

High Resolution Functional MRI Imaging of Material-Specific Visual Processing in Thalamic Nuclei

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Introduction: The thalamus is a relatively small structure (approximately 30x15x15 mm³) comprised of at least 13 major nuclei. Converging evidence across intraoperative mapping, neuropsychological, neuroimaging and lesion studies indicate that the various thalamic nuclei are specifically involved in category-dependent processing. For example, verbal language stimuli involve dominant (usually left) thalamic nuclei and nonverbal material stimulates activity in the right thalamus, [1-3] and distinctions have also been made among activation of posterior and anterior thalamic nuclei based upon stimuli type and task demands [1-3] Most fMRI imaging protocols do not provide enough spatial resolution for reliable distinction between these small thalamic nuclei in terms of their contribution to processing different types of stimuli. We present evidence of material-specific thalamic activity using high-resolution fMRI. EPI slice thickness is 2mm with a final approximate spatial resolution after smoothing in data analysis of 3mm³. This provides enough spatial resolution to distinguish sites of activation among many of the major thalamic nuclei.

Methods: Seventeen healthy subjects (10 F, 7 M, mean age 32.4 yrs, all R-handed, mean education 17 yrs) participated. Written informed consent was obtained for all subjects. The study is a memory test of visually presented material-specific stimuli (i.e., words, nameable objects, faces, nature scenes). Data for this report were analyzed from a familiar/repeating stimuli control condition for each of four types of material, allowing for determination of activation related to simply viewing each type of material without learning effects. The task was presented visually in an event-related design in which all stimulus presentation trials were alternated with scrambled picture trials. fMRI images were acquired on a 3T Siemens Trio scanner with a 12-channel receiver coil with a high-resolution EPI sequence: TR/TE/FA = 2000 ms/ 24.7 ms/ 90°; FOV = 100 mm; 64 x 64 matrix, 33 2 mm coronal slices covering the anterior-to-posterior extent of the MTL and thalamus, 1.56 mm x 1.56 mm x 2.0 mm voxels. A high-resolution T1-weighted MPRAGE scan (matrix size = 160x256x256 with resolution 1x1x1 mm³, TI/TR/TE = 900/2250/2.97 ms, flip angle = 9°) was acquired for anatomic reference. The observed fMRI voxel time-series was modeled as the convolution of the four material-specific repeating stimulus vectors and constrained 2-parameter [4] impulse responses (IRs). Voxelwise maps of IR amplitude (as a percentage of the estimated time-series baseline) were constructed. These functional activation maps were warped to Talairach space, resampled at a 1mm³ resolution, and subsequently spatially smoothed with a Gaussian kernel (FWHM = 3 mm). Within-group ANOVA was performed to assess the significance of activation for the four different material types as well as between-condition contrasts. Analysis was focused on the bilateral thalamus using a region specific mask with a model-based segmentation/registration tool. The t-maps of condition-level activations were further clustered ($|t_{i6}| > 2.5$; cluster volume threshold 100 μ l; corrected $p < 0.00008$). AFNI and FSL software packages were used for data analysis.

Results: As can be seen in the figure, highly significant areas of activation were observed during viewing repeated presentations of one stimulus from each of the four material types. Each stimulus type activated the medial dorsal nucleus bilaterally, although to different extents. Additionally, words (red) activated left inferior pulvinar, anterior, ventral lateral, and ventral posterior nuclei. Pictures of nameable objects (yellow) additionally activated left ventral lateral and ventral posterior as well as right inferior pulvinar and ventral lateral nuclei. Faces (blue) additionally activated left inferior pulvinar and ventral lateral nuclei and the right anterior nucleus. Nature scenes (green) additionally activated the pulvinar bilaterally and the right ventral posterior nucleus.

Discussion: The scanning resolution used in this study (1.56 mm X 1.56 mm X 2 mm) is higher than is typically reported for high-resolution fMRI studies. Consistent with prior literature suggesting the advantages of small voxel size in cortical specificity of BOLD fMRI [5], we were able to easily detect material-specific stimulus activations in individual thalamic nuclei at this resolution. Overlapping and exclusive activation was demonstrated for each of the four material types. Activation for the

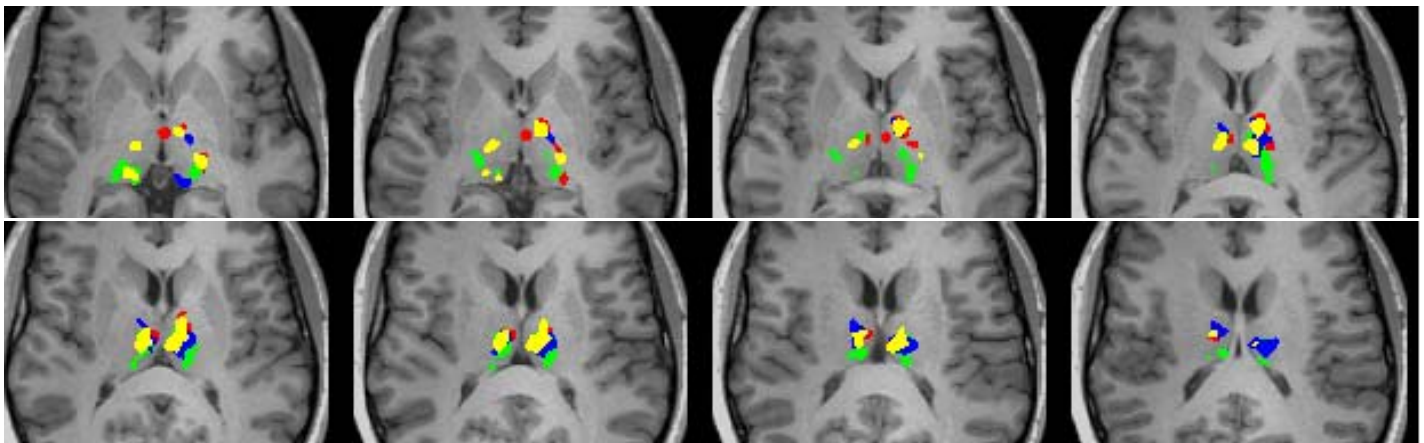


FIGURE: Areas of activation for each of the four types of material, overlaid on a representative subject's (thalamus-masked) brain anatomy in Talairach space. Color-coding is shown for activation to words (red), objects (yellow), faces (blue), and nature scenes (green). Axial slices proceed from $z = 2$ mm top row first image to $z = 16$ mm bottom row last image. Left hemisphere is on the right and vice-versa.

word condition was greater on the left and in anterior nuclei than the other stimulus types, and activation related to processing nonverbal nature scenes stimuli was greater in bilateral posterior nuclei such as the pulvinar and right ventral posterior nucleus. Thus, high-resolution limited-coverage acquisitions may prove particularly useful in the study of parcellation of material-specific processing in the thalamus.

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