Simultaneous Recording of ERP and fMRI for Cortical Source Imaging

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Introduction

In functional neuroimaging, it is of great interest to combine EEG and fMRI, to take advantage of the high temporal resolution of EEG and high spatial resolution of fMRI [1]. For the integration, it is desirable to acquire EEG and fMRI in a single session to avoid possible discrepancies due to different environmental and cognitive states in separate examinations. However, simultaneous recording of EEG and fMRI is challenging since the EEG recordings are prone to large artifacts induced by the high-frequency gradient and RF pulses inside the MR scanner, namely pulse sequence artifact (PSA), and motion of EEG leads within the static magnetic field, such as ballistocardiogram artifact (BA) caused by the pulsatile motion related to cardiac beats [2]. Notably, recent improvement of EEG device and signal processing holds the potential to continuously record EEG during concurrent fMRI scanning [3, 4]. Since the ultimate goal of EEG-fMRI concurrent recording is to integrate these two modalities for functional neuroimaging, it is important to assess the quality of EEG signals simultaneously recorded with fMRI in the context of EEG source imaging. In the present study, we explored EEG-fMRI simultaneous recording during VEP experiments for two human subjects inside a 3-T whole-body MR scanner. We compared the VEP waveforms acquired inside and outside MRI scanner, as well as their resulting cortical source images with and without combining fMRI priors. The correspondence of EEG source images with fMRI activations were also examined by means of receiver operating characteristic (ROC) curve.

Materials and Methods

Two right-handed male human subjects (initials VG and JS; age 19 and 20 years) participated in a checkerboard visual-stimuli experiment with written consent. A full rectangular checkerboard pattern was delivered to the subjects. Two sets of EEG data were acquired (outside the MRI scanner and inside the scanner during fMRI scanning), using a 32-channel MR compatible EEG system (BrainAmpMR 32 Plus, BrainProducts, Germany). Both structure MRI (sMRI) and fMRI data were collected using a 3-T MRI system (Siemens Trio, Siemens, Germany). The period cross-correlation method (with the CC $\geq$ 0.5) was applied to obtain the fMRI activation map. For the EEG signals simultaneously recorded with fMRI, post-processing was performed to reduce the artifacts induced by gradient and RF pulses, as well as cardiac motion [2]. A linear estimation approach [5] was used to estimate current source distribution on the folded cortical surface. We considered fMRI prior information by imposing different weighting factors to sources outside or inside fMRI activations (outside : inside = 0.1:1).

Results and Discussion

We first compared VEP waveforms recorded under different conditions. The VEP waveforms at occipital electrodes (O1, O2) for the subject VG are shown in Figures 1a,b. The waveforms recorded under all conditions were consistent with the typical VEP waveforms elicited by the checkerboard simulation. Also their overall morphologies coincided well with each other, while slightly different latency and amplitude of P1 peak were observed (latency difference < 2 ms, amplitude difference < 5 μV). Figure 1c shows the fMRI activation map projected onto the reconstructed cortical surface. The fMRI mapping shows BOLD activation at primary visual cortex, as expected, suggesting that the application of electrode cap did not introduce significant distortions to both sMRI and fMRI. We then reconstructed cortical source distributions with and without fMRI prior constraint. The cortical source powers estimated at every time slice were averaged, shown in Figure 2. It can be clearly seen that the estimated cortical source images are similar to each other and they are corresponding well to the simultaneously acquired fMRI map. We then evaluated ROC curves [6] between the estimated cortical source images and fMRI activation maps. Larger area below an ROC curve means that the EEG cortical image coincides better with the fMRI activation. Figure 3 shows the ROC curves and area below the curves (0 < area < 1). Clearly, the cortical source images estimated from different sets of VEP data end up with closely-correlated ROC curves, which suggests again the difference of VEP waveforms recorded with or without fMRI do not significantly affect the EEG source imaging results. Interestingly, the fMRI-guided source estimate not only increased the correlation between EEG sources and fMRI activations but also improved the correlation between the EEG source images. This suggests that the use of fMRI prior information diminished spurious sources which usually stems from noisy recording environments and restricted possible source space to physiologically more probable regions. The cortical source estimates for 'inside scanner recordings' coincided better with fMRI activation than those for 'outside recording', and the simultaneously recorded EEG and fMRI result in the best correspondence. These results further confirmed that the artifacts inherent in fMRI-EEG concurrent acquisition have been successfully removed in the present study. For the other subject (JS), all the analysis results were consistent with those presented in this abstract.

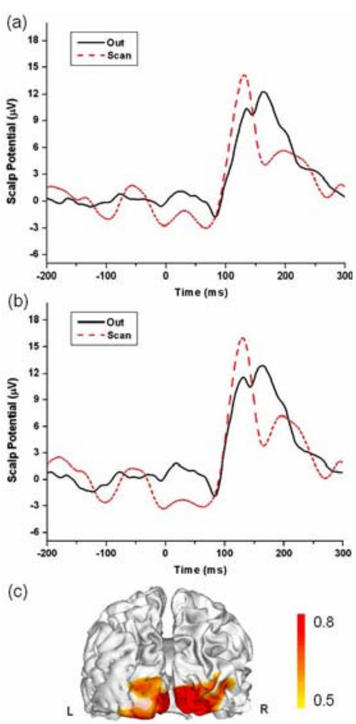

Figure 1. Subject VG's data: (a,b) VEP waveforms at occipital electrodes (a: O1; b: O2). (c) fMRI map projected onto the subject's cortical surface. Out: outside scanner, Scan: inside scanner during fMRI scanning

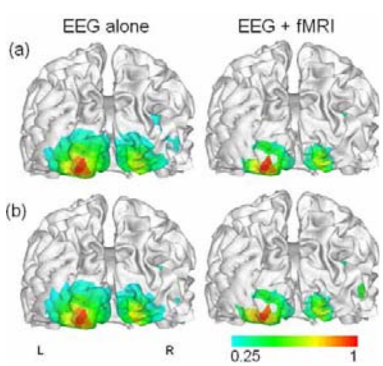

Figure 2. EEG source images (subject VG) (a) outside MRI scanner; (b) inside MRI scanner during fMRI scanning.

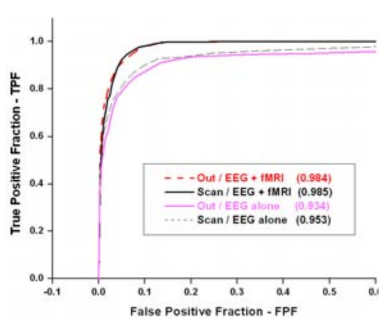

Figure 3. ROC curves with respect to fMRI activations. Values in parentheses represent areas below the curves.

Conclusions

In the present study, we explored the concurrent EEG-fMRI recording for two human subjects under checkerboard visual stimulation. From our comparative analysis on the VEP waveforms and their corresponding cortical source images by means of ROC curve analysis, we demonstrate that 1) VEP signals can be reliably recorded simultaneously with fMRI for the purpose of EEG-based or fMRI-EEG integrated cortical imaging; 2) the cortical source images estimated by VEP alone hold a high correspondence with fMRI activation, confirming the rationality of incorporating fMRI spatial information as constraints to EEG inverse problem; 3) the fMRI-constrained source estimate for VEP data can result in more reliable cortical images with better specificity than VEP alone.

References

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