i.e., inanimates). By 6–7 months of age, this distinction has become a central aspect of infants' categorical thinking. Evidence supporting the idea that motion patterns are highly relevant for the animate–inanimate distinction even at a preverbal age has been provided by different studies (Arterberry & Bornstein, 2012; Luo, Kaufman, & Baillargeon, 2009; Spelke, Philipps, & Woodward, 1995; Träuble & Pauen, 2011).

According to Mandler, movement-based categorization is then rewritten in the format of an image-schema that provides the basis for conceptual thinking. The author assumes that perceptual and conceptual representations get integrated when language comes into play (i.e., towards the end of the first year of life). Following this view, infants participating in a typical familiarization-preference-for-novelty task get engaged in ad hoc category formation whereas infants participating in other categorization tasks that require more cognitive involvement (e.g., the object-examination task) activate their already existent conceptual knowledge. Differences in the timing of the global-to-basic level shift between studies could thus be attributed to different cognitive processes explaining categorization performance.

Until today, the debate whether categorical representations of preverbal infants are primarily perceptual in nature or begin to reflect conceptual understanding still remains unresolved. Do infants use perceptual information as the basis for categorization (information readily available, such as body parts, faces, sounds) or do they rely on knowledge of category relations, animacy, or other conceptual information that joins category members?

On the one hand, numerous studies document that infants exposed to a set of unfamiliar objects can learn to categorize these objects based on information about the similarity of stimuli presented, thus supporting the idea that they can form perception-based categories during the experimental session. In addition, it has been demonstrated that manipulations regarding the stimulus selection or task-demands can affect categorization performance in laboratory tasks (Oakes et al., 1997; Oakes, Horst, Kovack-Lesh, & Perone, 2008; Younger, 1985). Hence, there is good reason to believe that bottom-up processes of category formation play a key role for explaining performance in categorization studies conducted with preverbal children.

On the other hand, a large number of studies demonstrate the relevance of the global animate−inanimate distinction in infants' categorical thinking and reasoning that can hardly be explained by pure bottom-up perceptual learning but rather suggests that performance in laboratory tasks is at least partly knowledge-based (e.g., Opfer & Gelman, 2010; Rakison & Poulin-Dubois, 2001). For example, Träuble and Pauen (2011) introduced the "ambiguous motion paradigm," showing 7-month-olds an unfamiliar (fantasy) animal rolling around on a small stage together with a ball in a self-initiated way following an irregular path, changing speed and direction. Even though the cause of this motion was ambiguous, infants attributed it to the animal, not the ball, as indicated by a shift in looking time preferences towards the animal from a baseline scene presenting both objects in separate corners (motionless) to the test-scene that was identical to the baseline scene but followed the motion event. This effect was shown to be independent of the a priori attractiveness of both objects. Using a different paradigm but a similar logic, Träuble, Pauen, and Poulin-Dubois (2014) presented two objects (one animal, one vehicle, both stationary) during a baseline scene. Following that, a screen was lowered to cover both objects and infants could see a "shadow" that either moved in a biological way (i.e., changing direction and speed multiple times) or in a nonbiological way (i.e., linear, continuous). The presentation did not reveal which of the two objects performed the motion, but 7-month-olds attributed the linear motion to the vehicle and the biological motion to the animal, as indicated by longer looking times to test-scenes revealing the nonmatching object. Finally, 12-month-old infants can categorize animals with a sequential touching task when first primed with point light displays of biological motion, but not when primed with random motion (Poulin-Dubois, Crivello, & Wright, 2015).

These studies suggest that infants apply previously acquired associative knowledge about the relation of a certain appearance with a certain (movement) behavior of natural objects, referring to the global animate–inanimate distinction.

Consistent with this idea, ERP studies found evidence for a global animal–furniture discrimination, using different procedures that lack any familiarization phase, thus reducing the impact of online-learning during the experimental session. Object-examination studies further reveal that infants can discriminate animals from furniture items equally well when within- and between-category differences of the stimuli used for probing categorization performance varies between conditions (Pauen, 2002b), again suggesting that perceptual abstractions formed during the familiarization phase are not sufficient to explain categorization performance at a preverbal age. Other work using visual tasks indicates that familiarization responses to dynamic point-light displays showing either biological (i.e., nonlinear complex) or simple linear motion patterns, transfers to static visual displays of animals and vehicles, as evidenced by longer looking-times to out-of-category members at 7 and 9 months of age (Arterberry & Bornstein, 2002). Finally, multiple studies reveal that previous real-world experience has a substantial impact on category performance in an object examination task, when it comes to studying abstract form categories at only 5 months of age (Bornstein & Mash, 2010) unfamiliar artifact categories at 11 months of age (Träuble & Pauen, 2007), and natural basic-level categories at 12 months of age (Träuble, Babocsai, & Pauen, 2009). Testing 4-month-olds with an eye-tracking procedure, Kovack-Lesh, McMurray, and Oakes (2014) recently demonstrated that infants' visual exploration of cat and dog pictures depends on whether or not the infants had previous experience with these pets. This shows that prior experience may guide infants' attention to certain visual features of stimuli presented in laboratory tasks, suggesting that categorization performance results from a mixture of top-down and bottom-up processes even in very young children.

Since perceptually based concepts are not likely to be completely discontinuous with the mature, "real" concept embedded in more abstract (causal and functional) knowledge (Murphy, 2010), the main challenge of modern theories of category development is to integrate both aspects. Computational models simulating processes of early category formation meet this challenge (e.g., Westermann & Mareschal, 2012), and provide data that closely matches developmental patterns observed in infant studies (Westermann, Pauen, Wahl, & Hoehl, 2014). They reveal that networks and infants similarly build representations linking specific object parts with specific causal roles (Rakison & Lupyan, 2008), thus suggesting that there is no qualitative shift from perceptual to conceptual understanding, but rather continuity in development (see also Madole, Oakes, & Rakison, 2011).

Taken together, we conclude that bottom-up processes of visual abstraction as well as top-down processes of memory activation can both contribute to object categorization in infancy. In addition, the nature of the task, procedure, and stimuli determines performance. We also see evidence suggesting that preverbal object categorization does not only rely on information about the static appearance of objects alone, but also refers to dynamic, as well as causal and functional information. Infants start by making rather broad categorical distinctions, including the animate–inanimate distinction, and seem to fine-tune their category discrimination later. As will be discussed in the next section, categories are acquired in a social and language environment that shapes their specific boundaries and content.

26.5 IS LANGUAGE A FACILITATOR OF CATEGORY FORMATION?

Although the evidence reviewed so far suggests that infants can form new categories before they can speak, concepts change with development. Some proposals revolve around the idea that language provides a powerful transforming effect on concept in children as well as adults. In infants, labels have been found to facilitate category formation in infants as young as 6 months (Waxman & Gelman, 2010), realign category boundaries (Plunkett, Hu, & Cohen, 2008), guide category-based inductive reasoning (Graham, Kilbreath, & Welder, 2004; Keates & Graham, 2008) and even interfere with category identification (Robinson & Sloutsky, 2004). Decades of research have shown that language provides an invitation to form categories (Waxman & Gelman, 2010). Category formation in these studies is usually assessed in terms of responses to novel stimuli which either belong to the same category as a familiarization set or are members of a new category. In adults, explicit category membership is typically required: faster learning and better accuracy are observed when learning labeled category exemplars in comparison to unlabeled exemplars. For infants, the familiarization–novelty/preference paradigm, is used which measures a preference for a novel out-of-category items over within-category items. This research has shown that (1) even preverbal infants are sensitive to a link between words and concepts, (2) this initial link is gradually fine-tuned as a function of infants' experience with objects and the structure of their mother-tongue (Waxman & Lidz, 2006), and (3) words exert a unique influence on conceptual representations, as compared to other auditory stimuli. In a series of studies, Waxman and Markow (1995) asked whether words influence infants' ability to conceptualize an object category such as animal in 12- to 13-month-old infants in an object examination task involving only a few different exemplars. During a familiarization phase, the experimenter offered infants four different exemplars of the same category (e.g., four animals) one at a time in random order. This was followed by a test phase, in which the experimenter simultaneously presented a new member of the familiar category (another animal) and an object from a novel category (a fruit). Infants were randomly assigned to three conditions that differed in the comments made by the experimenter: no word, adjective or noun. The results revealed that, contrary to the no-word control condition, infants in both the noun and adjective conditions showed reliable novelty preferences, suggesting that they had understood which level of categorization the experimenter referred to and detected category-based commonalities during the familiarization phase. The authors then explored the possibility that this effect could be triggered simply by the presence of a word by comparing performance when objects are named by the same word or multiple words. When objects were named with distinct words, infants aged 6 and 12 months failed to form categories at the global level.

Another potential confounding variable in the studies on the facilitative effect of naming on infants' categorization is the attention-getting function associated with any kind of auditory stimulus. Several recent studies have investigated this issue by comparing the effects of words to nonlinguistic stimuli, such as tones, melodies, and mechanical noises produced by simple toys.

Overall the results of these studies indicate a privileged effect of words to nonlinguistic stimuli as early as 6 months (Balaban & Waxman, 1997; Ferry, Hespos, & Waxman, 2010; Fulkerson & Waxman, 2007). However, it is important to point out that nonlinguistic stimuli can promote object categorization when they are accompanied by social, pragmatic, or linguistic cues (Fulkerson, 1997; Fulkerson & Haff, 2006; Namy & Waxman, 2002). In sum, infants are prepared to form a broad initial link between words and commonalities among objects. The most recent research on this topic has aimed to identify the mechanisms underlying this effect by tracking fine-grained modulations of attention directed at individual features of objects in categorization tasks using automatic eye-tracking methodology (Althaus & Plunkett, 2015).

A final issue that needs to be raised about the role of labels in object categorization is one of "inhibitor." For example, we have reviewed the evidence that the concept of animal emerges early in development and that most languages support the early acquisition of the concept of animal by having a name for it. However, the word "animal" is polysemous in English and can mean all animate beings or only non-human animals. Although infants distinguish animals from nonanimals (e.g., Scott & Moneson, 2009), as well as animals from humans (Pauen, 2000), they can also treat animate beings as inclusive (e.g., Luo et al., 2009; Rostad, Yott, & Poulin-Dubois, 2012). However, preschool children do not include humans when asked to generate names of animals (Winkler-Rhoades, Medin, Waxman, Woodring, & Ross, 2010) and deny that humans are animals until they are 9 years of age (Leddon, Waxman, Medin, Bang, & Washinawatok, 2012). Nonverbal categorization tasks for infants older than 12 months of age, such as object sorting and match-to-sample confirm the late inclusion of humans in the concept of animal due to the fact that parents of young English-speaking children have a discourse practice that support the contrastive concept of animal but provide little support for the inclusive concept (Wright, Kelley, & Poulin-Dubois, 2014). Recent cross-linguistic research confirms this powerful effect of language by contrasting Indonesian-speaking children's concept of animal to that of English-speaking children. In Indonesian, the word "animal" is not polysemous as it only refers to the contrastive definition. As expected, this cross-linguistic difference affects children's acquisition of the concept as they are less likely to place humans and animals in the same category than children who speak English (Anggoro, Waxman, & Medin, 2008). In sum, language impacts concept formation in both positive and negative ways.

26.6 CONCLUSIONS

Much of the evidence presented in this chapter suggests that, due to the development of sophisticated experimental procedures, it is now well established that infants' early object categories are global in nature and become gradually more fine-grained with age. The object categories documented during the first few months of life with visual attention procedures are most possibly perceptually grounded as infants have limited semantic memory skills and limited experience with category exemplars. For example, 3-month-olds categorize cats as equivalent in laboratory studies because the exemplars presented during familiarization share many appearance features with one another. However, sometime during the first year of life, infants also start to group a wide range of objects that have minimal common features (e.g., vehicles and furniture), and more importantly, they can infer that some dynamic properties (e.g., trajectory, manner of motion, etc.) glue together category members in tasks that require accessing information from memory as opposed to on-line processing (Arterberry & Bornstein, 2001; Pauen, 2002b; Saxe, Tenenbaum, & Carey, 2005; Träuble & Pauen, 2011; Träuble et al., 2014). For a number of researchers, this provides evidence that conceptual categories emerge early in development, with categories like cats understood not simply as objects looking alike, but as self-propelled entities that can serve as agents in causal events. Later on, children, like adults, will conceptualize cats as biological entities that grow, reproduce, eat, etc.

At this point, there is no clear understanding of what happens during the first year to make the transition to category representations more conceptual. Obviously, the richness of experience that infants acquire with members of categories (how they look, how they move, their function, etc.) will most likely be reflected in the concepts that children and infants form. In other words, it is important to explore what is uniquely human about concept formation. We need to learn more about which mechanisms contribute to bottom-up category learning (e.g., associative processes) and how they change with age. Perhaps even more importantly, we need to explore at what age, in which way, and under what circumstances top-down processes (e.g., memory activation) influence categorization performance.

Clearly, attempts to link unique representational formats to different ages will bring the additional challenge of explaining how one format is transformed into the other (Mareschal, Quinn, & Lea, 2010). There is still little empirical progress being made but we, and many other researchers, have developed paradigms such as the "ambiguous-motion paradigm," or the "shadow" procedure (see Section 26.4 for details) that will allow the identification of the static and dynamic features associated with different categories at different ages, thus shedding more light on developmental changes in conceptual representations.

How and when language acquisition impacts concept formation still remains to be better understood. As we reviewed, words facilitate the extraction of common observable properties in very young infants. However, by the time children are 4 or 5 years old, they extend novel words on the basis of causal powers more than observable properties (Gopnik & Sobel, 2000; Légaré et al., 2008). For example, if a red cylinder causes a machine to light up, then children are more likely to generalize the word to a blue cube that has the same function than to another red cylinder that does not. Similarly, children of the same age recognize that an animal cannot be transformed into another animal by only changing its appearance (Waxman & Gelman, 2010). Such theory-based categorization does not develop out of the blue and we share with others the assumption that children's concepts are never entirely pretheoretic (Gelman & Koenig, 2003; Keil, Smith, Simons, & Levin, 1998).

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