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Abstract

We present the results of a study examining the effects of category learning on the performance of five year-old children and adults on similarity judgment and same-different tasks. Participants in the learning condition learned to distinguish two kinds of invented alien stimuli by hearing an interactive story over the course of two days, at the end of which they performed three tasks. A comparison of their performance with control participants revealed a marked expansion effect in both children and adults, with learning groups judging between-category pairs to be more different than control groups did. There was no compression effect (within-category pairs were not judged as more similar by learning than control groups). We hypothesize that expansion occurred because distinguishing pairs of stimuli was difficult, as indicated by a high error rate on the same-different task for both child and adult participants.

Introduction

Nearly a decade of research now suggests that the space of similarities within which we locate objects undergoes a systematic change in metric structure in the course of category learning (e.g., Beale and Keil, 1995; Goldstone, 1994a; Goldstone, Lippa, and Shiffrin, 2001; Livingston, Andrews, and Harnad, 1998). This result contrasts sharply with the view of similarity taken for granted in classical descriptions of the category learning, where it is assumed that the metric of psychological similarity is fixed, with the result that the locations of objects within that space, and thus their relationships to one another, are entirely determined by their perceptual properties (e.g., Bruner, Goodnow, and Austin, 1956; Hutchinson and Lockhead, 1977). The more recent work suggests that the process of category learning itself may actually alter the similarity space and thus the representational structure of our categories.

Two different kinds of changes to psychological similarity space have now been documented in the literature. *Compression* occurs when one region of the n-dimensional space of similarities changes such that items falling within that region come to have more nearly equivalent encodings than they did prior to category learning. This pattern has been observed by Livingston, et al. (1998), and Kurtz (1996), for example, and manifests as (1) an increase, following category learning, in similarity ratings among items drawn from the same category as compared with items drawn from different categories, or, (2) as greater confusability among items drawn from the same category than among those drawn from different categories. In neural network simulations, the change has been measured directly as an increased similarity in activation patterns on hidden units in a simple feedforward network (Harnad, Hanson, and Lubin, 1995).

The other pattern of change in similarity space following category learning, called *expansion,* occurs when a region of the space of similarities changes such that items falling within that region are judged to be more different after category learning than prior to it, or are less confusable in a same-different task. This pattern has been extensively documented by Goldstone (1994a; 1994b; 1996; see also Goldstone, et al. 2001). In neural network simulations, the change has been measured directly as an a greater *dis*similarity in activation patterns on hidden units in a feedforward network (Harnad, et al. 1995; Tijsseling and Harnad, 1997).

In theory, both kinds of changes could occur in the course of category learning, but in general only one pattern is typically observed for a given set of stimuli. Research is currently ongoing to establish the conditions under which one observes compression versus expansion. One hypothesis under active investigation is that expansion is observed in those cases where the discrimination among exemplars in the training set is perceptually difficult, which results in discrimination learning. Compression, on the other hand, occurs when no difficult perceptual discrimination is required. What is important to note, regardless of the ultimate fate of this hypothesis, is that either compression or expansion is sufficient to produce the effect necessary for the psychological distinctiveness that characterizes concepts: a set of similarity relationships that sets the members of the category apart from non-members by its *relatively* greater degree of intra-category similarity (or, alternatively, inter-category dissimilarity).

It has been suggested by many of the researchers who have studied compression-expansion effects that the process may be so fundamental to category learning that it constitutes a basic mechanism by which abstract and universal representations (concepts) are formed (Damper and Harnad, 2000; Goldstone, 1996; in press; Livingston, et al, 1998). If this contention is correct, then evidence for the operation of this process should be found among young children as well as in adults. To count as truly fundamental to the process by which perceptual categories are built, it should not turn out that compression-expansion effects reflect a strategy acquired late in life or taking a long time to develop. Indeed, it does not appear that there is anything consciously strategic about the process at all; it seems to reflect the operation of an automatic recalibration of psychological similarity space in response to the discovery, during category learning, that a set of items needs to be partitioned in a consistent way. Nevertheless, evidence that this process operates in young children as well as in adults would strengthen the claim that it constitutes a basic mechanism of category learning.

Certainly there is little doubt that children and young infants can learn to make category distinctions, at least among perceptual categories of the kind at issue here (e.g., Quinn, Slater, Brown, and Hayes, 2001). There is also a growing, if still controversial, body of literature concerning the ability of young children to make use of information about function (e.g., Rakison and Cohen, 1999) or internal, inferred features (Gutheil, Vera, and Keil, 1998) when learning new categories or assigning novel objects to existing ones. There seem to be many similarities between the processes of concept formation in children and adults. To date, however, there has been no successful demonstration that children's category learning is characterized by compression-expansion effects (but see Katz, 1963 for suggestive findings).

The major purpose of the research reported here is to test the hypothesis that the category learning of children will show patterns of compression and/or expansion similar to those already observed among adults. In addition, the present study presents an opportunity to compare performance on similarity judgments with performance (errors and response times) on a same-different discrimination task. The similarity task may be more sensitive to the effects of category learning than the same-different task, but its conceptual complexity makes it difficult to use with children younger than five. Evidence that the same-different task can capture the effects of category learning would clear the way for future work with younger children.

The limited attention spans of young children necessitated the development of a more elaborate training and testing procedure than is needed with adults. Extensive pre-testing was required to design a story-based category learning task and engaging tasks for the testing process. Pilot studies revealed that the procedures are too demanding for children younger than five years of age, and even for older children must be spread across sessions on two consecutive days. Rather than rely on an implicit comparison to the adult literature, we included an adult sample that followed the same procedures used with the children.

Method

Participants

Participants were 27 kindergarten children between the ages of five and six, and 23 Vassar College students participating through an introductory psychology research requirement. Participants in each age group were randomly assigned to the learning or control conditions.

Stimuli

The stimuli were designed to resemble friendly-looking alien creatures and varied on the dimensions of torso width and arm length. Figure 1 shows stimuli with extremes on these dimensions; intermediate values were defined at equal intervals between extremes. All stimuli had yellow bodies, green feet, blue hands, and a pink nose.

For the learning condition, two categories were created and identified by the nonsense labels *Fip* and *Zug.* The Fips had longer arms and narrower torsos, while the Zugs had shorter arms and wider torsos. For each category there were three possible values on each dimension, for a total of nine possible members of each category. Of the eighteen different possible stimuli, fourteen (seven in each category) were used in the experiment. Stimuli were printed out on yellow paper, laminated, and glued onto felt with a black oval-shaped background. A 155-cm X 74-cm board covered in black felt served as the background for the story. To enhance the interaction of the children with the materials and make the story more interesting, felt props were also used. These props represented various objects and devices described in the story. For instance, when it was explained that the Zugs trained by lifting moon rocks and eating a diet of fuzzy pickles and purple pretzels, participants would be asked to place moon rocks, fuzzy pickles, and purple pretzels alongside the Zugs.

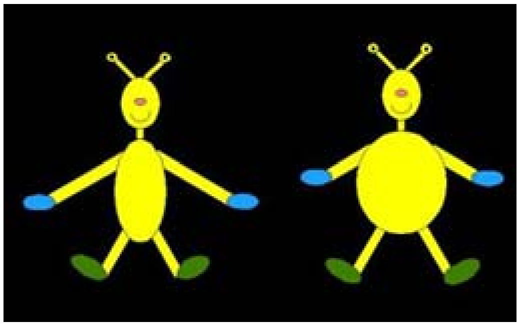

Figure 1. Examples of the stimuli.

Procedure

The learning condition. Those who learned to distinguish Fips and Zugs did so over the course of two, one-on-one sessions with an experimenter. Learning occurred in the context of a story, told using the large felt board and felt props, about two teams of four aliens, the Fips and the Zugs, who compete in an alien Olympics competition. The story is designed to hold a young child's attention so as to allow the experimenter to highlight the differences between the two categories in the context of an interactive dialogue rather than by direct instruction. For example, the long-armed Fips more easily get tangled in a cargo net while climbing, but their narrow torsos make them less likely to get stuck in an obstacle course. Interactivity is introduced by inviting the participant to help construct each scene. At several points in the script the participant is also asked to sort the aliens into categories, to allow provision of feedback as learning progressed.

On the second day of the learning condition, the story was continued. It concludes with a final competition, which results in a tie. The participant is told that he or she will get to stage one last game to settle the tie, but that first there are some other games to be played. These other games are the three primary data gathering tasks.

The participant gave similarity judgments for all fifteen possible pairs of six aliens, which include four that the participant had learned to categorize during the story telling (two from each category) and two not seen before (one from each of the two categories). Pre-testing indicated that fifteen judgments is an upper limit on five-year-olds' attention. The novel stimuli provide a check on whether what has been learned is a generalizable category. In the similarity judgment procedure one picture is placed at the left end of a long felt strip marked off into distinct intervals that allowed scores from 0.5 to 8.5 in 0.5 intervals. The participant is asked to place the other item according to how similar it was to the first item, with more proximal placement indicating greater similarity. The participant is trained on the task using pictures of different breeds of dogs. Pre-training continued until the judgments were being made reliably and with confidence. Once the system was understood, we presented the fifteen pairs of aliens. The experimenter recorded the judgment by reading the position of the center of the stimulus in relation to the marks on the strip.

In the second task, participants viewed twenty-one pairs of stimuli, presented simultaneously on a Macintosh Powermac G3 or Powerbook G3 using SuperLab Pro 1.75 software. The same six stimuli used in the similarity judgment task were used here as well. In addition to the fifteen pairs presented in that task, an additional six pairs were presented, comprised of each of the six stimuli presented with its identical twin. Careful training using pictures of flowers ensured that participants understood that a "same" response required the stimuli to be identical. Participants answered by pressing clearly marked keys on a keyboard. A colorful feedback screen indicated whether the response was correct. These screens were designed during pre-testing so as to assure that the children wanted to produce the "correct" screen and did not like the "incorrect" screen.

For the third and final task each participant was asked to sort a slightly larger set of fourteen stimuli into two groups, the Fips and the Zugs. To the eight stimuli used in the story, and the two added during testing, we added four more, two from each category. Pilot studies suggested child sorting becomes unreliable when more than fourteen stimuli were included. This final task provides data concerning whether participants in the "learning" condition actually did learn the category distinction, and if so how well they extend the concept to new instances.

The control condition. Participants in the control condition performed the same three tasks as those in the learning condition but did not learn the story or receive any information about categories or types of aliens. Because they had not learned to categorize them, we could not refer to them by name. The only change in the tasks required by this difference was to the sorting task instructions, which simply asked that the aliens be put into two groups according to which ones seem to go together.

Results

Similarity judgments. A 2 (age: child vs. adult) by 2 (group: learning vs. control) by 3 (pair type: Fip-Fip, Fip-Zug, Zug-Zug) analysis of variance with repeated measures on the third variable yielded a highly significant main effect of pair type (_F_(2, 90) = 81.140, _MSE_ = 1.004, _p_ < .0001) and a highly significant interaction between condition and pair type(_F_(2, 90) = 10.473, _MSE_ = 1.004, _p_ < .0001). The between-category pairs were judged overall to be less similar than the within-category pairs, and the between-category pairs were also judged to be less similar by the learning groups than by the control groups, a clear case of expansion at the category boundary following learning. There is no interaction with age (see Figure 2.) No other effects were statistically significant.

Same-different judgments. This task yielded two dependent measures, proportion of errors and mean response time. Single-sample _t_ tests demonstrate that all four groups performed the same-different task better than chance. A 2 (age: child vs. adult) by 2 (group: learning vs. control) by 3 (pair type: identical, same category non-identical, different category) analysis of variance with repeated measures on the third variable on the proportion of errors yielded a significant main effect of age (_F_(1, 46) = 4.611, _MSE_ = .045, _p_ < .04) and a highly significant main effect of pair type (_F_(2, 92) = 23.095, _MSE_ = .027, _p_ < .0001). Children made more errors than adults (.221 vs. .146) and different category pairs produced fewer errors (.057) than identical pairs (.218) or same category non-identical pairs (.275). No other effects were statistically significant.

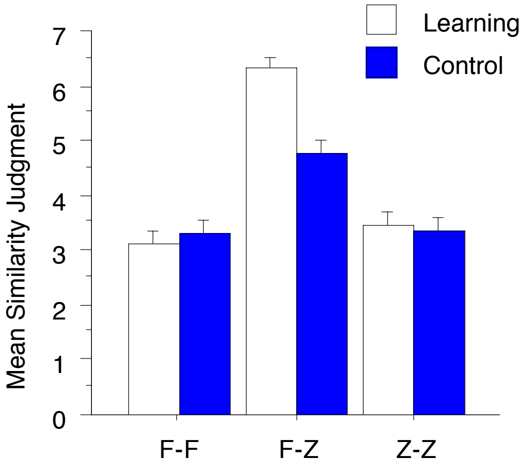

Figure 2. Mean similarity judgments by both learning and control groups for each of three pair types (FF, FZ, ZZ). Higher numbers indicate greater dissimilarity

A 2 (age: child vs. adult) by 2 (group: learning vs. control) by 3 (pair type: identical, same category non-identical, different category) analysis of variance with repeated measures on the third variable on the response times yielded significant main effects of age (_F_(1, 45) = 8.823, _MSE_ = 12859202, _p_ < .005) and pair type (_F_(2, 90) = 5.399, _MSE_ = 1932184, _p_ < .007), and a significant interaction of age and pair type (_F_(2, 90) = 7.748, _MSE_ = 1932184, _p_ < .001) . Adults were significantly faster than children overall (2679 msec. vs. 4577 msec.), but this difference was due entirely to the non-identical pairs (both same and different category), which were also faster overall than the identical pairs. No other effects were statistically significant.

Sorting task. An item was considered correctly sorted if it was placed with the majority of the items of its category. This allows characterization of sorts by control participants as correct or incorrect. If one of the groups was sufficiently larger than the other at the completion of the sorting, it might contain a majority of items from both categories. In that case, the larger majority was said to define the category and thus what counted as correct and incorrect in the two categories. A 2 (age: child vs. adult) by 2 (group: learning vs. control) analysis of variance on the number of items incorrectly sorted yielded significant main effects of age ($\underline{F}(1, 45) = 9.032$, $\underline{MSE} = 2.603$, $\underline{p} < .005$) and condition ($\underline{F}(1, 45) = 13.683$, $\underline{MSE} = 2.603$, $\underline{p} < .001$). The interaction approached significance ($\underline{F}(1, 45) = 3.846$, $\underline{MSE} = 2.603$, $\underline{p} < .06$). Children made more errors than adults and control groups made more errors than learning groups, with control children making by far the most errors. Single-sample $\underline{t}$ tests demonstrate that only the children in the control condition performed this sorting task no better than chance.

Discussion

The finding, based on similarity judgments, that both adults and children in the learning condition show the same pattern of expansion at the category boundary when compared with participants in the control condition is consistent with the idea that changes to the metric of similarity space may mediate concept formation in an age-independent fashion. The results thus provide encouragement to seek similar evidence from work with still younger children, and to pursue that idea that adjustments to the metric properties of similarity space constitute a general phenomenon in category learning. Unfortunately, the failure to find evidence for expansion using the same-different task suggests that this procedure is not a good candidate for extension to younger ages. We had hoped that there would be differential changes in speed of responding between experimental and control groups, even in the absence of differences in errors, but found none of the necessary interaction effects for that measure either. Clearly, other task candidates, like the match-to-sample technique (e.g., Smiley and Brown, 1979), will have to be explored. At least one finding from the same-different task bears noting, however. The fact that identical pairs and different pairs from within the same category produced the same high level of errors for both adults and children (over 20%) suggests just how difficult the discriminations were between items, and is at least consistent with the hypothesis that expansion effects at the boundary reflect perceptual discrimination learning rather than solely higher-order cognitive changes (Livingston, et al., 1998).

One of the more interesting theoretical -- and empirical, for that matter -- questions going forward will be how the operation of a similarity metric modification process like the one described here maps onto other patterns observed in the development of the child's system of concepts. We earlier highlighted the similarities between the concept learning of adults and children, but interesting differences have been noted and discussed in the developmental literature. For example, how does one square a compression-expansion mechanism with variations in criteria for classification, which have been said to shift from thematic to taxonomic (Smiley and Brown, 1979), or perhaps from basic-level taxonomic to thematic and then to superordinate-taxonomic (Gelman, Coley, Rosengren, Hartman, and Pappas, 1998). To address this issue more fully would require a more detailed analysis than is possible here, but two possibilities are immediately apparent. The first is that there is an important difference between perceptual categorization and conceptual categorization (Mandler, 2000), and that the processes we are describing apply only to the former. This is a highly controversial distinction (see the numerous commentaries that follow Mandler's paper), but if correct it would make it all the more important to find ways to pursue evidence for compression-expansion effects in toddlers and infants, for whom high-level conceptual processes are still poorly developed. The other possibility is that there is but a single process, mediated by changes in similarity metrics, and that variations in organizational structure, whether identified as thematic, taxonomic, holistic, analytic, or what-have-you, reflect shifts in the pattern of attention given to objects and events in the world, shifts that establish the basic dimensionality of the similarity space into which objects are sorted on a given occasion.

Conclusion

The successful demonstration of learned expansion in children shows that the modification of psychological similarity space that occurs in adult category learning operates very early in life and may indeed constitute a fundamental mechanism in concept acquisition. We suggest that further work is needed to extend these results to still younger children, and to resolve important theoretical issues about how the compression-expansion process is related to known developmental changes in concept learning during the childhood years.

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