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THEMATIC COLLECTION: RESPONSE

Understanding Early Categorization: One Process or Two?

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We are grateful for the opportunity to respond to the commentaries of Smith (this issue) and Mandler (this issue), especially in light of the critical challenges posed by the latter. We begin with what we believe to be the crux of the debate: Does early category formation need to be understood within a dual-process framework in which perceptual learning is dissociated from conceptual understanding? In one way or another, each of us believes the answer to this question at present is no. Smith would appear to agree when she notes that there may be "no such thing as

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knowledge dissociable from the processes of perceiving and remembering" (p. 94). In contrast, Mandler believes that perceptual categorization and concept formation are "two different things" (p. 99). We now consider issues related to this debate that are brought out in the commentaries at the level of metatheory, mechanism, and data.

METATHEORY

Mandler (1992) argued that infants use a process of perceptual analysis to derive image schemas that represent very abstract notions such as actor, object, causality, and so on, as well as abstract categories such as animal and artifact. However, she does not believe that this is the same process by which infants form sensory images of categories such as cat and dog. The precise reasons for denying that these are the same processes are unclear to us. In each case, there is an abstraction of common features from a category (Madole & Oakes, 1999). The only difference is that, in one case, you end up with fairly concrete features in common (e.g., the cat's head) and, in the other, you end up with more abstract and dynamic features in common (self-motion, biological motion, interaction from a distance). The feature extraction in both cases appears to us to be almost exactly the same kind of process. In contrast, Mandler (this issue) contends that one is conceptual and the other is not, noting in her commentary that conceptual category formation entails categorizing "objects in terms of how they move and interact with each other and, in an abstract way, the roles they take in events" (p. 108). However, as we believe and as Smith's (this issue) commentary implies, perceptual categorization of dynamic motion events may account for much of what Mandler (this issue) considers to be conceptual categorization (see also Haith & Benson, 1998). Our own view is that one can account for the evidence to date with sufficiently sensitive perceptual input systems (including that for language for the purpose of encoding nonobvious features) and a complex learning system. We believe that the underlying mechanisms that generate perceptual category representations and conceptual category representations may be the same, although the latter may include information that is more abstract and more dynamic.

MECHANISM

The strength of the computational modeling reported in the articles by Mareschal and French (this issue) and Quinn and Johnson (this issue) resides in their in principle demonstrations of the category representations that can be formed, their level of exclusiveness, and their relative time course of emergence in a learning device that receives inputs measured directly from the surfaces of the stimuli—inputs to which young infants might conceivably be sensitive. The modeling also provides a formalization of descriptive ideas contained within a differentiation-based theory of perceptual category learning (Gibson, 1969; Kellman & Arterberry, 1998; Werner, 1957). Smith (this issue) regards the simulation results and their close fit to the experimental data as evidence that a perceptually based account can work as an explanation for infant categorization performance at both global and basic levels.

Mandler (this issue) believes that connectionist modeling is a reasonable way to simulate perceptual category learning because the models are designed for a kind of learning that involves statistical extraction. We agree that the models learn by progressive extraction of statistical regularities in the input. The models pull apart categories more easily when quantitative inputs that separate those categories are characterized by large and clear value differences. However, we disagree with the implication that connectionist models may not be suitable for other kinds of learning like conceptually based learning. Connectionist mechanisms are not limited to having only perceptual features as inputs. Other less directly perceivable qualities can be encoded. Recent connectionist models of semantic representation have encoded both perceptual and nonobvious features (Farah & McClelland, 1993). It is important for us that the mechanism remains the same whether the input codes perceptual or higher level aspects of a stimulus.[1] In addition, if nonobvious features are encoded at the input, the onus is on the modeler to justify how those features are constructed by the infant; otherwise, the use of nonobvious features reduces to an ad hoc procedure with no explanatory value.

With respect to the appropriateness of the input schemes used by Quinn and Johnson (this issue) and Mareschal and French (this issue), we note that connectionist models have sometimes been criticized for adopting arbitrary input formats (Marcus, 1998). Moreover, deciding on input features in the domain of vision is a nontrivial matter because the features that infants (or adults for that matter) use to recognize objects are still a matter of much debate. However, the encoding of the geometric dimensions of the mammal and furniture stimuli by Quinn and Johnson (this issue) and the schematic animal stimuli of Younger (1985) by Mareschal and French (this issue) resembles a current theory of the perceptual primitives that underlie object recognition (Zhu & Yuille, 1996). Size differences (cats vs. elephants) and presence versus absence of movement were not included in the input scheme of Quinn and Johnson (this issue) because the stimuli presented to the infants were static and equated for overall size. The head–face contribution to the input scheme used by Quinn and Johnson (this issue) and Mareschal and French (1997) to model the acquisition of cat or dog + cat categories is motivated by the evidence that infants use both internal face and external

[1]This point is clearly illustrated in the arbitrary, global-level category learning simulations of Quinn and Johnson (1997) in which an identical connectionist network with the same inputs was able to form categories based on perceptual structure or on arbitrary (nonperceptual) classification of the inputs.

head information when forming representations for different classes of animals (Quinn & Eimas, 1996a, 1996b; Spencer, Quinn, Johnson, & Karmiloff-Smith, 1997).

Mandler (this issue) argues that the networks of Quinn and Johnson (this issue) rapidly learned the global categories of mammals versus furniture because the internal resources of the networks quickly learned to represent large value differences (positive values and zeros) in the attributes that distinguished the global level (i.e., the presence of faces and tails in the case of mammals and the absence of them in the case of furniture). The networks were slower to learn basic-level categories such as cats versus dogs or chairs versus tables because these distinctions were characterized quantitatively by smaller value differences along various attributes. We agree with this analysis, although we mention again that the no-face/no-tail simulations of Quinn and Johnson (1997) revealed that information in the geometry of the stimuli was able to support global category formation. On average, the mammals had longer legs but smaller bodies than the furniture when exemplars from the two categories were equated for overall size. Admittedly, this information was weaker and, as Mandler (this issue) notes, only able to support global category learning when used in conjunction with a category teaching signal (for discussion of additional geometric cues for global category differentiation, see Smith & Heise, 1992; Van de Walle, Spelke, & Carey, 1997).

At one level, Mandler (this issue) seems uncomfortable with the coding scheme presented to the networks and the categories presented to the infants by Quinn and Johnson (this issue), arguing that the networks and infants could simply have been learning to classify things with faces versus things without faces. This concern would also apply to the global category contrast of animals and vehicles investigated by Younger and Fearing (this issue).[2] At another level, Mandler (this issue) seems sympathetic with the overall modeling approach (although leaves herself open to her own criticism) when noting that she used movement versus nonmovement as an input attribute to model infants' conceptualization of animals versus vehicles. Our position would be that, in an ecologically valid world, categorization should follow closely from the structure of the input. If networks and infants are sensitive to attribute differences (e.g., face and movement vs. no face or movement) and those attribute differences tend to covary with global category differences (e.g., mammals vs. furniture), one at least has evidence that networks and infants can represent attribute information that serves to mark global categories as

[2]However, if the categorical distinctions of mammals or animals versus furniture or vehicles were based simply and solely on selective processing of face versus no face, one might have expected infants to display reliable spontaneous preferences for the mammals and animals given the general visual interest in faces that is present even in newborns (M. H. Johnson & Morton, 1991). That the infants did not display such preferences is consistent with the idea that the category representations are, in these instances, based on the processing of multiple attributes.

distinct from each other. We agree with Mandler (this issue) that significant attribute differences may also contribute to some category distinctions at basic and subordinate levels of exclusiveness (i.e., curliness of hair to distinguish poodles and terriers), but on the whole, we believe that larger attribute differences will tend to be associated with more inclusive categories, thus providing a basis for the more general trend of perceptual learning of global to more specific categories. By this view, mammals versus furniture or animals versus vehicles may not be special cases of global category differentiation but illustrations of a more general principle that the information separating global categories is more distinguishing than the information individuating basic-level categories.

Both Mandler (this issue) and Smith (this issue) raise the difficult but important issue of how to relate network (and infant) learning in an individual experimental task with development that occurs in real-time spans of months and years and the associated changes that occur in maturation of sensory mechanisms and increase in world experience.[3] Although we cannot offer a definitive resolution to this issue, we make the following observations. First, although the models reported do not take into account changes in maturing visual capacities (i.e., contrast sensitivity and resolution acuity), it would be possible to simulate such changes through alteration to the input (i.e., introducing noise values into the input scheme for attributes affected by spatial frequency filtering). We agree with Mandler's (this issue) speculation that the low-pass characteristic of the young infant's visual system could serve to further underscore global category superiority if some of the fine-grained featural values that differentiate basic-level categories from the same global category were no longer resolvable. Second, although the relation between amount of experience of a network and age of an infant is far from precise, we still believe it reasonable to draw parallels between less experienced networks and younger (less experienced) infants (see also Schafer, 1999). Although younger infants are unlikely to have observed the exact stimuli presented in familiarization–habituation experiments prior to their participation in such tasks, they have been exposed to related stimuli that may be sufficient to build up representations that could influence learning occurring within those tasks (for further comment and theory on the relation between world experience and within-task learning, see Needham & Baillargeon, 1998; Quinn & Eimas, 1998). Why world experience should be thought of as affecting laboratory categorization performance in the object-examining task at 7 months (Mandler & McDonough, 1998) but not in familiarization–habituation tasks at 2 through 4 months is not clear to us.

Related to the issue of network learning and its connection to human development is Mandler's (this issue) characterization of networks as not growing or developing over tasks and the accompanying assertion that less experienced

[3]One part of the problem is that networks do not have any world experience when we start to train them, although infants always arrive in a lab with some degree of world experience.

networks are equivalent to more experienced networks. Although the learning algorithm within a particular section of a network will remain invariant, some networks do grow over time (Mareschal & Shultz, 1996). Furthermore, networks do develop different levels of category representation (knowledge) over different time scales in the context of a single task (see Figure 4 of Quinn & Johnson, 1997, p. 246). Progressive experience with objects from a structured training environment allows different levels of knowledge representation to be constructed over time (e.g., global only or global and basic), which in turn influences the response of the network to new inputs.

It may be helpful to recognize that there are both long-term and temporary representations within a network (Munakata, 1998). Also important for us is the fact that the computational characteristics of both representations are compatible with each other. The long-term knowledge representation is encoded in the connection weights, and the transient representation of the current state of the world is encoded in the pattern of activation throughout the network. This framework is consistent with Smith's (this issue) contention that knowledge is not dissociable from the processes of perceiving and remembering. The knowledge embodied in the connection weights of a network is only retrievable when activation passes through the network. It is through the act of perceiving that memories (and hence knowledge) are retrieved.[4] From this perspective, one is left to wonder how a dual-process framework could be implemented at a mechanistic level with one format for encoding long-term knowledge representations and another format for encoding the immediate inputs of perception. At the very least, what would seem to be required is a separate system of representation for translating the outputs of perception into the inputs of conception and back again. We believe it more parsimonious to try to build a "baby" with a single integrated system of representation (see also Goldstone & Barsalou, 1998, for an attempt to reunite perception with conception in the adult literature).

EMPIRICAL EVIDENCE

At issue for Mandler (this issue) is the strength of empirical support for global-to-basic perceptual category learning. As noted earlier, the reports of Younger and Fearing (this issue) and Quinn and Johnson (this issue) involve mammals (or animals) contrasted with furniture (or vehicles). This choice of categories could be problematic because of the possibility of specialized processing mechanisms for animals (but see previous discussion). It will, therefore, be important to determine

[4]That said, we may not want to go as far as Smith (this issue). Our discussion makes clear that we believe that representation is a useful construct when discussing infant behavior. For example, as described by Mareschal and French (this issue), responses to novel exemplars depend on the similarity between their internal representations and those that are produced by familiar exemplars.

if global-to-basic development can be observed for other global category distinctions such as furniture and vehicles. In this regard, Mandler (this issue) notes that Behl-Chadha (1996) did not find evidence that 3- and 4-month-old infants could form a category representation for furniture that excluded vehicles. However, this was only because the infants already showed a strong spontaneous preference for vehicles over furniture, a result consistent with global category differentiation based on preferred perceptual properties possessed by members of one category but not by the other (Eimas & Quinn, 1994). Exactly what those properties may be in the case of vehicles versus furniture is difficult to specify at this time, but possibilities include amount of shine, quality and brightness of coloration, degree of curvature, or some complex combination of these properties.

Mandler (this issue) also raises questions about the data and conclusions of Younger and Fearing (this issue). One concern is that Younger and Fearing espouse global-before-basic category development in the beginning of their article but do not say where such global categorizing might stop. Mandler (this issue) contends that, in presenting members of two quite distinctive categories (cats and cars or cats and birds), Younger and Fearing were presenting sets of stimuli that varied widely in appearance, thus posing a difficult categorization task for young infants. The suggestion is that young infants were not forming global perceptual categories and may not have been categorizing at all.

Although we believe that Mandler (this issue) is correct in the inference that lack of a looking preference could mean that either infants had formed a global category or they failed to categorize at all, it is important to note that infants in all age groups did show a significant decrease in looking across habituation trials in all three experiments, suggesting that at least some category representations were being formed. Younger and Fearing (this issue) also included a third test comparison in the cat–car and cat–bird experiments (the results of which were not reported in their article). The comparison was between a novel member of one of the two familiarized categories and a picture of a human face. Infants at all ages preferred the face. To us, these findings suggest that the younger infants had formed some kind of category. What this category might consist of is not clear, and a much broader set of test comparisons would be needed to make this determination. Although cats and cars (as categories of objects) have few features in common, all of the stimuli used in the study were pictures of objects, and there was considerable overlap between the categories in the colors of the objects. Perhaps the younger infants formed a category of colorful objects. Although such a category would not represent a global domain in the traditional sense, it would represent a broader, more inclusive category than those formed by the 10-month-old infants, and in that sense, it is consistent with the global-before-basic principle brought forth in the Younger and Fearing article.

Mandler (this issue) also suggests (based on Figure 1 of Younger & Fearing, this issue) that there were no common features that infants could have used to form a global perceptual category of animals in the cat–bird experiment. Younger and

Fearing selected exemplars that varied widely in coloration and stance. As a result, it is true that features such as tails and eyes were not visible in all exemplars. They were, however, apparent in most. Inspection of the full set of stimuli revealed that 10 of 15 birds used in the study had visible eyes (5 had a high degree of contrast, making the eyes very striking). Fourteen of 15 birds had tails (i.e., distinguishable tail feathers). Among the cats, 14 of 15 exemplars had tails, and all of the cats had visible eyes (8 with a high degree of contrast). Thus, there was considerable overlap between the two familiarized categories (cats and birds) in the presence of salient perceptual features.

With respect to the sequential-touching data reported by Rakison and Butterworth (1998b), we agree with Mandler (this issue) that one could take issue with the across-category confound task (the one in which the stimuli were half animal and half vehicle) on the grounds that it confused the infants. However, it is not as easy to explain the overall pattern of findings obtained over multiple experiments in this way. For example, there was positive evidence in all age groups tested by Rakison and Butterworth (1998b) for the categorical differentiation of animals and vehicles. Were infants relying on previously formed conceptual representations of animals and vehicles (concepts activated by the exemplars presented in the task) as a basis for their touching? If the concepts were clearly conceptually grounded, one would have expected them to be resistant to perceptual perturbations of the stimuli. However, when the legs were removed from the animals and the wheels from the vehicles, the infants no longer performed the categorical differentiation. A glance at Figure 1 of Rakison and Butterworth (1998b) suggests that adults would still have conceived of the cow without legs as an animal and the train car without wheels as a vehicle. Why not infants? The only conclusion we can draw is that infants (well into their 2nd year of life) may actually be using prominent perceptual attribute differences between groups of objects as a basis for their performance in sequential-touching categorization tasks. To our way of thinking, the work of Rakison and Butterworth continues to have major significance because of its challenge to the view that infants are using conceptually based representations to constrain performance in the sequential-touching procedure.

Mandler (this issue) also argues that it is not plausible to conclude that infants' failure to categorize insects as different from furniture, for example, is because the objects share parts such as legs. The claim is that there is little basis for assuming that a table leg bears much relation to an insect leg. However, recent studies by Rakison and Butterworth (1998a) suggest that such a basis does in fact exist. Using the sequential-touching procedure, it was found that infants under 22 months attend not to individual parts per se but to the structural configuration of the parts perceived as a whole. Thus, it is possible that infants fail to categorize insects as different from furniture because the exemplars from these categories possess similar structural configurations as given by parts.

Sensitivity to structural configuration could also help to explain why infants respond equivalently to cups and pans in generalized imitation studies, given that both categories are characterized by a structural configuration that includes a base, sides extending upward from that base, and an appendage (handle) attached to the vertical rise. Forklifts and airplanes, despite many surface differences, both have a wheel base. Also, fish, like many other animals (including cats, rabbits, birds, armadillos, and humans) but not vehicles, may be put to sleep in a bed because they possess an abstract structural configuration that consists of a set of facial attributes adjoined to an elongated body axis with skeletal appendages. These examples should make it clear that we are not convinced that the generalized imitation technique taps what infants know independently of what they perceive.

An additional challenge for perceptual theorists posed by Mandler (this issue) is to explain how 9-month-old infants categorically differentiate between birds and airplanes with outstretched wings (Mandler & McDonough, 1993). The airplanes had wheels and tail fins not possessed by the birds. The tail fin feature might be especially conspicuous in that it adds a vertical dimension to the planes that is not present in the birds. There were also visually specified textural differences between the birds and planes. Any or all of these cues could have provided a perceptual basis by which to distinguish between the two categories. Also, to the extent that infants can draw on their world experience when identifying the exemplars presented in the laboratory as birds versus planes, movement and auditory cues would seem to be key features. Planes fly along smooth regular trajectories and produce continuous noise, whereas birds flap their wings, change direction, and produce pulsed chirping sounds.

Overall, in reviewing the evidence at issue, we are not compelled to abandon a perceptually based frame of reference for understanding early categorization or retreat from reports of global-to-basic perceptual category learning in infants.

CONCLUDING SUMMARY

It may be instructive to return to the originally stated goal of the symposium and draw summary conclusions from the group of contributions. The symposium was designed to allow four research teams that had adopted a perceptually based approach to investigating early categorization to communicate their findings in an open discussion format. Two of the contributions, Quinn and Johnson (this issue) and Younger and Fearing (this issue), report global-to-basic category formation in infants from 2 through 10 months of age. Quinn and Johnson (this issue), with their simulations, provide a demonstration that global-to-basic category learning could occur in a connectionist learning system on the basis of perceptual input. Mareschal and French (this issue) show how connectionist networks could also extract correlated attribute structure from an input set and use that structure as a basis for responding to that input as two discrete categories. The ability to extract correlations among attributes may be one of the abilities that underlies category formation at both global and basic levels of exclusiveness. Finally, Rakison discusses evidence that calls into question the view that categorization performance by infants performing in sequential-touching tasks is conceptually driven. Global category formation appeared to be disrupted by perceptual part manipulations of the exemplars in ways that are not easily assimilated by a conceptual account. Rakison's data indicate that the perceptual structure present in parts and their configurations is a significant determinant of infant categorization well into the 2nd year. Collectively, the contributions suggest that many aspects of infant categorization performance can be captured by perceptual learning processes that can be simulated in a mechanistic framework and that, with experience, produce increasingly differentiated representations. We suggest that similar mechanisms may be involved in conceptual categorization, albeit with more abstract and dynamic representations.

The convergence among the contributions strikes us as impressive in a discipline already rife with hard-to-replicate results (cf. S. P. Johnson, 1998). The combination of empirical results and computational simulations also seem to fit Smith's (this issue) model of cognition emphasizing "the dynamic creation of a moment of knowing out of previous moments of knowing" (p. 95). However, as Mandler (this issue) emphasizes, an important objective for the future will be to determine whether the global-to-basic trend in perceptual category learning by infants can be extended to global category contrasts other than mammal (or animal) versus furniture (or vehicle). In closing, we hope that this thematic collection of contributions and commentaries will serve as a stimulant for continuing work on the complex problem of understanding how infants form category representations of their experiences.

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