Neural Correlates of Integral and Separable Processing During Category Learning

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Introduction
Categorization is a fundamental cognitive function imposing order on stimulus; whether objects or actions, sights or sounds. Crucial to the ability to categorize is the ability to selectively attend to the relevant attributes of the to-be-categorized input. Garner (1974) used the term perceptual structure to describe the way dimensions of a stimulus combine perceptually. Factors such as sensory constraints, development, or learning can affect whether attributes are integrally related, i.e., correlated, or separably related, i.e., seen as distinct dimensions. Attributes that are integrally related form a single percept. Separable attributes remain distinct and the percept is of a collection of attributes. Developmentally, integral processing has been shown to precede the onset of separable processing (Smith, 1969) and adults can be biased smoothly towards either type of processing depending on category structure. In addition to the properties of the input, it is important to consider factors that may influence how the observer uses those properties during category learning. This study has two goals.

1. To explore how strategy or attentional set interacts with stimulus dimensions of face stimuli during categorization.
2. To examine the neural correlates associated with processing categories that mediate the seamless switching between these two types of attentional processing.

Method
Scanning was done on a Siemens Allegra 3T system. Stimuli were rear projected onto a mirror in the head cage. Responses were recorded with an MRI compatible button box. Subjects were normal, healthy adults.

Judgement Tasks
Subjects first made similarity judgments about pairs of schematic faces. One group based their judgments on the similarity of features (eyes or mouth; separable priming) whereas the other group judged the similarity of features (eyes or mouth; separable priming) whereas the other group judged the similarity of features (eyes or mouth; separable priming). Subjects were normal, healthy adults.

Categorization Tasks
Following the judgement task, subjects were asked to categorize a set of new faces into two categories. All subjects categorized the same set of faces; however, for one group, the faces were categorized on the basis of a single feature (separable task), and for another group, the same faces were categorized on the basis of two features that covaried (integral task). Subjects categorized the entire set of faces three times; i.e., there were three categorization blocks.

Behavioral Data
Forty subjects performed the judgement and categorization tasks outside of the magnet. An analysis of the correct response times during categorization yielded a significant main effect for Categorization Task, F(1, 68) = 7.43, p < .01, and a significant interaction between Judgement Task and Categorization Task, F(1, 68) = 4.33, p < .05. An analysis on the mean accuracy of responses during the categorization task yielded a similar pattern of results, i.e., a main effect for Categorization Task, F(1, 68) = 46.24, p < .001, and an interaction between Judgement Task and Categorization Task, F(1, 68) = 3.77, p < .06.

Performance on the categorization task was also analyzed for subjects who were scanned. The pattern of results was similar to that obtained for subjects who had not been scanned. The data were analyzed separately for the three categorization blocks. All subjects found the filtration (separable) task to be simpler than the Categorization (integral) task no matter what judgment task they had originally performed. In addition, those subjects who had made feature judgments were better on the filtration task than on the Categorization task. Those subjects who had performed the emotion judgments were equally good on both types of categorization tasks.

fMRI Analysis
The fMRI scans were analyzed with the FSL software (Image Analysis Group, FMRIB, Oxford, UK). Each block of categorization trials was contrasted with a block of rest. The results of this analysis were used in a second-level, between-subjects analysis. This analysis found a trend in the data similar to that found in the behavioral data. Specifically, a significant main effect was found for Categorization Task and for the interaction between Judgement Task and Categorization Task.

Task Effect: The between-groups analysis of the fMRI data mirrored that of the behavioral data in showing a significant task effect; i.e., the filtration task was easier than the condensation task. Areas demonstrating supra-threshold activation were anterior cingulate, caudate, cingulate gyrus, and medial frontal gyrus. Shown below are the t-maps for the third categorization block.

Results

Interaction Effect: In addition to the task effect, the between-groups analysis revealed a significant interaction between the judgement task (Emotion, Feature) and categorization task (Condensation, Filtration) reflecting those areas most active when the categorization task was incompatible with the judgement task.

Discussion
Our finding that anterior cingulate, caudate, cingulate gyrus, and medial frontal gyrus are involved in category processing replicates other work that has examined the neural correlates of category processing. What we believe to be unique is our finding that parahippocampal gyrus and posterior cingulate appear to moderate the way stimulus features are processed. These areas were most active when the attentional set (emotion or feature) conflicted with the type of category structure being learned (integral or separable). In addition, the principal components analysis indicates that category learning is reflected in the location and orientation of patterns of activation specific to the level of knowledge attained.

References


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PCoA Analysis: Supra-threshold voxels were eroded using a connectivity measure to eliminate sparsely connected voxels. The remaining voxels were analyzed using the following principle components analysis: the voxel coordinates of the of the remaining voxels were placed in an N X 3 matrix, M, and then an eigen-decomposition was then performed on the covariance matrix of M. M.

PCA Analysis: Supra-threshold voxels were eroded using a connectivity measure to eliminate sparsely connected voxels. The remaining voxels were analyzed using the following principle components analysis: the voxel coordinates of the of the remaining voxels were placed in an N X 3 matrix, M, and then an eigen-decomposition was then performed on the covariance matrix of M. M.