Categorization in infancy

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Human infants display complex categoriztion abilities. Results from studies of visual preference, object examination, conditioned leg-kicking, sequential touching, and generalized imitation reveal different patterns of category formation, with different levels of exclusivity in the category representations formed by infants at different ages. We suggest that differences in levels of exclusivity reflect the degree to which the various tasks specify the relevant category distinction to be drawn by the infant. Performance in any given task might reflect prior learning or within-task learning, or both. The extent to which either form of learning is deployed could be determined by task context.

The way we group items together or categorize them determines how we learn about the relationships between objects and how we generalize these relationships to novel items. Thus, categoriztion as a mental process is considered to be critical for the organization and stability of cognition. Although a previous scholarly generation considered categoriztion to be a developmentally late achievement[1], more recent research suggests that categoriztion has an early onset, with even newborns displaying primitive categoriztion abilities[2]. In this article, we review evidence of categoriztion by infants from birth up to the age of 30 months.

Because the perceptual and motor skills of infants undergo considerable change during their first two years, it has proven difficult to devise a simple test of categoriztion that is applicable to all infants. Different methods have been devised for testing infants at different ages, and so care must be taken to consider the demands of these different tasks when trying to compare categoriztion performance across ages. In the next few sections we discuss what the use of these different experimental methods has revealed about infants' abilities to categorize stimuli. The principle methods used are: (1) visual preference; (2) object examination; (3) conditioned leg-kicking; (4) sequential touching; (5) generalized imitation (Box 1 provides a detailed description of these procedures). In all of these procedures, categoriztion is inferred if infants respond equivalently to exemplars from a common category and respond differentially to exemplars from contrast categories.

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Results from visual preference studies

Early studies provided evidence that infants under one year of age could form perceptual category representations for visual patterns, such as schematic faces and geometric forms[3–6]. For example, when presented with dot pattern exemplars generated from either diamond, square, or triangle prototypes, 3–4-month-old infants generalized looking times to novel instances from the familiar form category, and displayed visual preferences for novel instances from novel form categories. Under certain conditions known to facilitate prototype abstraction in adults (i.e. increased numbers of exemplars, increased number of categories, delayed visual preference test), infants also displayed a prototype effect; that is, they responded as if an unfamiliar prototype was more familiar than a previously observed exemplar[3,4].

Subsequent investigations explored whether young infants could form perceptual category representations for more computationally complex visual stimuli[7]. In these studies, realistic colour photographs of individual exemplars of basic-level animal categories (e.g. cats) and furniture (e.g. chairs) were presented to 3- and 4-month-olds. At a narrowly tuned basic level, infants were found to form a category representation of domestic cats that included novel cats, but excluded birds, dogs, horses and tigers, and a category representation for chairs that included novel chairs, but excluded couches, beds, and tables. At a broader, more global level, infants were observed to form a category representation of mammal that was inclusive of instances of novel mammal categories, but exclusive of birds, fish, and furniture, and a category representation of furniture that was inclusive of exemplars of novel furniture categories, but exclusive of mammals. The category formation processes of infants can thus be viewed as flexible and responsive to the variability characteristics of the input.

One interesting nuance in the study of category formation by infants with visual preference procedures is that infants sometimes display asymmetries; that is, they will prefer instances from novel category B after presentation with exemplars of familiar category A, but not prefer instances from novel category A after presentation with exemplars from familiar category B (Refs 8,9). For example, under some familiarization conditions, infants presented with cats will form a category representation of cats that excludes dogs, but will not form a category representation for dogs that excludes cats. The idiosyncratic nature of the cat–dog exclusivity begs the question of how infants separate exemplars into two distinct categories in the first place. The presence of a mixture of exemplars from both categories in the familiarization set is not sufficient to cause the infants to partition the categories. When presented with mixed

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Box 1. Details of infant experimental methods

Several different methods have been devised for testing infants at different ages (Table I). These methods are described in turn below.

Visual preference methodology

Infants are tested by means of a portable visual preference apparatus, adapted from that used by Fagan[a,b]. The apparatus provides an enclosed viewing chamber with a grey stage that contains two compartments, which can be used to display two posterboard stimuli simultaneously to the infant (one to the infant's left, the other to the right) (Fig. I). Once in the apparatus, infants are seated on a parent's lap and observers can measure infant-fixation duration to the stimuli through peepholes in the display stage. The criterion for fixation of a stimulus is the observation of corneal reflection of a stimulus over the infant's pupil. During familiarization, stimuli are randomly selected, different for each infant, and presented during six or eight 15-s trials (two different stimuli per trial). After this familiarization phase infants are presented with a novel same-category exemplar and a novel different-category exemplar for two 10-s test trials. Left–right locations are counterbalanced across infants on the first test trial and reversed on the second test trial.

Object examination methodology

Infants are seated in a high chair with the experimenter facing the infant. The experiment consists of several trials of fixed duration. A toy is placed on the high chair table and the infants' attention is directed to the toy (Fig. II). Infants are allowed to manipulate the toy. The initial trials are familiarization trials with (typically) two or three blocks of four different exemplars from the same category. Presentation order is randomized within each block. The test phase typically consists of three trials inclusive of presentation of: a novel instance from a familiar category, a novel instance from a novel category, and a completely novel stimulus. Coding for active examination involves both handling and looking criteria[c,d].

Table I. Experimental method and approximate age range tested

Experimental method	Age tested
Visual preference	0–12 months
Conditioned leg-kicking	3–6 months
Object examination	7–11 months
Generalized imitation	9–14 months
Sequential touching	13–30 months

Fig. I. Example of a 6- to 7-month-old in a Fagan box. This infant is about to be shown two photographic images of cats. During testing, the display panel is swung upwards to present the two pictures. The central peephole is used to observe the infant. Additional peepholes to the left of the left stimulus compartment and to the right of the right stimulus compartment allow for assessment of inter-observer reliability. Photograph provided courtesy of Paul Quinn.

Conditioned leg-kick methodology

This procedure is based on operant conditioning. Infants are placed face up in a crib or an inclined seat and with a multi-element mobile (e.g. six painted cubes) overhanging in full view[e,f] (Fig. III). During reinforcement phases, the overhanging mobile is attached via a ribbon to the infant's ankle such that kicks activate the mobile. During non-reinforcement phases, the mobile remains in view but the ribbon is disconnected so that leg movements do not cause mobile movements. Each session begins with a two-minute non-reinforcement phase during which a base-rate of kicking is measured. This is followed by a 6–9 minute reinforcement period during which the ankle ribbon is attached to the mobile. During this phase the infant learns to associate leg kicking with the movement of the overhanging mobile. Each reinforcement phase is then followed by a final non-reinforcement phase (1–2 minutes). This serves as an immediate retention test and is used as a standard comparison in delayed recognition tests occurring 24 hours, one week, or two weeks later. In categoriztion tasks, infants are familiarized with two or three different mobiles on successive training days, and tested with a novel mobile from the familiar category or a novel mobile from a novel category. The degree to which the conditioned leg kicking is transferred to the

familiarization sets, infants sometimes form individuated category representations, but at other times form a common global category representation that encompasses both sets of exemplars[10–12]. What does appear to be significant is the distinctiveness (i.e. the amount of feature overlap) of the two categories mixed together[11].

Co-variation information between features in the familiarization set is one cue that 10-month-olds, but not 4-month-olds, can use to tease apart categories[13–15]. It might be that the younger infants are performing some kind of feature weighting that could be the result of inherent preferences (i.e. biases) to attend to particular features. This featural information could then be used as a basis for categorical partitioning. Indeed, Quinn and colleagues found that the internal features of the face and the external contours of the head are sufficient for 3–4-month-olds to form distinct category representations of cats and dogs[16–18].

Results from object examining studies

Some investigators have used small, three-dimensional toy models of objects for stimuli and a manual habituation methodology to measure infant categoriztion performance. Oakes and colleagues have argued that combining looking with touching (i.e. examining) provides a measure of more active information processing about objects than just looking time[19,20].

Fig. II. Examples of some toy replica stimuli used in tasks involving manipulation, such as the object examination tasks, the sequential touching tasks and the generalized imitation tasks. Photograph provided courtesy of Lisa Oakes.

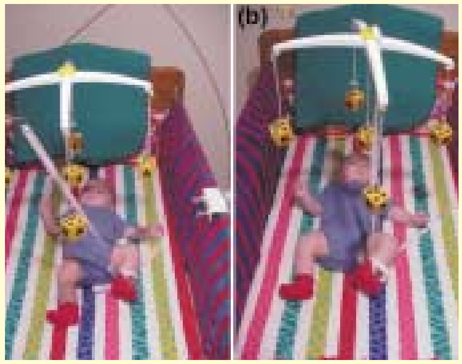

Fig. III. The experimental arrangement in the mobile conjugate reinforcement (conditioned leg-kick) task, shown here with a 3-month-old. (a) The arrangement used during baseline and the delayed recognition test: The ribbon and mobile are attached to different hooks so that kicks cannot move the mobile. (b) An acquisition phase: The ribbon and mobile are attached to the same overhead hook so that kicks move the mobile. Photographs provided courtesy of Carolyn Rovee-Collier.

novel mobile from the familiar category, but not the novel member of the novel category is used as an index of categoriztion.

Generalized imitation methodology
These tasks involve modelling an action with an object, then presenting the infant with a novel object from the same category or a novel object from a novel category and observing which test object the infant generalizes the observed action to[g]. The infant is seated on a parent's lap across a table from an experimenter. Infants' demonstrations of the properties are evaluated once before modelling (baseline) and once after modelling (generalization). In the baseline condition, participants are given the target item, a distractor, and the prop item used to demonstrate the test action. Upon completion of the baseline condition, the items are removed from sight and an action (accompanied by an appropriate vocalization) is demonstrated three times with the prop item. During testing, the test items are placed to the left and right of the infant and the experimenter repeats the action-appropriate vocalization. The item selected by the infant to produce the action is recorded. When more than one item is selected, both the first and second choices are considered.

Sequential touching methodology
Infants are seated in a high chair. For a given object-manipulation task in which a particular category contrast is tested, eight objects (toy replicas of real-world objects), four from each category, are randomly placed on the high chair table. The infant is encouraged to manipulate the objects, and is allowed to manipulate the objects for several minutes with no further intervention by the experimenter, with the exception that any object that falls off the table is surreptitiously replaced on the table by the experimenter. Infant manipulation is recorded on video and scored off-line. The order in which objects are touched (by hand or with another object) is recorded. The dependent measure is the mean length of successive touches to the objects of each category[h–j]. These are compared against average sequence lengths as generated by Monte-Carlo simulation.

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Outcomes from studies using visual preference and object examining methodologies are similar. For example, both 10- and 13-month-olds responded to categories on the basis of feature distributions in the exemplars presented during familiarization[21]. When presented with a perceptually diverse familiarization set, 10-month-olds made no distinction between categories of land- and sea-animal. As was the case with the visual preference methodology, the perceptual variability of the familiarization set appears to be a determinant of whether one category excludes exemplars from the other category. Infants form an exclusive category when familiarized with a set of exemplars with low perceptual variability, but form an inclusive category when familiarized with a set of exemplars with high perceptual variability.

The object examining procedure reveals further that the frequency and typicality of the exemplars encountered constrains the exclusivity of the categories acquired[22]. When tested with a land-animal versus sea-animal contrast, 10-month-olds who repeatedly experienced a typical exemplar of a land animal (e.g. half the exemplars were zebras) acquired a category of land animal that excluded sea animals. By contrast, 10-month-olds who repeatedly experienced an atypical exemplar of land animals (e.g. half the exemplars were rabbits) formed a category of land animal that *did not* exclude sea animals. In this study, an exemplar was deemed typical if it was perceptually similar to the other exemplars in the familiarization set.

Relying on the same methodology, Mandler and McDonough found that infants begin to categorize animals and vehicles as early as seven months, and do so robustly by nine months, but that they fail to respond to basic-level distinctions within these global categories[23]. For example, 9-month-olds did not show any differentiation of furniture, and both 9- and 11-month-olds distinguished between dog and bird forms, but did not differentiate cats from dogs until 11 months of age[24]. The reader might note that the visual preference methodology indicates that 3–4-month-olds can represent basic-level categories when presented with a familiarization set consisting entirely of the target basic-level category, and on this basis believe that there is a significant discrepancy in outcomes from the visual preference and object examining procedures. However, the difference in findings might simply be the result of parametric variation in the number of exemplars used to define the category (i.e. 12 in the case of visual preference versus four in the case of object examination).

Results from conditioned leg-kick studies

In the studies reviewed thus far, infants were given relatively brief exposure (typically 15–30 seconds per exemplar) to a number of exemplars (from 4–16) defining a category. They were then tested within a few minutes of familiarization. Studies in this section expose infants to a smaller number of exemplars (typically two or three) for a longer period of time (nine minutes). Exemplars are encountered at 24-hour intervals and testing occurs from 1–14 days later.

Initial findings suggested that 3-month-olds could form category representations of shape (either a letter or a number) when familiarized with different coloured exemplars of the same shape class across training trials[25]. Spontaneous performance of the conditioned leg-kick response disappeared after 14 days, but could easily be reinstated with an appropriate novel exemplar of the familiar category. However, both the elicitation of category-based responding 24 hours later or reinstatement of category-based responding 14 days later are highly dependent on very specific cues. Cues present in all the exemplars (such as the background colour of the mobiles)[25] are not sufficient to elicit generalization of response to a novel exemplar of the familiar category. Moreover, just changing the conjunctions (but not the independent components) of form and colour is sufficient to inhibit the transfer of the category-specific response to the novel exemplar[26].

In older infants the specificity of the category-based response is even more acute. Although 6-month-olds appear able to form category-based response associations after having experienced just two different exemplars, their responses are highly context dependent. These infants will only display generalization to a novel exemplar if the same crib background is in place[27]. The high specificity of the cues required to show category transference in both 3- and 6-month-olds has led to the suggestion that infants encoded the categories as sets of individual exemplars rather than in terms of summary statistics, such as average prototypes and variance[28,29]. Given the small number of exemplars presented in the conditioned leg-kick studies, and the depth of processing of these exemplars, it should not be viewed as surprising that the infants have formed exemplar-based representations[4].

Results from generalized imitation studies

In these studies, various properties or actions appropriate to animals or vehicles are modelled to 14-month-olds[30,31]. The results are consistent with the idea that infants can represent broad, global-level category distinctions and not basic-level category distinctions. The infants generalized the properties of ‘drinking’ and ‘sleeping’ throughout the animal domain and the properties of ‘being keyed’ (i.e. inserting a key) and ‘giving a ride’ throughout the vehicle domain. For example, they would generalize a drinking action modelled with a toy dog equally often to another similar toy dog, as to a toy cat, rabbit, or aardvark. However, infants generalized domain-independent actions (such as going into a building) to both domains.

A key debate in recent research is whether or not infant categories are based on perceptual information (Box 2). The results of generalized imitation studies have been used to support the claim that infants base their inductions on category representations that transcend perceptual similarity. However, although it is true that critical test stimuli from different global categories sometimes shared a similar form, they also differed by a small set of defining features. For example, although a toy bird with open wings and a toy aeroplane shared a common general form, the aeroplane had wheels, which were also present on the car that was used to model the actions appropriate to vehicles, and the bird had head features that were also present in the dog used to model the actions appropriate to animals (Ref. 30, Fig. 1 on p. 319). These might have been the features on which the infants based their category distinctions, rather than taxonomic domain distinctions. As such, it remains unclear to us whether these studies demonstrate that infants are representing meaning dissociated from perceptual resemblance.

Results from sequential-touching studies

Results from sequential-touching studies are somewhat ambiguous. When presented with a set of toy replicas of animals or vehicles, infants again

Box 2. From percept to concept: one versus two-process frameworks

A source of debate within the infant categoriztion literature is centred on the processes that infants rely on to represent category information. A dual-process framework for thinking about the category representations of infants begins with the idea that 'seeing is not the same as thinking'[a]. This view embraces the idea that category representations formed on the basis of static perceptual attributes are merely perceptual schemas that define what a group of things looks like (i.e. categories based on appearance), but that do not contain the content required to define the meaning of something. True category representations or concepts are formed through the analysis or redescription of continuous perceptual input – a process that produces output representations called 'image schemas' (i.e. categories based on meaning). Image schemas are the forerunners of mature concepts and can be used to separate animals from non-animals by conceptual primitives, such as whether the members of the concept are self-starters or non-self-starters. The dual-process framework thus suggests that infants possess both perceptual schemas that can be used for *identifying* entities and image schemas that can be used for *conceptualizing* entities – different systems of representation for perception versus conception that operate in parallel.

Another view argues that the category representations of infants develop gradually through a process of quantitative enrichment[b]. By this view, infants develop a category representation for animal or animal-like entities, for example, by encountering various animals over time, and joining together into a common representation perceived attributes such as an elongated body shape, skeletal appendages, facial attributes bounded by a head shape, biological movement patterns, and communicative sounds.

The observable static and dynamic attributes that can be detected from the surfaces and trajectories of the exemplars by perceptual input systems can be supplemented by less apparent information regarding biological structures and functions, such as 'has a heart' and 'can reproduce', that is acquired at times by means of language. Language in this view serves as an additional input system that can deliver information that further defines representations already established through vision (and other sensory modalities). Indeed, 'a representation like animal that may begin by picking out relatively simple features from seeing and other sensory modalities comes over time to have sufficient knowledge to permit specifying the kind of thing something is through a single continuous and integrative process of enrichment'[b]. The single-process framework has received support from computational simulations in which an identical connectionist network was able to form category representations based on perceptual structure or on arbitrary (non-perceptual) classification of input[c].

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display evidence of global representations[32,33]. From 18–30 months, infants respond categorically only to global-level contrasts, such as vehicles versus animals, but do not respond categorically to basic-level contrasts within global categories. Not until 30 months do infants consistently represent basic-level contrasts within a global-level (e.g. rabbit vs. dog or car vs. truck). Similar results were also reported for the domains of plants and furniture.

Rakison and Butterworth used the sequential-touching procedure to replicate the finding that older infants respond to the global category contrast of animals versus vehicles[34]. However, they also examined how sequential-touching performance would be affected when toy exemplars that have no ecologically valid counterpart are used to test the infants. When presented with novel hybrid items constructed from mixed parts of vehicles and animals (e.g. a cow body with wheels or a tractor body with cow legs), 14- and 18-month-olds do not divide these items in accord with global category membership, but rather, according to whether they possess specific features or parts (i.e. has legs or has wheels). On the basis of this evidence, it was argued that 14–22-month-olds represent categories only when there are between-category part differences and within-category part similarities to act as the basis of classification. Moreover, these infants will also rely on the structural relationships between the object parts to form category representations[35]. Of course, it can always be argued that responses to non-ecologically valid stimuli reflect different categoriztion processes from those that operate in everyday settings, a point that we will return to in the final section of this article.

A possible synthesis: category learning versus category retrieval

Studies not requiring a familiarization phase (i.e. sequential touching and generalized imitation studies) find that infants separate entities according to broad, global category distinctions. By contrast, studies that require a familiarization phase (i.e. visual preference, object examination, and

Box 3. Connectionist models of category learning in infancy

Connectionist autoencoders are efficient, unsupervised category learning devices[a], which have recently been used to model the relation between sustained attention and representation construction in infancy[b–d] (Fig. I). The networks learn to reproduce on the output units the pattern of activation across the input units. In an autoencoder, the number of hidden units is smaller than the number of input or output units. This architecture produces a bottleneck in the flow of information through the network, thereby forcing the network to develop a more compact internal representation of the input (at the hidden unit level) that is sufficiently rich to reproduce all the information in the original input. This process is analogous, but not equivalent, to computing a principle component representation of the input data[e]. The successive cycles of training in the autoencoder are an iterative process by which a reliable internal representation of the input is developed. Not only do these systems learn to classify the same category exemplars in the same way as the infants do, but they also show the same extension and exclusivity errors as the infants when presented with the same items[c]. The networks have also produced a common result, in that global categories preceded basic-level categories in order of appearance[f]. The global-to-basic developmental profile has been found to hold true for infants from a variety of age groups (i.e. birth to 2.5 years), performing in looking, touching, and generalized imitation procedures[g–k]. In these studies, infants have provided evidence of global category representations earlier and more readily than basic-level representations.

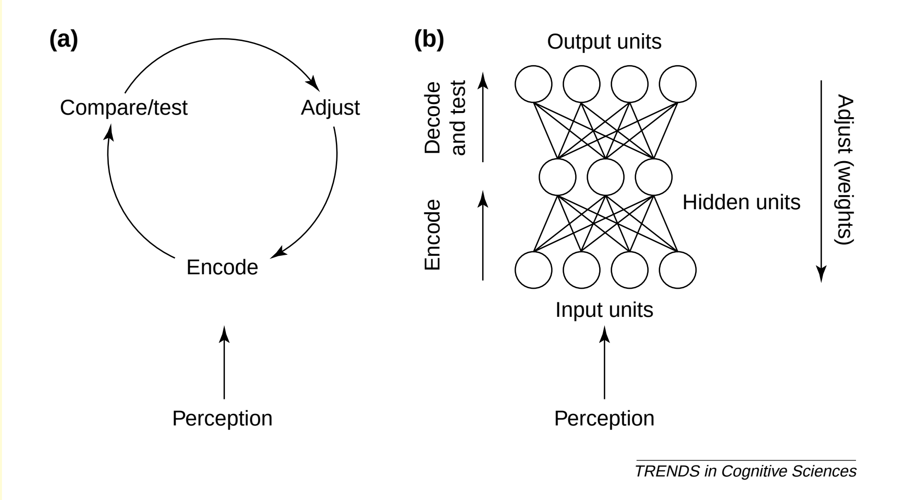

Fig. I. The process of habituation depicted as representation construction in (a) infants and (b) autoencoder connectionist networks. Both are viewed as an iterative process of representation construction, in which the contents of some internal representations are actively compared to the current environment features. Modifed from Ref. 50.

The exciting thing about these models is that they begin to provide some process account of category learning in infancy[l]. That is, they attempt to explain how feature-distribution information inherent in the environment gets translated into the observed infancy behaviours. This is achieved through a statistical learning mechanism that generates internal representations that reflect the distribution characteristics of the environment.

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conditioned leg-kicking) find that infants can sort entities into global categories, but they can also form more finely tuned basic-level categories, and in some instances are even sensitive to the exemplar-specific characteristics of the individual instances presented during familiarization. We suggest that these studies can be reconciled in terms of the amount of learning that occurs within an experiment.

In visual preference, examining, and leg-kicking tasks, infants are provided with experience of the target category prior to the testing that occurs at the end of the task. This manipulation defines (or begins to define) the boundaries for the appropriate category distinction required by the task. Such manipulations have a long history in the adult category learning literature[36–40], and it is now well established that adults can tune their perceptual discriminations in response to the requirements of a categoriztion task[41,42].

By contrast, sequential touching and generalized imitation might provide less within-task specification of the relevant category distinction. For example, there is no familiarization (i.e. teaching) phase in the sequential-touching procedure. This task thus requires the infants to respond without any prior indication of the experimenter-defined

Questions for future research

- How does knowledge from outside the testing room affect infants' within-task category learning?
- What developing neural systems enable different kinds of category learning during infancy?
- How does the acquisition of language affect the spontaneous categoriztions made by infants?
- Are infant categories represented as sets of exemplars or in terms of summary structures?
- Are there multiple category learning processes operating during infancy? If so, what are they and how do they operate?

classification. In the generalized imitation studies, there is some prior indication, but only for a *single* action–object pairing. Without such indications, coarse categoriztions that broadly separate the items placed on the table in front of the infants seem reasonable. Thus a failure to show basic-level categoriztion in these tasks might reflect a differential setting of an acceptable level of categorization, rather than the actual absence of categoriztion abilities *per se*. Infants' categorical differentiation between toy animals and people provides a clear demonstration of this idea. Ten-month-olds will show categoriztion of toy people versus toy animals in an object examination task (requiring inspection and processing prior to testing), but infants fail to show clearly the same categoriztion in a sequential touching task until 16 months[43].

Does prior knowledge affect performance on tasks that do not involve a familiarization phase? Evidence suggesting that it does comes from tests of memory using sequential touching[44]. Toddlers were found to recall sequences that follow an ecologically valid causal order much better than ones that do not. This finding suggests that the infants are using their previously acquired world knowledge to help guide their touching sequences. It follows that the touching sequences observed in categoriztion tasks might tap some of the representations stored in long-term memory and acquired through real-world experiences.

Performance on sequential touching tasks that rely on hybrid objects is consistent with this interpretation. Hybrid objects, composed of both animal and vehicle parts[34], do not mesh neatly with information in long-term memory. Thus representations from long-term memory are unlikely to have a strong impact on guiding touching sequences in these tasks. Hence, feature similarity can govern touching performance with hybrid stimuli.

A similar story can be applied to the generalized imitation studies. Categoriztion outcomes obtained with toy replicas of common animals and vehicles are consistent with the idea that infants rely on associative links in long-term memory to guide their actions. However, induction studies relying on the same imitation methodology but which use novel objects paired with unexpected sounds have found that infants base their imitations on perceptual similarity[45]. Here again, in the absence of experience with any similar objects, infants appear to rely on a computation of feature similarity to drive their actions.

This is not to say that long-term memory representations have no impact on categoriztion in tasks that involve within-task learning. Indeed, there is ample evidence in the adult literature that prior knowledge influences how novel categories are acquired[46]. In the infant literature, Quinn and Eimas[9] have argued that young infants' categoriztion of humans versus non-human animals in a visual preference experiment is the result of differential experience with members from the two classes that occurs prior to the experiment. The effect of prior knowledge on infant category learning is likely to be an area that will be explored in detail in the future.

Finally, with a few exceptions[47–49] (Box 2), what most of these studies have failed to provide is some account of the mechanisms by which infants learn categories. Although they describe what kind of categories infants can acquire, and on what basis they will form categories, they do not make explicit how those categories are acquired, nor in what representational format they are stored. To date, the only mechanistic models of both within-task and across-development category learning in infants are connectionist (Box 3). However, none of the current models describe how prior knowledge can affect category learning, nor how the input feature space on which similarity is computed develops with age and experience.

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