High Resolution fMRI of the Functionally-defined Fusiform Face Area using 7T

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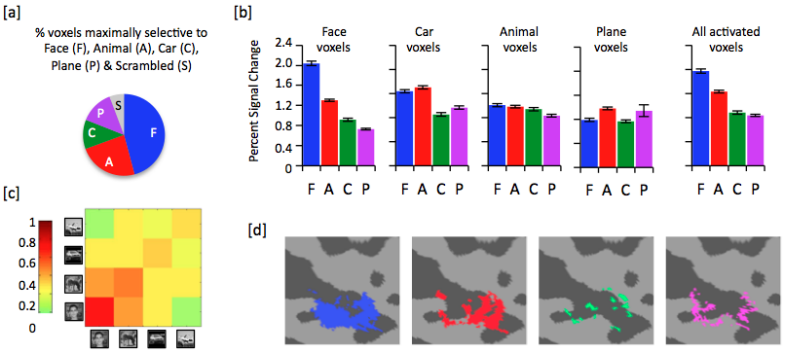
Introduction. High resolution (HR) functional magnetic resonance imaging (fMRI) at 7 Tesla offers novel insight into human brain function by increasing the observed signal, which then allows a decrease of the voxel volume, reducing the partial volume averaging effects that limit sensitivity at lower fields. While 7T imaging permits higher spatial resolution and more accurate localization of functional responses, inherent susceptibility variations can lead to geometric distortion, imaging artifacts, blurring and signal losses. These effects are especially prominent in areas proximal to the air-filled cavities and, thus, have restricted HR imaging of the temporal lobe. The goal of this work is to explore the fine-grain neural architecture of a human functionally defined region – the fusiform face area (FFA) [1] – located at the floor of the temporal lobe. We overcome severe air-canal susceptibility artifacts with a novel scanning paradigm that uses a radiofrequency-spoiled 3D fast field echo (FFE) acquisition sequence with sensitivity encoding (SENSE) for scan time reduction. The FFE-SENSE imaging sequence offers an alternative to echo planar imaging (EPI), with comparable temporal resolution (an image acquired every 1-2 seconds) but a higher spatial resolution and minimized signal loss and image distortion. Bilateral FFAs were defined using a single functional localizer run, which allowed for real-time alignment of HR slices to include voxels within the inferior-temporal lobe that activated more strongly to images of faces relative to objects. HR data were then acquired while participants viewed blocks of faces, animals, cars and planes.

Methods. All imaging was performed on a Philips 7T Achieva scanner at the Vanderbilt University Institute of Imaging Science. Twenty-five individuals were recruited to participate. Functional localizers were acquired with 30 slices oriented in the coronal plane at a resolution of 2.2 x 2.2 x 2.5 mm. The blood oxygenation level dependent (BOLD)-based signals were collected using a fast T2*-sensitive radiofrequency-spoiled 3D PRESTO sequence (FOV = 211.2 mm, TE = 22 ms, TR = 21.93 ms, Volume repetition time = 2500 ms, flip angle = 62 degrees and matrix size = 96 x 96). In a single functional run (20 20-s blocks of alternating faces and objects) we identified face-responsive areas in the fusiform gyrus of the inferior-temporal cortex using the built-in realtime fMRI analysis on the scanner, thereby guiding the subsequent alignment and prescription of 24 HR slices oriented in the coronal plane. We used a radiofrequency-spoiled 3D FFE- SENSE acquisition sequence (FOV = 160 mm, TE = 22 ms, TR = 32.26 ms, Volume repetition size = 4000 ms, flip angle = 45 degrees, matrix size = 128 x 128) to obtain 1.25 mm^3 isotropic voxels. Participants completed 6 HR runs with 20 20-s blocks employing a 1-back matching task with category-specific blocks of faces, animals, cars, planes, and scrambled matrices. In addition, HR T1-weighted anatomical volumes were acquired using a 3D MP-RAGE-like acquisition sequence (FOV = 256 mm, minimum TE, TR = 3.68 ms, matrix size = 256 x 256) to obtain 172 slices of 1 mm^3 isotropic voxels. HR anatomical images were used to align sets of functional data, for volume rendering (including inflation and flattening of the cortical surface), and for visualization of functional data. Functional data were analyzed using Brain Voyager (BV) (http://www.brainvoyager.com) and Matlab (http://www.themathworks.com). Data preprocessing included 3D motion correction and temporal filtering (using a high-pass criterion of 2.5 cycles/run) with linear trend removal. No spatial smoothing was applied at any resolution.

Results. We defined FFAs based on the 3D PRESTO Faces > Objects contrast (n=20 in the right hemisphere, n=21 in the left hemisphere). We employ multivoxel pattern analysis and classification to sort HR voxels based on visual category preferences. First, category means were computed for relevant timepoints across each block and for related blocks across each HR FFE run and used to compute a percent signal change (PSC) estimate for all intact-object categories in each voxel using scrambled blocks as the baseline comparison. PSC values from one half of the data were used to determine voxel preference based on the category evoking the maximum response, and these voxels were then sorted based on their preferred response. Second, PSC values from the other half of the data were used to plot the average response amplitude within each category of voxels.



(a) The proportion of FFA voxels showing highest selectivity (PSC BOLD response) for faces, animals, cars & planes. Cross validation using independent halves of data shows reliability of reported proportions across individuals. (b) Functional heterogeneity in the FFA: voxels maximally preferential to one category also respond to non-preferred categories. Error bars represent standard error of the mean. (c) Heatmap representing the voxel-by-voxel correlation between the magnitudes of category-specific PSC in even runs with those in odd runs. Within-category correlations for face *and* non-face categories are reliable across independent datasets. (d) Heterogeneity of FFA response of a flattened hemisphere, where regions of face-selectivity are interdigitated amongst regions relatively more selective to other object categories.

Discussion. We imaged the inferior temporal lobe in humans at 7T, using the 3D FFE-SENSE sequence to allow for bilateral imaging of the FFA with minimal artifacts and image distortions. We demonstrate robust and reliable functional heterogeneity of the fine-grain neural architecture of bilateral FFA. Responses proved to be reliable (e.g., within-category voxel-by-voxel correlations were significantly greater than between-category correlations for all object categories; Figure(c)), and the identity for all 4 categories could be decoded well-above chance using linear pattern classification. Moreover, clusters of voxels maximally responsive to non-face categories (irrespective of hemisphere) are spatially interdigitated amongst regions showing maximal response to faces. We demonstrate that a functionally-defined region that appears to be homogenously face-selective at standard resolution (~3mm isotropic) is, in fact, functionally heterogeneous when explored at HR.

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