Removal of Motion Artifact Responses via Post-Processing Methods in a Block Design fMRI Study

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Introduction

During magnetic resonance imaging, task-related motion of tissue outside the image FOV has been shown to alter the static magnetic field, creating geometric distortions in the image and false positives in fMRI activation maps.[1] To avoid the issue of dynamic geometric distortions, fMRI studies of speech, swallowing and jaw motion have typically utilized event-related (ER) designs,[2] which suffer from low contrast-to-noise ratio (CNR) when compared to block designs.[3] Previous studies have shown that motion artifact responses (MARs) usually occur instantaneously whereas hemodynamic changes are delayed by a lag time.[1] One study has used this phase difference to separate MARs from real activation in an ER design study.[4] In this study, post-processing methods are sought to identify MARs and remove the associated voxels from activation maps in a block design study involving jaw motion.

Methods

Five male subjects (aged 29.7 ± 4.8) were imaged in a Bruker Biospec 30/60 3 Tesla scanner using a local gradient coil and an end-capped birdcage RF coil. Twenty 3-mm-thick axial slices were acquired in an echo-planar sequence (TR = 2000 ms, TE = 27.2 ms, FOV = 20 cm, matrix = 64 × 64, BW = 125 kHz). A gum chewing task was performed in a block design experiment for seven different periods of equal time on/off (8, 10, 12, 14, 16, 18, 20 s) for a total of 149 time points in each acquisition.

Analysis

A complex cross-correlation analysis was performed,[5] correlating the data with sine and cosine waveforms, the results of which can be used to compute correlation magnitude and phase. The time series of the voxel with the highest correlation was used to create a time-averaged response vector. Cross-correlation proceeded with this new waveform. Correlation phase thresholding was then applied. In this technique, activated voxels were accepted only if the correlation phase fell within a range of 120°–180°, as expected for the hemodynamic response. Next, the standard deviation threshold was applied. In this technique, the response was averaged across all trials and the resulting standard deviations were averaged across all time points. Voxels were accepted only if the trial-averaged standard deviation average fell below 3.5%, as determined by histogram analysis of true and false positives. Lastly, a cluster threshold (minimum of 4 voxels with $P < 10^{-5}$ yielding an $\alpha = 0.01$ as revealed by Monte Carlo simulations) was applied to remove isolated voxels likely to be a result of motion artifacts. These activation maps were multiplied by a mask over the sensorimotor cortex to approximate true positive activation for each run.

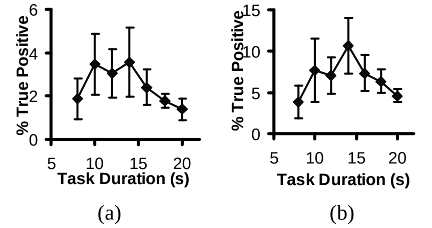

Figure 1. Percent true positive (a) before and (b) after correlation phase threshold over five subjects.

Results

As task duration increases, there is an increase in CNR, but the phase of the MARs becomes similar to the phase of the BOLD response, increasing the amount of false positive activation. This suggests that an ideal task duration exists to maximize BOLD response and minimize MARs. For each task duration, the volume of true positive activation was divided by the volume of activation both before and after the correlation phase threshold at $P_{unc} < 0.001$ (Fig. 1). It can be seen that a task duration of around 10–14 s is ideal for maximizing CNR while minimizing MARs, which agrees with the simulations of Birn et al.[6] Figure 2 shows the 14 s task activation map after successive thresholding for one subject. The volume of activation remaining can be seen to decrease significantly after each technique (Table 1).

Discussion

Although task-correlated motion outside the FOV can create false positive activation, it has been shown here that post-processing methods can be used to remove much of this. Four steps have been identified: 1) the use of a 14 s task duration, 2) correlation phase thresholding, 3) standard deviation thresholding, and 4) cluster thresholding. Although some false positives and false negatives may remain, it is believed that these steps can be applied to improve block design fMRI studies of speech, swallowing and jaw motion.

Table 1. Volume of activation (µL) remaining after successive thresholds

Threshold Technique	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
$P_{unc} < 0.001$	176,647µL	226,551µL	118,556µL	72,731µL	81,086µL
+ Correlation Phase Thr.	46,898	59,058	39,032	28,860	30,453
+ Standard Deviation Thr.	25,250	38,763	26,490	19,953	21,327
+ Cluster Thr. ($P_{vox} < 10^{-5}$), $\alpha = 0.01$	5,862	8,919	3,262	3,228	6,096
Bonferroni Thr. only, $P_{cor} < 0.01$	30,170	41,655	14,634	9,343	13,844
Cluster Thr. only, $\alpha = 0.01$	31,005	44,466	12,613	4,775	13,363

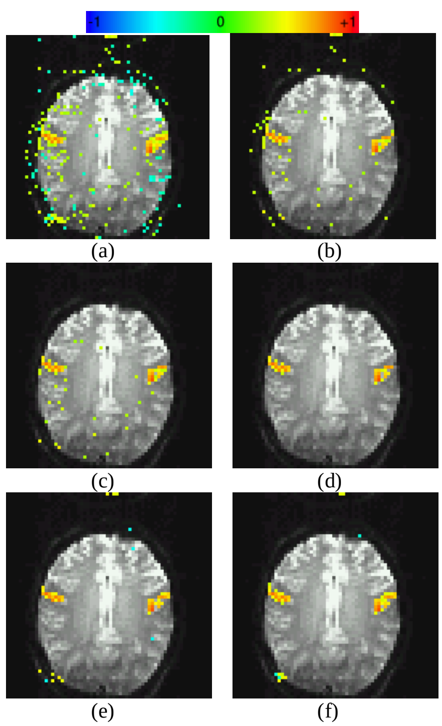

Figure 2. Activation maps for mid-axial slice after successive thresholding methods: (a) $P_{unc} < 0.001$, (b) correlation phase threshold, (c) standard deviation threshold, and (d) cluster threshold ($\alpha = 0.01$). Also shown are activation maps after (e) Bonferroni thresholding only ($P_{cor} < 0.01$) and (f) cluster thresholding only ($\alpha = 0.01$).

References

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