Functional Magnetic Resonance Imaging of the Motor Network with 65ms Time Resolution

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Introduction: While fMRI provides a relatively high spatial resolution, the time resolution is low (few seconds) compared to some other neuroimaging techniques such as EEG. We developed a method to achieve a 65ms time resolution for a voluntary hand movement experiment by temporally re-ordering continuously acquired fMRI data. Our aim with this project was to investigate the spatial/temporal variability of the hemodynamic response function (HRF) for the brain regions involved with motor function.

Methods: *Image Acquisition* – Using a 3T Allegra scanner (Siemens Medical, Erlangen, Germany) we acquired 48 slices with 3mm isotropic voxels in 9 sessions of 300 volumes in each. The TE was 30 ms while the slice-to-slice TR was 65ms (3.12s per volume) resulting in 15m37s acquisition time per session. Simultaneously EMG data was recorded from the right lower arm along with a pulse indicating the time of excitation of each slice. The subject was instructed only to lift the right hand at intervals of at least 15s. No other instructions or stimuli were given in order to isolate the motor network.

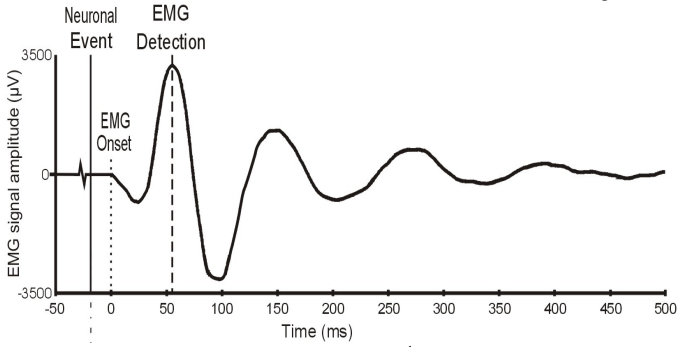


Image post processing: Figure 1 displays the mean of fifteen EMG responses. Based on this, all events were identified by the second peak which was approximately 55ms after the onset of the event. As it takes approximately 17ms for neuronal transmission to reach the lower arm muscle (1) from the cortex we estimated the cortical neuronal event to occur 72ms (55ms+17ms) prior to the second peak of an EMG event. All EMG events happening less than 15s after the previous EMG event were excluded. For each valid EMG event, the slice was identified during which the neuronal event must have occurred and placed as the 5th volume of a pseudo time series while keeping the slice position within the volume. The 5th volume was arbitrarily chosen to represent the time of the neuronal event in order to have about 250ms of data prior to the neuronal event (stored in the first 4 volumes). This pseudo time series had 235 volumes because we assumed that the duration of the BOLD response was 15s and we wanted to keep data for 4 additional time points – i.e. 235 ~ 15s/65ms+4 volumes. The slice acquired immediately after the one in which the neuronal event occurred was placed into the 6th volume of this time series while keeping the slice position and so on. This way we placed one slice into each of the following 230 image volumes. The four slices prior to the one with the neuronal event were used to populate the first four volumes of the pseudo time-series. Note that the resulting images are equivalent to peri-stimulus-time histograms or can be considered as retrospective gating. Using SPM (http://www.fil.ion.ucl.ac.uk/spm/) we fit this pseudo time series data either with two gamma functions or with fourier series up to the first 10 basis functions. The functional regions of interest in Figures 2 & 3 were chosen based anatomical location and confirmed with a standard event related analysis on the original data before reordering.

Results: Figures 2 (model = 2 Gamma functions) and 3 (model = Fourier series with 10 basis functions) display the data and the model fits (bold lines) for the primary motor cortex (top) the supplementary motor area (middle) and the primary somato-sensory area (bottom). Figure 4 gives further examples of HRFs in the brain at different voxel coordinates (top = caudal cyngulate motor area, middle = frontal lobe, bottom = superior temporal gyrus). The data were not normalized, hence the voxel coordinates are not indicative of the standard Talairach space.

Figure 2 – Gamma function

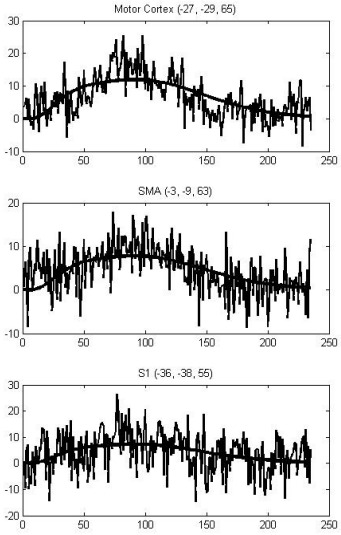


Figure 3 – Fourier series

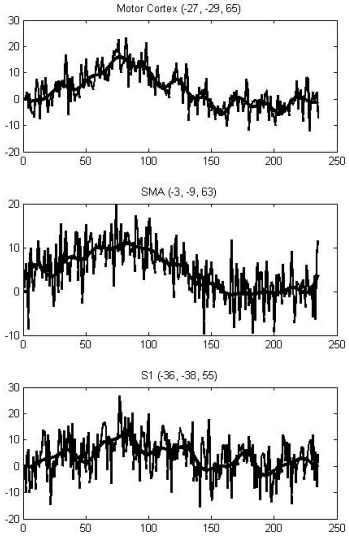
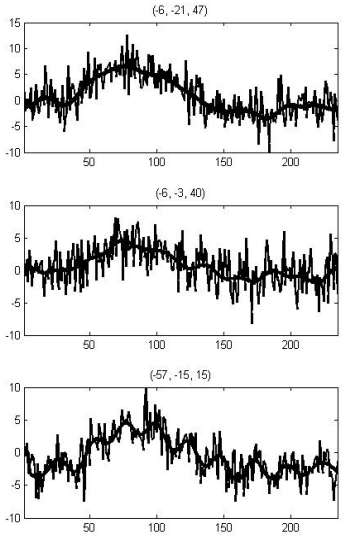


Figure 4 – Some examples



Discussion The analyses of fMRI time series commonly use a generic HRF function to detect BOLD activation. It has been noted however that the HRF has regional variability (2-3). In this study, we generated a pseudo time-series with a 65ms time resolution in order to characterize the spatial/temporal variations of the HRF. The results not only illustrate how the shape of the HRF varies among regions of the brain, but also that higher frequency components exist in some specific locations (see Figure 3 top and bottom or Figure 4 bottom). There is a possibility that the reordering of the slices artifactually create this high frequency component but in our experience it is unlikely because then the high frequency component should be observable in all voxels of a given slice. This, however, we do not find. Future work will involve model selection to establish systematically which model fits best at different spatial locations.

References: (1) Ashby (1992) Corticospinal Projections to Upper Limb Motorneurones, J. Physiol. 448 p 397; (2) Handwerker,D.A.; Ollinger,J.M.; D'Esposito,M. (2004) Variation of BOLD hemodynamic responses across subjects and brain regions and their effects on statistical analyses, Neuroimage, 21(4) p1639-1651; (3) Aguirre,G.K.; Zarahn,E.; D'Esposito,M. (1998) The variability of human, BOLD hemodynamic responses, Neuroimage 8(4) p 360-369