Acquisition Strategies to Improve the Specificity of Block-Design fMRI Studies of Overt Speech

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Introduction

Block-design functional MRI (fMRI) experiments involving speech are corrupted by signal changes caused by out-of-field-of-view motion.[1] Event-related (ER) designs have been instituted to allow a separation of signal changes caused by brief motion from the delayed hemodynamic response.[2] Generally, block-design experiments are advantageous in that they provide a higher contrast-to-noise ratio (CNR) than ER designs.[3] Therefore, if the problem of motion artifacts can be solved, block-design fMRI experiments of overt speech would offer advantages for the neurophysiological investigation of speech. A recent study found an optimum task duration for block-design fMRI in the presence of jaw motion, as well as post-processing solutions for separating true BOLD responses from false positives caused by motion artifact responses.[4] In the current study, optimum acquisition strategies were examined. It was determined that the use of small voxels and coronal slices leads to higher specificity in block-design fMRI studies of overt speech.

Methods

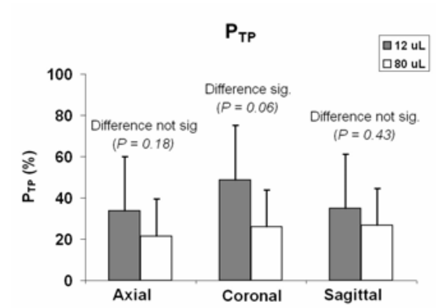
Fifteen subjects were imaged in a GE 3T Excite scanner using an 8-channel array RF head coil. All subjects signed a written consent form approved by the local IRB. Subjects were visually cued to alternately phonate the sounds /e/ and /i/ in block-design overt speech tasks. An optimum block size of 12 s on, 12 s off was used.[4] A T_2^*-weighted EPI sequence (TR/TE/FA = 2000ms/30ms/77°) was used to acquire partial brain volumes (20 slices) covering the bilateral primary motor cortex in three different slice orientations (axial, coronal, sagittal) and four different voxel dimensions ($2\times2\times3$ mm^3, $3\times3\times4$ mm^3, $4\times4\times4$ mm^3, $4\times4\times5$ mm^3). Whole brain EPI volumes at matching spatial resolutions were acquired and used as base volumes during registration. Calculations of activation volume were performed in Talairach space.

Analysis

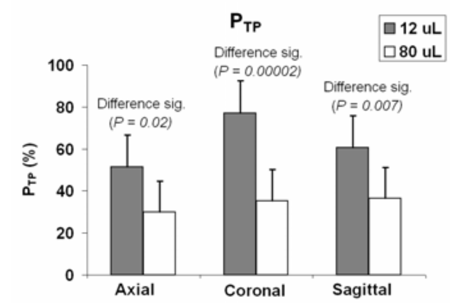
Data were analyzed using AFNI[5] and code written in MATLAB (The Mathworks, Natick, MA). Multiple regression analysis was employed to determine activation maps, which were thresholded at $F > 21.35$ ($P < 10^{-5}$). Three motion-suppression thresholds (correlation phase threshold, noise-to-baseline ratio threshold, and cluster threshold) were then applied to the activation maps to remove false positives likely caused by motion artifacts.[4] The remaining activation was termed the total activation volume, V_{TOT}. This was hypothesized to contain both true and false positive activation. A mask was defined covering the cortical areas expected for activation with the speech articulation task. This consisted of the middle primary sensorimotor cortex, the supplementary motor area (SMA), and the left insula. The activation volume, V_{TOT}, was then multiplied by this mask to yield the true positive activation volume, V_{TP}. The percent of activation volume that was true positive, P_{TP}, was then calculated for each run: $P_{TP} = V_{TP}/V_{TOT}$.

Results

Two subjects were eliminated immediately because a majority of the runs produced zero true positive activation. Fig. 1a compares P_{TP} between acquisitions using the smallest and largest voxels for all three slice orientations in the remaining 13 subjects. These results suggest that smaller voxel volumes yield higher values of P_{TP} but the difference is only somewhat significant for the coronal acquisition ($P = 0.06$). Subjects producing mostly weak activation (average $P_{TP} < 20\%$) were eliminated, and the data were reanalyzed, omitting single runs with zero activation. It was believed that poor task performance or severe motion artifacts could have led to poor activation. The results from these strongly activating subjects (Fig. 1b) confirm that acquisitions with smaller voxel volumes yield higher values of P_{TP} for all three slice orientations. Qualitative differences can be seen in activation maps for the large voxel acquisition after applying only a cluster threshold (Fig. 2a), the large voxel acquisition after applying motion-suppression thresholds (Fig. 2b), and the small voxel acquisition after applying motion-suppression thresholds (Fig. 2c).

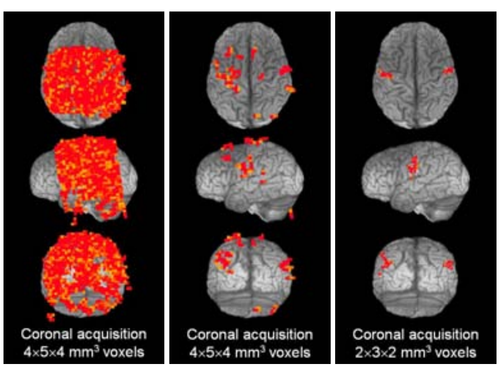


(a)



(b)

Fig.1. Comparison of P_{TP} between small and large voxel acquisitions for axial, coronal, and sagittal acquisitions (a) using 13 subjects and (b) using the 9 strongly activating subjects.



(a) (b) (c)

Fig. 2. Single subject 3D rendered brain images shown transparent to activation (V_{TOT}) remaining for (a) large voxel acquisition and cluster threshold ($\alpha = 0.01$) only, (b) large voxel acquisition and application of motion-suppression thresholds ($\alpha = 0.01$), and (c) small voxel acquisition and application of motion-suppression thresholds ($\alpha = 0.01$).

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Discussion

Motion artifact signal changes during orofacial motion result from tissue-motion-induced field inhomogeneities. Just as increasing spatial resolution can reduce geometric distortion,[6] increasing spatial resolution should also reduce the amount of task-correlated signal changes due to dynamic field perturbations. Experiments using block-design speech tasks have verified this hypothesis, revealing that improved specificity results from acquisitions using small voxel volumes (Fig. 1b). Statistical tests have found that P_{TP} was significantly higher for the smallest voxel volume ($2\times2\times3$ mm^3) compared to the largest voxel volume ($4\times4\times5$ mm^3) for axial ($P = 0.02$), coronal ($P = 0.00002$), and sagittal ($P = 0.007$) acquisitions in strongly activating subjects. For the case of the $2\times2\times3$ mm^3 voxel size, it was also found that the coronal acquisition yielded higher values of P_{TP} compared to axial ($P = 0.004$) and sagittal acquisitions ($P = 0.06$). Activation maps acquired from small voxel acquisitions showed activation more confined to the primary motor cortex than activation maps acquired from large voxel acquisitions (cf. Fig. 2b,c). It is concluded that block-design fMRI studies of overt speech on single subjects can yield activation maps with high specificity when using optimum acquisition strategies and post-processing methods to remove motion-induced false positives. Smaller voxel volume does not reduce signal loss due to echo shifts,[6] which may explain why several runs in this study had either weak or no activation.

References

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