Effects of global signal regression and EEG motion censoring on frequency specific simultaneous EEG-FMRI coupling

Introduction

Simultaneous EEG-FMRI is a popular tool for combining neurophysiological and hemodynamic signals in a single recording session, in order to examine temporal coupling between neuronal and vascular activity.

However, EEG signals recorded inside the MRI scanner are corrupted by several artifacts including the ballistocardiogram and head motion artifacts, which are difficult to remove cleanly using current methods1. These artifacts overlap neuronal frequency bands of interest and are linked to systematic changes in the FMRI BOLD signal2,3, complicating the interpretation of EEG power fluctuations recorded inside the scanner.,

In order to quantify the extent to which EEG-FMRI coupling is driven by physiological noise, we examined the effects of EEG motion censoring (EEGMC), and BOLD global signal regression (GSR) on EEG-FMRI cross correlations. We were particularly interested in the differences in the alpha (8-13Hz) and gamma (40-80Hz), as these bands are frequently associated to BOLD in the literature4,5.

Methods

EEG and BOLD signals were acquired simultaneously in 9 healthy humans on a 3T Philips Ingenia, sampling EEG at 5000Hz with 64 channel Brainvision MR-compatible EEG, acquiring BOLD images at 3.75mm isotropic, full brain (33 slice), multiband 3, TR=0.693. Six (6) experimental runs were performed retinotopy (8.5 minutes, two runs), event-related visual stimulation (8.5 minutes, two runs), continuous visual movie stimulation (8.5 minutes, one run), and rest (5 minutes, one run). Gradien artifacts were removed using BrainVision Analyzer, and ballistocardiogram was removed using in-house matlab scripts. ICA denoised EEG scalp signals were source-localized using minimum norm estimates and power from 1-100Hz was computed at 2Hz intervals in each source voxel, then down-sampled to BOLD temporal resolution. BOLD was motion corrected, EPI-corrected, and denoised using MELODIC6. Global signal regression was performed using AFNI’s 3dTproject7. Cross correlations between BOLD and EEG power were performed from -14 to 14 seconds. EEG motion censoring (EEGMC) was performed by isolating motion ICA components from the EEG and computing broadband power, then replacing in all data the highest 5% of time-points with broadband noise with the mean of that frequency. All states were pooled (9 subjects, 5 states, 9\*5 => n=54) when calculating t-tests.

Results

A single subject FMRI time series (Figure 1A) corrupted by head motion is displayed, which manifests in the EEG spectrogram as broadband power increases matching abrupt shifts in voxel intensity. After EEGMC, there was significantly reduced broadband gamma (40-80Hz) coupling with BOLD when averaging cross correlations across all voxels (Figure 1B). The broadband gamma cross-correlation curve partially overlapped the canonical hemodynamic response function (HRF), and this overlap was reduced by EEGMC, although EEGMC did not improve the correlation between broadband gamma cross-correlation curve and HRF (Figure 1C). Voxel-wise analysis revealed widespread decreases in gamma-BOLD coupling due to EEGMC (Figure 1D).

Cross-correlation of the global signal (GS) with EEG power in each voxel yielded positive alpha/beta-GS coupling at 0s time lag, and negative alpha/beta-GS coupling at 6-10s time lag, after averaging across all source voxels (Figure 2A). GSR significantly reduced alpha/beta-BOLD coupling (Figure 2B), but increased the correlation between the alpha/beta-BOLD response function and the HRF (Figure 2C). Voxel-wise analysis revealed increased alpha/beta-BOLD coupling in the default mode network (DMN) post GSR.

Conclusion

The correlation between broadband gamma and BOLD appears to be mainly due to head motion artifacts, which has implications for the interpretation of neurovascular coupling results in the literature4,5. The fact that GSR increases the similarity of the alpha/beta-BOLD response function to the HRF is further evidence that GSR removes physiological noise from the BOLD signal, and is a useful pre-processing step.

1. Jansen, M. et al. *Neuroimage* **59**, 261–270 (2012).

2. Chang, C. et al. *Neuroimage* **68**, 93–104 (2013).

3. Power, J.D. et al. *Neuroimage* **59**, 2142–2154 (2012).

4. Scholvinck, M.L. et al. *Proc. Natl. Acad. Sci.* **107**, 10238–10243 (2010).

5. Wen, H. & Liu, Z. *J. Neurosci.* **36**, 6030–6040 (2016).

6. Jenkinson, M. et al. *Neuroimage* **62**, 782–90 (2012).

7. Cox, R.W. *Comput. Biomed. Res.* **29**, 162–173 (1996).