A simultaneous EEG and high temporal resolution fMRI study of trial-by-trial fluctuations in visual evoked potentials

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Introduction

Simultaneous electroencephalography and functional MRI (EEG-fMRI) take advantage of the high temporal resolution of EEG to detect neuronal events of interest, while fMRI can localize, with a high spatial resolution, the hemodynamic response function (HRF) associated with these events. However, the poor temporal resolution of standard fMRI experiments, of the order of seconds, prevents an accurate estimation of the HRF shape at the single-trial level. While the HRF is known to be temporally sluggish, a high temporal resolution may still detect subtle spatial variations related to distinct events visible on EEG. Recently, the development of MR-encephalography (MREG) has allowed whole-brain fMRI with a high temporal resolution of the order of 100 ms [1-3]. This study uses this new technique to investigate trial-by-trial fluctuations related to visual evoked potentials (VEP) recorded with simultaneous EEG-fMRI.

Methods

Data from 7 healthy subjects were acquired on a 3T Trio Tim scanner (Siemens, Germany) using a 32-channel head coil. The acquisition was performed using a single-shot k-space trajectory consisting of 3D spirals along the surface of concentric shells. The non-uniformly sampled k-space volumes were reconstructed using a conjugate gradient method with Tikhonov regularization, resulting in the following image parameters: TR=100ms, 64x64x64 matrix, 4mm voxel size. During the acquisition, EEG sampled at 5 kHz was recorded using an MR-compatible EEG cap and amplifier (Brain Products, Germany). Gradient and ballistocardiographic artifacts were removed by averaged artifact subtraction followed by an independent component analysis to remove residual noise. During the scan, subjects underwent 30 visual stimuli consisting of a flashing checkerboard lasting one second, with a random inter-stimulus interval between 17.5-22.5 seconds. The motion-corrected fMRI data were analyzed in the general linear model (GLM) framework by modeling the fMRI signal as a canonical HRF at each stimulus time point. Motion, cardiac, and respiratory regressors were included as confounds. The visual activation areas were determined by thresholding the resulting t-statistic maps at $p<0.05$ (cluster-wise corrected). The fMRI time courses in activated voxels were then fitted with gamma functions to determine HRF amplitudes and delays in each stimulus trial. Similarly, gamma functions were fitted to the average EEG in channels O1, O2, Oz, PO7, PO8, and POz to determine VEP P1 and N1 amplitudes in each trial. Correlations across trials between the EEG and HRF parameters were then investigated.

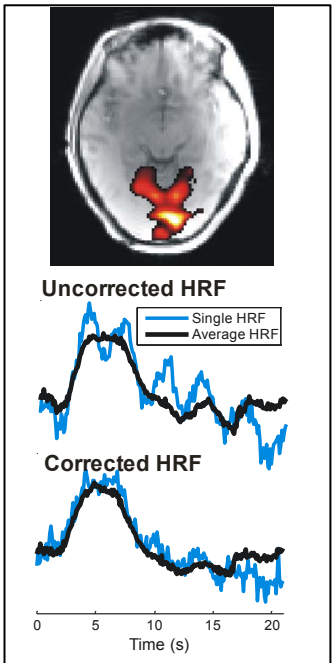

Figure 1. Visual activation map and example raw HRF before and after regressing out physiological artifacts.

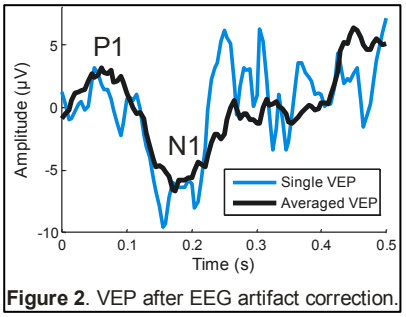

Figure 2. VEP after EEG artifact correction.

Results

Activation was confined to visual cortex, where the raw HRF to individual stimuli could be sampled with a high temporal resolution, allowing the removal of cardiac and respiratory noise through the use of physiological confounding regressors in the GLM (fig. 1). Moreover, the artifact-corrected EEG was of sufficient quality to detect the single-trial VEPs (fig. 2). A correlation coefficient greater than 0.2 was observed between P1 and HRF amplitudes in 17.0% of activated voxels, and between N1 and HRF amplitudes in 11.9% of activated voxels. Correlations between P1 and HRF amplitudes were mostly observed in the center of the activated area, while correlations between N1 and HRF amplitudes were more confined to the periphery (fig. 3). The difference between P1-HRF amplitude correlation and N1-HRF amplitude correlation was taken as a measure of whether a voxel was more strongly associated with the P1 or N1 wave of the VEP. This measure was significantly negatively correlated with the HRF delay in 5 of 7 subjects ($p<0.05$), indicating that regions associated with the P1 wave had earlier HRF delays than regions associated with the N1 wave, which is consistent with the VEP time course. The correlation was not significant in 1 subject, and significantly positive in the remaining subject. On average, the HRF delay in regions more associated with P1 was 5.3s, while the HRF delay in regions more associated with N1 was 5.4s.

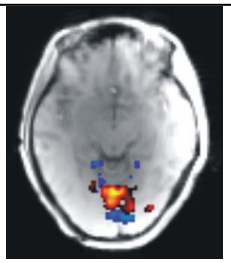

Figure 3. Regions with correlation greater than 0.2 between P1 and HRF amplitudes (yellow-red colormap) and between N1 and HRF amplitudes (blue-green colormap).

Discussion

MREG results in fMRI data with high temporal resolution, allowing the removal of non-aliased physiological artifacts, as well as a more accurate estimation of the HRF shape to individual stimuli compared to standard fMRI sequences. This technique allows the determination of regions showing trial-by-trial HRF amplitude fluctuations associated with specific VEP transients measured on EEG and separated by mere fractions of seconds. These regions also show small HRF delay differences consistent with the EEG time courses. MREG thus shows great promise in the study of fast neuronal events that cannot be distinguished by lower temporal resolution techniques.

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References

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