Global-Before-Basic Object Categorization in Connectionist Networks and 2-Month-Old Infants

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A 3-layered backpropagation connectionist network, configured as an autoassociator, learned to form global (e.g., mammal) before basic-level (e.g., cat) category representations from perceptual input. To test the predicted global-to-basic order of category learning of the network, 2-month-olds were administered the familiarization/novelty-preference procedure and examined for representation of global and basic-level categories. Infants formed a global category representation for mammals that excluded furniture but not a basic-level representation for cats that excluded elephants, rabbits, or dogs. The empirical results are consistent with the global-to-basic learning sequence observed in the network simulations.

A number of years ago it was suggested that object categories were initially represented at the basic level and that superordinate categories developed later when separate basic-level representations were joined in a common superordinate structure (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Supporting data came
from an experiment in which 3-year-olds were presented with three objects and asked to identify which two were alike. The children succeeded in a basic-level version of the task (e.g., Airplane 1, Airplane 2, dog) but performed poorly at the superordinate level (e.g., airplane, car, dog; see also Daehler, Lonardo, & Bukatko, 1979; Horton & Markman, 1980; Mervis & Crisafi, 1982).

A challenge to the traditional basic-to-superordinate view of category development has been issued in a series of articles by Jean Mandler and her collaborators (Mandler, Bauer, & McDonough, 1991; Mandler & McDonough, 1993). These investigators argued that the critical sorting experiment of Rosch et al. (1976) was confounded, in that the basic-level task could be solved on the basis of either basic-level knowledge (how much two airplanes are alike), superordinate-level knowledge (how much two airplanes are different from the dog), or both. The more appropriate test of basic-to-superordinate development is to determine if children (or infants) can differentiate basic-level categories chosen from the same superordinate category before they can differentiate between two superordinate categories. Mandler and her associates have now reported a number of studies adopting this experimental design, and the outcomes are consistent with the idea that initial category representations may take the form of global categories that are more inclusive than basic-level categories (Mandler et al., 1991; Mandler & McDonough, 1993). Specifically, when given the opportunity to explore small toy stimuli in the object-examining and sequential-touching procedures, infants and toddlers between 7 and 24 months of age more readily form global representations differentiating animals from vehicles than basic-level representations distinguishing horses from dogs or cars from trucks.

Experimental work on the emergence of category representations at different levels has also been conducted with younger infants in the age range of 3 to 7 months (reviewed in Quinn & Eimas, 1996b, 1997). The infants were presented with realistic, pictorial exemplars of various categories in a familiarization/novelty-preference procedure. Although this work is often cited as evidence that infants form basic-level category representations, it would be more accurate to say that what is obtained when exclusivity is examined is evidence for a child-basic level of category representation. A child-basic representation can refer to a level of representation between a broad global level and a narrow adult-basic level (Mervis, 1987). For example, 3- and 4-month-olds form a child-basic representation for domestic cats that excludes birds, horses, dogs, and tigers but includes novel domestic cats and female lions (Eimas & Quinn, 1994). Three months later, in 6- to 7-month-olds, the representation for domestic cats excludes female lions, suggesting that differentiation is occurring over time, allowing representations to become more adult-basic in their level of exclusiveness. A broader-to-narrower developmental trajectory is thus observed in young infants that is in keeping with the finding of global-before-basic category representation reported for older infants.
Further in accord with the data obtained by the Mandler team (Mandler et al., 1991; Mandler & McDonough, 1993) is evidence that young infants can also form a global level of category representation (Behl-Chadha, 1996; Behl-Chadha, Eimas, & Quinn, 1995). Three- and 4-month-olds familiarized with instances from a number of mammal categories (e.g., cats, dogs, tigers, rabbits, zebras, elephants) form a global representation of mammals that includes novel mammal categories but excludes instances of nonmammalian animals (i.e., birds and fish) and human-made artifacts (i.e., furniture).

One issue that remains unexplored is the course of category development in infants younger than 3 months of age. Are the earliest category representations formed by infants more nearly global or adult-basic in their level of exclusiveness? That is, are the representations formed by newborns and 1- and 2-month-olds more or less inclusive than the representations of infants 3 months of age and older? Does development consist of differentiation of the specifics from the global or grouping together of the specifics to form the global?

To examine this issue, we (Quinn & Johnson, 1996, 1997) investigated the emergence of global and basic-level category representations in connectionist learning systems. From a developmental perspective, connectionist models may help us understand the initial formation of category representations because the models are composed of connected processing units that form representations as connection strengths between the units change with experience according to one or another learning algorithm (Elman et al., 1996). For input, we used measurements of various surface attributes of the mammal and furniture stimuli used in the Behl-Chadha studies (Behl-Chadha, 1996; Behl-Chadha et al., 1995), and we found that a series of simple three-layered (i.e., input–hidden–output) networks taught by a backpropagation learning algorithm produced a common result, namely, that global categories (e.g., mammals, furniture) preceded basic-level categories (e.g., cats, tables) in order of appearance (see also McClelland, McNaughton, & O’Reilly, 1995; Rumelhart & Todd, 1993; Schyns, 1991). This global-level superiority was maintained even when (a) head and tail attributes of the mammal stimuli were excluded from the input scheme and (b) a global category teaching signal was not provided at the output layer.

Although these simulation results are informative, it can be argued that the global-to-basic order of category emergence was dependent on a category teaching signal at the basic level. That is, even in the networks without a global category teaching signal, the vectors representing individual training exemplars at the input layer were mapped through a layer of hidden units to vectors representing basic-level categories at the output layer. One can question whether this is an appropriate way to model infant categorization performance because there is no external teacher supervising infants in most perceptual categorization tasks (for possible exceptions, see Husain & Cohen, 1981; Kuhl, 1979). It therefore becomes important to determine whether the prediction of global-to-basic category emergence will hold up in networks that have no category teaching signal.
In the remainder of this article, we (a) describe the performance of a series of autoassociative networks learning global and basic-level categories without the benefit of a category teaching signal at either level and (b) evaluate the global-before-basic prediction from the modeling by examining the category representations formed by 2-month-old infants.

SIMULATIONS

We used a three-layered backpropagation network architecture with an autoassociative configuration; the input had to predict the output (which was just a copy of the input) through a layer of hidden units. As described by Mareshcal, French, and Quinn (1999), the number of hidden units in an autoassociator is kept smaller than the number of input or output units. This architectural feature creates information compression at the hidden unit layer but also means that the hidden unit layer is forced to retain enough of the statistical properties of the input so that each input exemplar can be successfully reproduced at the output layer. The pattern of activation across the units of the hidden layer generated by the input exemplars can thus be used to examine the similarity structure (i.e., the global and basic-level categories) extracted by the network at different points during the course of training.

Method

Description of networks. The networks had 13 inputs, from three to six hidden nodes, and 13 outputs. The inputs were 13 attributes of pictorial instances of cats, dogs, elephants, rabbits, chairs, tables, beds, and dressers, stimuli used in the categorization studies conducted with 3- to 7-month-olds (Behl-Chadha, 1996; Quinn & Eimas, 1996b, 1997). Outputs were identical to inputs. All simulations were performed on TLEARN (Plunkett & Elman, 1997).

The inputs encoded geometric and head–face dimensions of the stimuli: vertical extent of mammal bodies (exclusive of leg, head, and tail length) and furniture exemplars (exclusive of leg length), horizontal extent, number of legs, leg length, tail length, head width, head length, ear separation, eye separation, ear length, nose width, nose length, and mouth length. The coding of geometric aspects corresponded with the skeleton extraction model of object recognition developed by Zhu and Yuille (1996). This model represents individual objects as a set of connected parts or perceptual primitives whose axes form two-dimensional skeleton structures. The networks were provided with the dimensions of individual skeleton parts of the mammal and furniture exemplars. The large number and detailed nature of head and face attributes were selected because of evidence that infants (a)
are highly attracted to facial information (M. H. Johnson & Morton, 1991) and (b) appear to use information from the face and head region of some animal species to categorically distinguish between them (Quinn & Eimas, 1996a). There are also psychophysical and neurophysiological data suggesting that some face and head attributes in the input scheme (eye separation, head length and width, mouth width, nose length and width) may be used in face recognition (Rhodes, 1988; Yamane, Kaji, & Kawano, 1988; Young & Yamane, 1992). It should be noted that, in referring to inputs as legs and ears, we do not mean to imply that the infant has a conceptual understanding of them. The inputs were all surface dimensions of the stimuli and potentially available to low-level parsing routines that segment a shape into a number of component parts. Each input value was measured directly from a stimulus in centimeters and then linearly scaled so that the values for each attribute ranged from 0.0 to 1.0.

Training and testing procedure. Training consisted of presentation of a variable number of blocks of 24 trials (sweeps) during which each of three stimuli from each of the eight basic-level categories were presented in a random order. Results regarding the emergence of categories at different points during training are reported in training sweeps (1 sweep = 1 presentation of a single stimulus). Generalization testing consisted of presentation of a novel exemplar (i.e., one not presented during training) from each of the eight basic-level categories.

Decision rule. Patterns of activations generated on the hidden units were used as a basis for determining whether the network had formed a representation for a particular global or basic-level category. Given that the range of activation on any unit in the network was 0.0 to 1.0, activation values on each hidden unit for each training and test stimulus were rounded to 0.0 if the actual value was less than .50, and to 1.0 if the actual value was greater than .50. If the resulting pattern of activation was consistent across a given category of training and test exemplars and not found among contrast categories, the network was said to have learned a representation for that category (e.g., for three hidden nodes: cat = 010, dog = 011, elephant = 001, rabbit = 000, chair = 110, table = 111, bed = 101, dresser = 100).

Results and Discussion

Table 1 displays the training sweep values at which the two global categories and first basic-level category emerged in networks trained with different starting seeds and with hidden nodes that varied in number from three to six. The values were based on testing done after each block of 24 training sweeps. It can be seen that, in each of the 16 cases, the network developed representations for mammals and furniture at the hidden unit layer before representations for any of the basic-level cate-
categories had appeared. All of the simulations clearly reflected a global-to-basic sequence of category emergence.¹

One interesting trend that could be observed was that networks with smaller numbers of hidden nodes (i.e., three and four) were slower to develop basic-level category representations than networks with larger numbers of hidden nodes (i.e., five and six). Even when the outlier training sweep values for initial emergence of basic-level category representations generated with a starting seed value of 1 (28,320 and 3,480) were removed from statistical consideration, there was still a reliable difference between the mean training sweep value for initial basic-level category emergence in networks with three and four hidden nodes ($M = 552.00, SD = 281.12, N = 6$) and networks with five and six hidden nodes ($M = 384.00, SD =$

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¹To check whether the learning of global-before-basic categories observed in the networks was a function of the particular number of categories or stimuli presented for the global and basic levels, the simulations were repeated with (a) two (instead of four) basic-level categories within each of the two global categories and (b) three cats, one dog, one elephant, and one rabbit representing the mammal category and three chairs, one table, one bed, and one dresser representing the furniture category. In the first simulation, global categories were learned before basic-level categories, and in the second simulation, mammals and furniture were learned before either cats or chairs. The results of both simulations provide support for the idea that the global-to-basic learning sequence is not limited to a specific number of categories or exemplars presented for the global and basic levels.
116.87, \( N = 8 \), \( t(12) = 1.97, p < .05 \), one-tailed. Hidden node number did not, however, affect speed of global category emergence, \( M(3 \text{ and } 4) = 66.00, SD = 35.71, N = 8 \); \( M(5 \text{ and } 6) = 60.00, SD = 25.65, N = 8 \); \( t(14) = 0.39, p > .10 \), one-tailed. In general, the trend for faster basic-level category emergence in networks with more hidden nodes can be said to reflect the greater representational capacity and flexibility of such networks. In particular, many of the networks displayed a tendency early in the training sequence to overcommit to coding the global level by allotting more than one hidden node to partition mammals and furniture. Whereas networks with five and six hidden nodes had sufficient remaining numbers of hidden nodes to code differences between basic-level categories, networks with three and four hidden nodes were in some instances left without sufficient representational resources to efficiently code the basic level.

Another observation was that all of the networks formed intermediate or child-basic representations in the course of their learning path from global to basic representations. Table 2 shows just one example of this trend for the network simulations conducted with a starting seed of 50. If we test the representations of the network at a training sweep value beyond when the initial global representations have been formed, we can observe child-basic representations such as “cat + dog” and “chair + table.” These results are important because they reveal the gradual, continuous emergence of the category representations (for possible correspondences with experimental data, see Eimas & Quinn, 1994; Mervis, 1987; Younger & Fearing, 1998).

The major finding that global category representations are observed before those at the basic level in an autoassociative network indicates that this learning sequence is not dependent on a category teaching signal at either the global or basic level. Given that global and basic-level representations have been observed with 3- to 4-month-olds, and on the assumption that what occurs in network training is analogous to what happens during development (i.e., both the networks and infants experience more and more category instances over time), the global-before-basic order predicts that global representations should emerge before those at the basic level prior to 3 months of age.\(^3\)

\(^2\)Evidence of child-basic representations was obtained when a network was learning to differentiate within a global category. After learning to respond to each global category but before learning to respond to each basic-level category within a global category, there were instances in which networks responded with a consistent and distinct pattern of activation across the hidden nodes to the training and test instances from two or three basic-level categories from the same global category (e.g., cats and dogs). Further training would be needed to allow these child-basic representations to be split apart into structures more closely approximating adult-basic representations (e.g., cats vs. dogs).

\(^3\)The link between network performance in an individual training session and predicted infant performance over longitudinal development is based on the idea that younger infants, like networks with less training, would have less exposure to category exemplars prior to their participation in a laboratory-based category familiarization task. Consequently, these infants should be less likely to form finer grained category representations in the context of such a task (see Quinn & Eimas, 1998, for further comment on the relation between infant experience and performance in laboratory categorization tasks).
TABLE 2
Category Representations Formed in Simulations Conducted With a Starting Seed of 50 at a Training Sweep Value Beyond When the Initial Global Representations Appeared

<table>
<thead>
<tr>
<th>No. of Hidden Nodes</th>
<th>Training Sweep Value</th>
<th>Global</th>
<th>Child-Basic</th>
<th>Adult-Basic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4,800</td>
<td>Mammal</td>
<td>Cat + dog</td>
<td>Elephant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Furniture</td>
<td>Chair + table</td>
<td>Dresser</td>
</tr>
<tr>
<td>4</td>
<td>7,680</td>
<td>Mammal</td>
<td>Cat + dog</td>
<td>Elephant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Furniture</td>
<td>Chair + table</td>
<td>Rabbit</td>
</tr>
<tr>
<td>5</td>
<td>480</td>
<td>Mammal</td>
<td>Cat + dog + elephant</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Furniture</td>
<td>Chair + table</td>
<td>Dresser</td>
</tr>
<tr>
<td>6</td>
<td>960</td>
<td>Mammal</td>
<td>Cat + dog</td>
<td>Elephant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Furniture</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EXPERIMENT 1

Experiment 1 was conducted to test the global-before-basic prediction by examining whether 2-month-old infants could form (a) a global category representation for mammals that excluded furniture and (b) a basic-level category representation for cats that excluded dogs, rabbits, and elephants. At the basic level, a group of 12 infants was presented with pictorial exemplars of 16 cats during eight 15-sec familiarization trials and then given two 20-sec preference tests, each consisting of two 10-sec trials. One test paired a novel cat with either a rabbit or an elephant, whereas the other paired a novel cat with a dog. At the global level, a different group of 12 infants was familiarized with 16 mammals (2 from each of eight different mammal categories) over the course of eight 15-sec familiarization trials and then given two 20-sec preference tests, each consisting of two 10-sec trials. One test paired a novel member of a familiar mammal category with a novel member from a novel mammal category, whereas the other paired a novel member from a novel mammal category with a novel furniture exemplar. The expectation from the modeling is that infants may form a global category representation for mammals but not a basic-level representation for cats. This pattern of outcomes would be evidenced by (a) infants in the global tests preferring furniture over exemplars from novel mammal categories but not novel exemplars from novel over familiar mammal categories and (b) infants in the basic-level tests not responding preferentially to novel elephants, rabbits, or dogs over novel cats.

Results and Discussion

Familiarization trials. Individual looking times were summed over both stimuli on each trial and then averaged across the first four and last four trials. The
mean looking times for cats at the basic level were 10.47 sec (SD = 1.72) for Trials 1 through 4 and 10.14 sec (SD = 2.41) for Trials 5 through 8 and, for mammals at the global level, 10.85 sec (SD = 2.42) for Trials 1 through 4 and 9.64 sec (SD = 3.33) for Trials 5 through 8. An analysis of variance, Category Level (Basic vs. Global) × Trial Block (1–4 vs. 5–8), performed on the individual scores revealed no significant effects, $F(1, 22) < 2.07, p > .15$, in each case. That a reliable decrement in looking time reflective of habituation was not observed is consistent with previous studies that used the same stimuli with 3- to 7-month-olds (Behl-Chadha, 1996; Eimas & Quinn, 1994; Quinn, Eimas, & Rosenkrantz, 1993) and is presumably the result of numerous complex and multidimensional stimuli maintaining infant attention during familiarization.

Preference test trials. For each global and basic-level test of categorization, each infant’s looking time to the novel category stimulus was divided by the looking time to both test stimuli and converted to a percentage score. The mean preference scores to the novel category are shown in Table 3. For those infants familiarized with cats at the basic level, the preference scores for rabbits and elephants (combined) and for dogs were not reliably different from the chance preference of 50%. For those infants familiarized with mammals at the global level, exemplars from novel mammal categories were not reliably preferred over novel exemplars from familiar mammal categories, but furniture exemplars were preferred to exemplars from novel mammal categories.

<table>
<thead>
<tr>
<th>Familiar Category</th>
<th>Novel Category Exemplars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elephants or Rabbits</td>
</tr>
<tr>
<td>Cats</td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>52.55</td>
</tr>
<tr>
<td>$SD$</td>
<td>22.02</td>
</tr>
<tr>
<td>$N$</td>
<td>12</td>
</tr>
<tr>
<td>$t$ (vs. chance)</td>
<td>0.40</td>
</tr>
</tbody>
</table>

| Mammals           |                          |             |
|-------------------|--------------------------|
| $M$               | 52.99                    | 59.82       |
| $SD$              | 23.86                    | 17.82       |
| $N$               | 12                       | 12          |
| $t$ (vs. chance)  | 0.43                     | 1.91*       |

* $p < .05$, one-tailed.
The results indicate that 2-month-olds formed a global representation of mammals that included instances of mammal categories not experienced during familiarization but excluded furniture; 2-month-olds did not, however, form a basic-level representation for cats that excluded exemplars of other mammal species. Given that 3- and 4-month-olds (M age = 3.5 months) have been shown to form both global and child-basic category representations (Quinn & Eimas, 1996b), the findings that infants 6 weeks younger form only global category representations is consistent with the global-to-basic learning sequence observed in both standard backpropagation (Quinn & Johnson, 1996, 1997) and autoassociative connectionist networks. The data also correspond with evidence of global category superiority obtained with older infants performing in object-examining (Mandler & McDonough, 1993), sequential-touching (Mandler et al., 1991); and inductive inference procedures (Mandler & McDonough, 1996). The studies with older infants have been interpreted as providing evidence that infants use "conceptual primitives" as a basis for grouping together members of global categories, on the assumption that perceptual similarity is not sufficient to ground such categories (Mandler, 1992). However, the simulation and experimental results obtained with young infants suggest that at least some global category representations can also emerge on the basis of perceptual information (Haith & Benson, 1998).

EXPERIMENTS 2 AND 3

Before further discussion of the findings as the outcome of a perceptual categorization process, it is important to consider two alternative accounts of the reliable preference for furniture exemplars over exemplars from novel mammal categories. First, the reduced contrast sensitivity of younger infants (Banks & Salapatek, 1981; Dobson & Teller, 1978) could render a variety of mammalian exemplars indistinguishable from one another. If infants were not able to discriminate among individual mammals, they would have experienced the familiar mammal category exemplars, even those viewed on the test trials, as a single exemplar. Thus, what might be interpreted as a preference for a novel over a familiar category was actually a preference for a novel over a familiar stimulus, and what was intended to be an examination of categorization amounted to a study of discrimination. A control experiment was therefore performed to test for within-category discrimination. Each of

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4A weakness in the link between the modeling and experimentation is that the models were trained with both mammal and furniture categories together, whereas the infants were familiarized with mammals (or cats) but not with contrasting furniture items. However, Younger and Fearing (1998, 1999), using an experimental task more closely resembling the task presented to the models, also reported global-to-basic category development in 4- to 10-month-old infants.
12 infants was familiarized with a single mammal for one 15-sec familiarization trial and then given two 10-sec preference test trials that paired the familiar with a novel mammal. The results were a mean looking time during the single familiarization trial of 12.48 sec ($SD = 3.54$) and a mean preference for the novel mammal during the test trials of 68.60% ($SD = 18.37$), which was significantly greater than the chance value of 50%, $t(11) = 3.51, p < .005$, one-tailed. The reliable preference provides evidence that the 2-month-olds differentiated between individual mammal stimuli.

It is also possible that the preference for furniture over mammals reflected an a priori preference that would have been present with or without a familiarization experience with mammals (cf. Behl-Chadha, 1996). However, a control experiment to assess spontaneous preference in which each of 12 infants was presented with randomly selected pairs of pictures from the two categories during a series of eight 15-sec trials yielded a mean furniture preference score of 49.49% ($SD = 12.67$), a value not reliably different from the chance value of 50%, $t(11) = -0.23, p > .20$, two-tailed. This outcome indicates that the preference for furniture in Experiment 1 was not the result of an a priori preference. The combined results of the control experiments reinforce the conclusion that 2-month-old infants formed a global category representation for discriminally different mammals that excluded instances of furniture.

**GENERAL DISCUSSION**

Although a conventional view of early category development has been that basic-level categories are learned before those at the superordinate level (Rosch et al., 1976), the simulation and experimental results reported are consistent with a global-before-basic learning sequence. The young age of the infants and the fact that the stimuli were realistic photographic exemplars of the categories suggest that the global category representations formed are perceptually based. Although it is difficult to specify precisely what perceptual information infants are using to form global category representations, network performance on global category differentiation of mammals versus furniture is boosted by the presence of face and tail inputs for the mammals and the absence of them for furniture (Quinn & Johnson, 1997). More generally, Quinn and Eimas (1996b, 1997; see also Aturan, 1987, 1990; Berlin, 1992; Rakison & Butterworth, 1998) have reasoned that the information that differentiates mammals from furniture (and possibly other global categories) could be presence versus absence of certain attributes such as facial features, fur, and tails, and that such information may be more discriminable than the information that may be used to separate mammals from one another (e.g., specific dimensional values of facial features, hair length and coloring, and tail length). However, global category formation may not be
based entirely on attribute presence versus absence, given that a network reported by Quinn and Johnson (1997) also learned global categories when operating only with inputs reflecting the basic spatial dimensions of the stimuli. On average, the mammals tended to have smaller bodies (i.e., smaller mean values for horizontal and vertical extent) but longer legs than the furniture exemplars. In addition, Van de Walle, Spelke, and Carey (1997) reported that older infants may form global category representations on the basis of the curved contours of the mammal bodies versus the rectilinear contours of the furniture stimuli. Smith and Heise (1992) also presented evidence indicating that some global category distinctions (i.e., animals vs. vehicles) can be supported on the basis of surface texture appearance. Thus, global category formation may reflect the confluence of multiple cues.

An issue left unanswered by available evidence is how to think about the full course of development of global and basic-level category representations. A possible summary view of the data is that one tends to find global (and child-basic) superiority effects in infants and toddlers up to approximately 24 months of age (e.g., this study; Eimas & Quinn, 1994; Mandler et al., 1991; Mandler & McDonough, 1993, 1996; Mervis, 1987; Younger & Fearing, 1998; but see Roberts & Cuff, 1989; Waxman & Markow, 1995). In contrast, basic-level superiority effects have been reported with older participants, including both children (e.g., Daehler et al., 1979; Horton & Markman, 1980; Mervis & Crisafi, 1982) and adults (e.g., Murphy & Smith, 1982; Rosch et al., 1976). Furthermore, adult participants who become experts within a domain may come to represent subordinate-level categories as robustly as basic-level categories (K. E. Johnson & Mervis, 1997; Tanaka & Taylor, 1991).

The effects of age and experience are consistent with the idea that as individuals begin to encounter objects within a domain, their initial representation of those objects will tend toward the global level. The greater rapidity of global category learning may be the result of the features that unite a global category being more discriminable and more frequently encountered relative to properties that define each basic-level category from the same global structure. Increasing frequency of experience with objects in a domain results in a greater likelihood that those objects will be represented at the basic or even subordinate levels.

These suggestions have a correspondence with the behavior of connectionist networks that possess multiple hidden nodes and are provided with extensive training on a category learning task (Quinn & Johnson, 1996, 1997; see also earlier discussion in Simulations section). What is observed during the course of network learning is an initial allocation of hidden nodes to coding the global level, with the remaining nodes not yet committed. The early global-coding nodes quickly learn to represent large differences in attribute values that distinguish the global categories. As learning proceeds, there is a gradual decrease in the proportion of the overall representation that codes for the global level and a gradual increase in the
proportion of the overall representation that codes for the basic level. This is because more and more of the hidden nodes become committed to encoding basic-level distinctions that are characterized quantitatively by smaller value differences along various attributes. However, the global level never drops out of the overall pattern of representation. By this view, one might think of global category representations as precursor representations from which basic-level (and eventually subordinate-level) category representations evolve. Once basic-level representations emerge, however, they may in some instances replace global representations in displaying superiority because more internal resources (i.e., hidden nodes) are needed to represent them.

Additional issues regarding the emergence of category representations during the period of early infancy remain for future research. First, because the familiarization (training) stimuli were limited to four-legged mammals and the test comparisons did not include bird and fish exemplars (cf. Behl-Chadha, 1996; Behl-Chadha et al., 1995), this study leaves open the question of just how global a representation can be formed by quite young infants. It would appear that perceptual information is sufficient to allow the infants to form a global category representation inclusive of at least prototypical mammals (i.e., four-legged nonprimates). However, conceptual information could be required for infants to group together (a) mammals as perceptually diverse as whales and bats and (b) animals more generally (Mandler & McDonough, 1993; but see Quinn & Eimas, 1998). These findings also do not address category development during the time period from birth to 2 months. Given that novelty-preference procedures can be used to study categorization in newborn infants (Slater, 1995), it should be feasible to examine the levels of category representation available to the neonate and thereby gain insight into the initial beginnings of category formation for complex stimuli. In closing, we note that this work illustrates the potentially fruitful interaction between connectionist modeling and empirical studies with infants. We believe that programs of infancy research centered on testing the predictions of such models will yield deeper insights into both the infant mind and the nature and limits of artificial learning systems.

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