Quantifying the fMRI BOLD Signal to Characterize the Event-Related Electrophysiological Response

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INTRODUCTION

Conventional functional magnetic resonance imaging (fMRI) analysis entails the use of classical (or Bayesian) statistical inference to create, at each voxel, a probability of getting the observed fMRI data in the absence (or presence) of a particular effect [1]. Although such statistical inference is believed to reveal the locations of corresponding neuronal activations, its physical relevance to the "strength" of neural response remains ambiguous. In addition, the "amplitude" of fMRI response has been quantified using different signal features, such as the mean steady-state height, peak-to-peak height and signal integral (i.e. height times width at half height) [2]. However, none of these signal features has a well-defined physical interpretation in terms of the underlying neuronal activity.

Here, we propose a model-based approach for quantifying the fMRI signal to characterize the time integral of the event-related electrophysiological response [3]. The assumption is a linear temporal convolution model that links the power of synaptic current to the BOLD fMRI response. This assumption is in agreement with the previous experimental finding that the BOLD response is correlated with the local field potential (LFP) convoluted by a linear hemodynamic impulse response function [4].

MODELING

The event-related electrophysiological response is specified as the synaptic current flow, $\mathbf{s}(\mathbf{r},t)$, within a short duration T_s, where r indicates location and t indicates time. For a block of *N* repeated stimuli with a sufficiently large inter-stimulus interval T_{ISI}, the fMRI signal at an activated voxel is modeled by using a linear hemodynamic impulse response function (HRF), denoted as $h(t)$. The model is illustrated as Fig. 1 and mathematically expressed as Eq. (1).

$$f(\mathbf{r},t)=\sum_{n=1}^{N}\delta(t-nT_{ISI})*s^2(\mathbf{r},t)*h(t)+f_n(\mathbf{r},t) \quad (1)$$

Considering the HRF evolves much slower than the event-related electrophysiological response, the model can be further simplified as Eq. (2)

$$f(\mathbf{r},t)=p(t)\int_{T_S}s^2(\mathbf{r},t)dt+f_n(\mathbf{r},t) \quad (2)$$

where $p(t)=\sum_{n=1}^{N}\delta(t-nT_{ISI})*h(t)$ and it only depends on the stimulus function and the HRF.

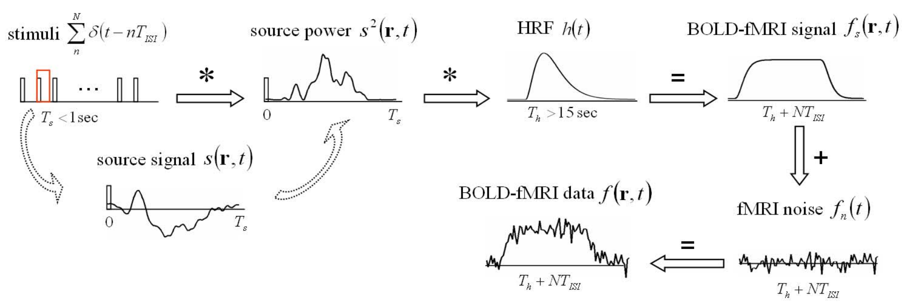

Fig. 1. Illustration of the linear system that describes the relationship between electrophysiological signals and BOLD-fMRI responses under a train of repeated stimuli

Clearly, $\int_{T_S}s^2(\mathbf{r},t)dt$ can be viewed as the regression parameter associated with the regressor *p*(t). Given a discrete time series of the observed fMRI signal in each voxel, the regression parameter can be estimated simply by using the linear least-square algorithm. Importantly, the estimated regression parameter has an explicit physical interpretation as the time integral of the power of the event-related local synaptic current flow [3].

CONCLUSION

When the fMRI response is described in a general linear model (GLM) and the regressor is a stimulus-defined delta function train convoluted with a known HRF, the regression parameter (previously known as the BOLD effect size) has an explicit physical interpretation as the time integral of the power of the event-related local synaptic current flow. Since the synaptic current is commonly believed to be the "source" generating scalp electroencephalography (EEG) and magnetoencephalography (MEG) signals, quantifying the fMRI response in the proposed way also contributes to a theoretical framework (illustrated in Fig. 2) for fusing fMRI and EEG/MEG [3]. In this framework, the quantified fMRI response is used to constrain the time integral of electrical source power (or variance), which is assumed to be time-variant. This multimodal integration framework allows combining event-related potentials or fields with block-design or event-related fMRI, and it has been demonstrated to have a better performance than the conventional fMRI-weighted EEG/MEG source imaging approach in both computer simulation and experimental settings [3, 5].

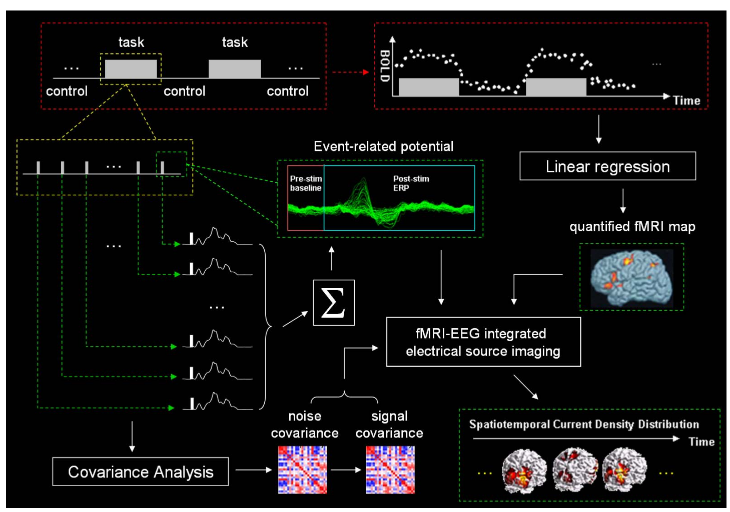

Fig. 2. The schematic diagram of the spatiotemporal neuroimaging integrating the event-related potentials and block-design fMRI.

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REFERENCES

1. K.J., Friston et al., NeuroImage 2002, 16, 465-483.
2. S. Ogawa, et al., PNAS, 2000, 97, 11026-11031.
3. Z. Liu and B. He, NeuroImage, 2007, doi: 10.1016/j.neuroimage.2007.10.003
4. N.K. Logothetis et al., Nature, 412, 150-157.
5. Z. Liu et al., PNAS, submitted.