Spatiotemporal neural dynamics from fMRI: Deconvolution with a spatiotemporal HRF

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Abstract

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Introduction:

Although the spatial resolution of fMRI is in the order of mm almost all fMRI neuroimaging analyses focus on the temporal BOLD response, restricting neuronal inferences between spatially averaged regions in fMRI. The basis for averaging, or in some cases ignoring, the spatial properties of the BOLD response is the assumption that the hemodynamic response function (HRF) is separable in terms of its temporal and spatial components and simply "blurs" underlying neural activity, thereby limiting the resolution we can retrieve from fMRI. However, recent advances have shown that the HRF is nonseparable [1-5] and contains nontrivial structure such as hemodynamic traveling waves [1]. With this new perspective, this study used the rich hemodynamic structure to deconvolve synthetic and previously recorded fMRI data to resolve evoked neural activity on scales of mm and s. This study shows that by using a physiologically informed model of the BOLD response, neural activity is accurately estimated whereas using a naïve HRF affords erroneous responses incompatible with independent recordings of neural activity.

Methods:

Estimating the neural drive from BOLD data was achieved by spatiotemporal deconvolution based on the Wiener filter. These estimates were dependent on the noise to signal ratio - estimated from the noise levels at high frequency, and the HRF – which was derived from a physiological model of hemodynamics [1,2,4] verified in a previous study [1]. In addition the assumed separable HRF was used to demonstrate its deficiencies in providing neuronal inferences.
The deconvolution method was tested on synthetic data that was calculated from the hemodynamic model. The synthetic data included the BOLD response to localized neural drive as well as the BOLD response to two separate neural drives separated by a few mm.
Functional MRI data were previously recorded for 4 subjects using cubic 1.5 mm voxels and a jittered temporal sampling of 250 ms while they viewed an evoked visual stimulus, as described in [1]. The BOLD responses evoked approximately straight parallel lines on the surface of the primary visual cortex and so were averaged across these lines to extract one-dimensional evoked BOLD responses. The parameters of the HRFs were extracted from this data set and explained in [1].

Results:

On application to synthetic data with a single neural drive, the neural response was recovered using a conservative NSR and the HRF derived from physiology; i.e., the HRF that was used to generate the synthetic BOLD data. In contrast, using the separable HRF afforded an estimate of the neural drive with spurious neural features such as slow neural waves over a similar spatial extent. The differences between the two filters were even greater when applied to the synthetic BOLD response to two neural sources in Fig. 1. Using the physiological HRF successfully retrieves the neural drive; however, deconvolution using the separable HRF yielded "ghost" neural responses, further emphasizing the artifacts that an inappropriate stHRF creates in model inversion.
The evoked responses from fMRI data contained waves traveling 2-12 mm/s from the center of the activation and deconvolution of this fMRI data with the physiological HRF estimated a localized and short

neural drive consistent with independent physiological measures. In contrast, the separable HRF estimated slowly evolving neural waves traveling less than 1 mm/s, at least 1-2 orders of magnitude slower than previously recorded neural waves [1].

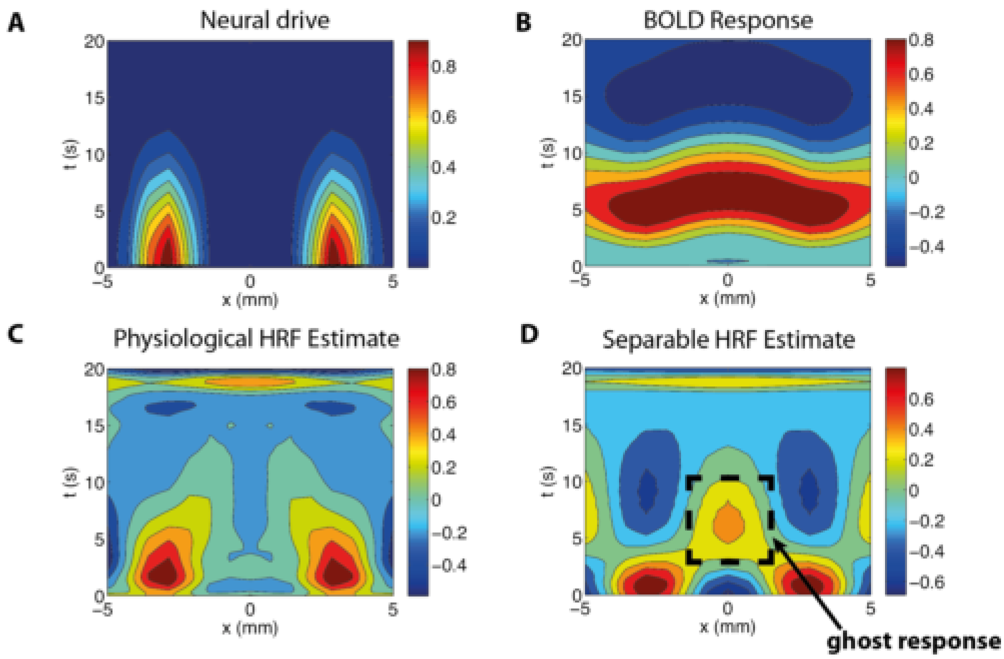

Fig.1: Recovery of the neural drive (**A**) from synthetic data (**B**) using a physiological HRF (**C**) and a separable HRF (**D**). Contour plots are nomalized to have ampilitude unity.

Conclusions:

This study has moved beyond analyses in the temporal regime and combines a theoretical model with data inversion to estimate spatiotemporal neural activity in the order of mm and s. This study further emphasizes the importance of using the HRF that more closely resembles the underlying physiological processes as the estimates may contain artifacts such as incorrect neural delays or artificial or "ghost" neural responses.

Modeling and Analysis Methods:

Exploratory Modeling and Artifact Removal

Reference

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