Direct detection of neuronal magnetic field changes using MRI:Timing effect of Stimulation

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Introduction: Magnetic source MRI (msMRI) has been recently developed to directly detect neuron activities by measuring the neuronal magnetic field. However, controversial theoretical and experimental results have been reported [1-3]. In this paper, we used a median nerve stimulation paradigm to demonstrate the timing effect of stimulation in detecting of msMRI signal.

Method: Six healthy subjects participated in this study. All subjects provided informed consent. The median nerve was stimulated at the right wrist by a Grass S8 stimulator. Pulse duration was 0.1msec. Shock intensity was adjusted to obtain a thumb twitch. Pulse amplitudes ranged from 80-120V.

Protocol and Data acquisition: All MRI data were acquired at Siemens 3.0 T Trio scanner. Three slices were scanned and the second slice was the target slice to detect the msMRI effect. A gradient echo EPI pulse sequence was used with imaging parameters of TR/TE/flip angle = 300 s/27 ms/40 degree was used for msMRI. An inter-stimulus-interval (ISI) of 600 ms has been used here to drive BOLD MRI signal to steady state. Each run includes 600 ON/OFF cycles with two images for each cycle (one ISI). The whole paradigm is shown in Fig 1. Somatosensory evoked potentials (SEPs) consists several components (e.g. N20, P30, P80). msMRI experiments were conducted to detect P80 component and early components (e.g. N20, P30). Control scan has same paradigm as msMRI scans but the target slice was scanned before stimulation. Therefore, no msMRI effect should be included in control scan.

Data analysis: A two-dimensional motion correction was carried out to minimize in-plane motion. Data interpolation between image slices was purposely avoided because different slices were acquired at different time. A cross-correlation analysis was performed to generate a statistical parametric image (SPI) for each run. Fisher's z-transformations were performed to convert correlation coefficients to z-values. An intensity threshold (z-value threshold) of 3.0 ($p < 0.001$) and cluster size threshold of 3 voxels was applied to detect significant activation. The thresholded SPI was, then, overlaid onto the anatomic image acquired from the same slice. The locations of activations were identified by neuroradiologist based on T1 anatomic images.

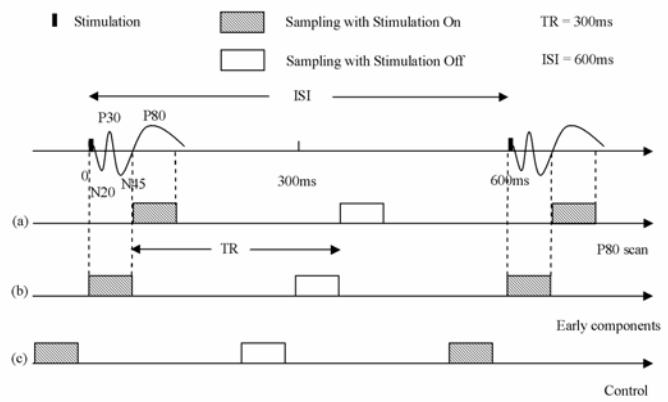

Fig 1. The paradigm of msMRI scans for detecting P80 component (a) and early components (b) and control scan (c)

Results: Figure 2a shows BOLD activation maps and 2b shows msMRI effect of P80 component for the same slice. Significant activation clusters were observed in the contralateral primary sensory cortex (SI) for both BOLD and msMRI scans. msMRI effects for the early components (0-60ms) were shown in Fig 2c. Activations in SI area were absent. In control scan, as expected, no activations were found in SI area and BOLD effect has been minimized by our experiment design.

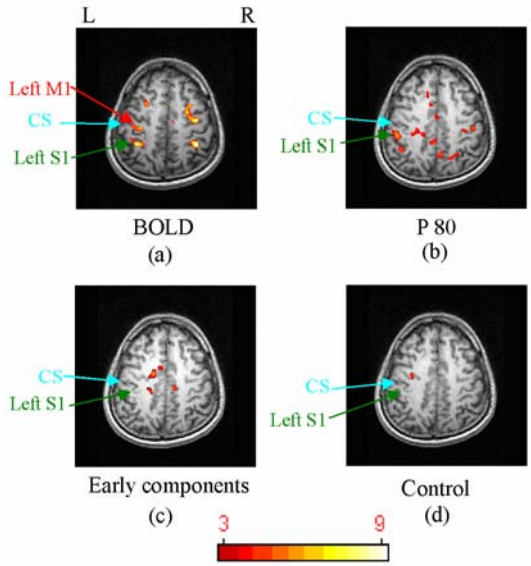

Fig 2. Activation maps for BOLD and msMRI experiments

Discussions and Conclusion: SEPs generate a bipolar neuronal magnetic field which has a cancellation effect and may result in msMRI signal undetectable. The early components of SEPs consist of several peaks with opposite orientations. Failed detection of these components in SI area has demonstrated this cancellation effect. In control scans, no activation was found in SI area since stimuli haven't been presented when target slice was scanned. BOLD effect, in contrast, should have no such cancellation effect and has a weak dependence on the onset of stimuli because the blood oxygenation level always increases when brain area is activated and has a long lasting effect. Therefore, our results demonstrated that these activations were originated from msMRI effect. In short, msMRI signal has a strong dependence on the time and could only be detected in the right position and within the right sampling window. Therefore, stimuli onset, TE and slice position need be carefully selected to detect the neuron activity in a specific area.

References: [1] Xiong J, et al. Human Brain Mapp, 2003. [2] Xue Y, et al. NeuroImage, 2006. [3] Chu R, et al. NeuroImage, 2004.

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