Frequency-dependent correlation between estimated LFPs and BOLD responses in human

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The relationship between electrophysiologic and hemodynamic signals used in brain imaging remains largely unknown. Resolving this issue is important for advancing non-invasive neuroscientific research, and in particular for relating results from different brain imaging techniques. Logothethis et al [1] recently combined intracranial electrical recordings within the primary visual cortex of anesthetized monkeys with the simultaneously acquired fMRI data during passive viewing of visual stimuli. These authors showed that the blood oxygen level dependent (BOLD) signal was more strongly correlated with local field potentials (LFPs) within the gamma band than with multi-unit activity (action potentials).

In the present study, we present a methodological approach for addressing this question non-invasively in human subjects throughout the entire brain volume. We present the results from a study with subjects performing a passive visual task and show that the relationship between the BOLD signal and the estimated LFP changes over frequencies and anatomical regions.

Material and Methods

Eight subjects participated in separate EEG and fMRI sessions involving an identical experimental protocol. Subjects passively viewed a visual stimulus (flickering wedge of circular checkerboard) for durations of 12s followed by 18s of rest. The experiment consisted of 42 (fMRI) or 126 (EEG) repetitions of the stimulation block.

fMRI images were acquired at 3T and analyzed with SPM2. To directly compare fMRI and EEG results, the fMRI dataset was sub-sampled to the spatial resolution of the EEG inverse solution (e.g.: 6x6x6 mm^3, restricted to the gray matter).

Continuous 128-channel EEG was acquired at 512Hz. After artifact rejection, single trials of EEG data (from 500ms pre- to 500ms post- stimulus onset) were submitted to the ELECTRA distributed linear inverse solution [2] to estimate intracranial LFPs. At each node of the inverse solution space, the power spectrum for each trial was computed. For each frequency separately (0-256Hz at 2Hz intervals), power post-stimulus was non-parametrically contrasted with that pre-stimulus in order to obtain one statistical spatial map per frequency.

We qualitatively compared fMRI and LFP group activation maps in the Brodmann areas (BAs) defined according to a standard atlas. Within each region *r* and for each LFP frequency *f*, we computed the following metric:

$$\text{resemblance}(r,f) = 1 - \frac{\left| m_{f,\text{LFP}}(f) - m_{r,\text{fMRI}} \right|}{m_{f,\text{LFP}}(f) + m_{r,\text{fMRI}}},$$

where $m_{r,\text{LFP}}(f)$ represents the fraction of LFP active voxels within the region *r* at frequency *f*, and $m_{r,\text{fMRI}}$ represents the fraction of fMRI active voxels within the region *r*. By construction, this metrics is comprised between 0 and 1 and higher values indicate higher local resemblance of the two activation maps.

Results

The statistical comparison of LFP spectral power for the post- versus pre-stimulus onset periods shows that the single-trial analysis is a suitable technique to detect activations in estimated LFP datasets. It further reveals that not all frequencies show stimulus-related power changes. Some frequencies (e.g. 52 and 216Hz) show power changes at locations similar to those identified by fMRI, whereas other frequencies (e.g. 30Hz) show few and relatively sparse voxels displaying power changes to visual stimulation.

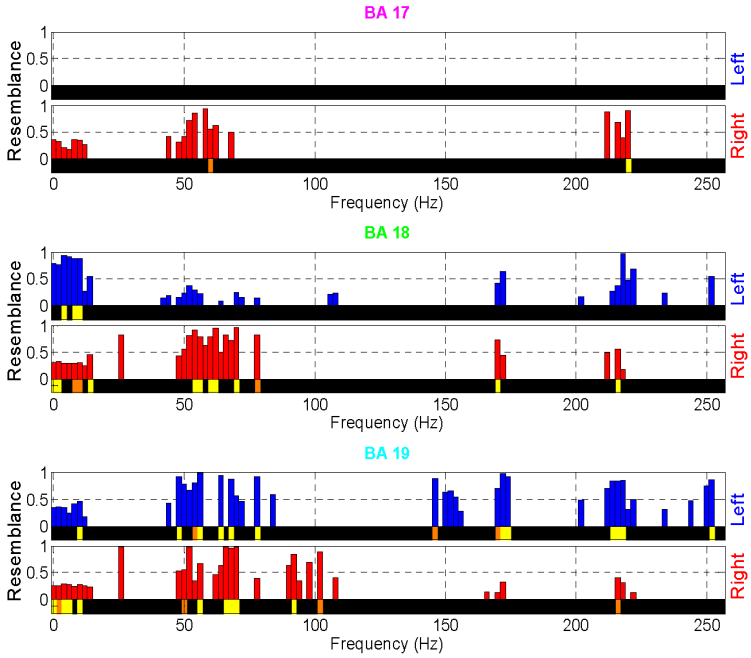

Fig. 1: Resemblance between fMRI and LFP analyses within BAs 17, 18, and 19. Below the barplots orange ($0.05<p<0.1$) and yellow ($p<0.05$) lines indicate the statistical significance of the resemblance value. Blue bars represent the left hemisphere, red bars the right hemisphere.

To qualitatively measure the similarity of fMRI and single-trial EEG activation maps, we computed the resemblance metric across the entire brain. For the sake of simplicity we report here the results for the visual Brodmann areas BA17 right (BA17 left did not show any active voxel), BA18 and 19 bilaterally (see Fig. 1). Within these areas, this metric varied across frequencies, showing peaks within the gamma band and around 200 Hz. Moreover, when passing from the primary to the higher visual cortices, an increased number of frequencies show a power change locally co-varying with the BOLD signal.

Discussion

The proposed analysis procedure allows the direct comparison of LFP oscillations with BOLD responses in humans throughout the brain volume. These results suggest that there is a frequency-dependent relationship between BOLD and EEG signals within restricted brain regions, at least in case of a passive visual task. In accordance with [1], our results show a main contribution of gamma band within primary visual area (BA17), but also show the contribution of very high frequency oscillations (>200Hz) and suggest that this spectral relationship varies across anatomical areas.

References

[1] Logothetis et al. (2001) Neurophysiological investigation of the basis of the fMRI signal. *Nature* 412(6843):150-157

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