Representations of materials in the human visual cortex

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Our ability to recognize surface qualities and infer the materials that make up objects allows us to interact appropriately with the objects. Little is known, however, about the mechanisms of material representation in the brain. In this study, we investigated how information about various materials is processed in the brain using a combination of multivoxel pattern analysis of functional magnetic resonance imaging data and perceptual and image-based physical measures of material properties. We found that information about materials is transformed from image-based representations in early visual areas into perceptual category representations along the ventral pathway.

Key words: vision, functional magnetic resonance imaging, material perception

Objects made from various materials (metal, wood, fabric, etc.) are characterized by different surface qualities. These characteristics provide important information for object identification and categorization, shaping affective impressions and mediating our interactions with the objects.

Previous studies (Cant & Goodale, 2007; Cavina-Pratesi et al., 2010) have shown that surface properties are encoded near the fusiform gyrus and collateral sulcus (FG/CoS). In the present study, we further examined representations of materials in the human visual cortex.

Methods

Participants. Five adults (three females) with normal vision participated in this study.

Stimuli. Eight exemplars for each of nine material categories (metal, ceramic, glass, stone, bark, wood, leather, fabric, and fur) were synthesized using computer graphic software (LightWave 3D; Figure 1).

Psychological experiments. Perceptual dissimilarities between images were assessed using the semantic differential (SD) method and 12 adjective pairs that described visual and nonvisual impressions of the surfaces (e.g., 'matte–glossy', 'soft–hard').

Image statistics. Image-based physical dissimilarities were assessed using 20 low-level image statistics consisting of 12 subband statistics (four orientations × three spatial frequencies) and eight moments of CIELAB coordinates (mean and standard deviation of $L^*$, $a^*$, $b^*$ and skew and kurtosis of $L^*$).

Functional magnetic resonance imaging (fMRI) acquisition and analysis. During fMRI acquisition, each image ($7.5^\circ \times 7.5^\circ$) in the category blocks was

Figure 1. Example images from the nine material categories (colored stimuli were used in the experiments). Modified from Hiramatsu et al. (2011).
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Figure 2. (a) Dissimilarity matrices for each analysis. (b) Correlation between neural dissimilarities in each ROI and image-based or perceptual dissimilarities. Modified from Hiramatsu et al. (2011).

Results

Matrices in Figure 2(a) depict dissimilarities between categories in each analysis. Image-based (upper left panel) and perceptual (upper right panel) dissimilarities were calculated as Euclidean distances between the category pairs using mean image statistics and mean ratings from the SD method across the eight exemplars, respectively. Neural dissimilarity matrices for early retinotopic areas (V1/V2) and higher ventral areas near the FG/CoS were obtained based on mean pairwise classification accuracy in each ROI across subjects. The significance of the correlation between neural dissimilarities with image-based dissimilarities was higher for V1/V2 (one-tailed permutation test, $p<0.0001$) than for FG/CoS ($p<0.029$; Figure 2(b), upper panels), whereas the opposite was observed for the correlation with perceptual dissimilarities ($p=0.016$ for V1/V2, $p=0.0001$ for FG/CoS; Figure 2(b), lower panels).

Discussion

The neural dissimilarities in early and higher ventral visual areas correlated with image-based and perceptual dissimilarities differently. This suggests that representations of materials change from image-based representations in early visual areas to perceptual category representations along the ventral pathway. The results indicate that information about multimodal characteristics of materials is processed in the ventral cortex near the FG, where the signals can be used to categorize the materials.

References

