Ipsilateral FMRI Response in Primary Somatosensory Cortex (Area 3b) of Awake Marmosets

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Introduction

Recently, there has been much interest in understanding the cortical representation of tactile information of the hands in non-human primates [1]. Unilateral stimulation elicits a strong fMRI response in the contralateral primary somatosensory cortex (SI) and a weak response in the ipsilateral SI [1]. Because the contralateral SI response is driven primarily by thalamic inputs, whereas the ipsilateral SI response is driven primarily by corticocortical neural projections, differences between them shall provide insight into the cortical processing of sensory information. One such difference, revealed by BOLD fMRI in human, is that ipsilateral SI response is much more transient than contralateral SI response to a long (20 s) somatosensory stimulus [2]. Here, we compared the BOLD fMRI responses to unilateral stimulation of the wrist in awake marmosets at 7T.

Methods

All fMRI measurements were performed in awake adult marmosets (n=7) that were acclimated to body and head restraint [3]. The animals' heads were secured rigidly yet comfortably by custom-made helmets shaped to each individual's head anatomy. While in the magnet, the animals were continuously monitored by an MR-compatible camera. Experiments were performed in a horizontal 7T/30cm MRI (Bruker AVIII, Ettlingen, Germany) equipped with a 15 cm gradient coil (Resonance Research Inc, Billerica, USA). Images were acquired using a home-built transmit volume coil and a two-element (1.2 cm ID) receive surface coil array.

BOLD fMRI was obtained using a 2D gradient-echo EPI sequence from 7 coronal slices (TE: 20ms; TR: 1000ms; thickness: 0.7mm; field-of-view: 21×27mm; resolution: 0.35mm). T_1-mapping based on inversion-recovery was conducted (180˚ inversion, 90˚ excitation; TI: 0.15, 1.5, 4.7s; TR: 12.5s), using an identical EPI sequence so that T_1 map and fMRI data were spatially co-registered. Electrical stimulation of peripheral nerves (pulse duration: 0.4 ms) was delivered by pairs of electrode pads placed across each arm. Four types of experiments were run:

I) Frequency tuning: stimulation frequency varied from 1Hz to 125Hz, with fixed current intensity of 1.5mA and duration of 4s. II) Duration tuning: stimulation duration varied among 1, 2, 4, 8, 16s, with fixed current intensity of 1.5 mA and frequency of 50Hz. III) Intensity Tuning: current intensity varied among 0.7, 0.9, 1.1, 1.3, or 1.5mA, with fixed stimulation duration of 20s and frequency of 50Hz. IV) Unilateral stimulation is compared against bilateral stimulation, with fixed duration of 20s, frequency of 50Hz, and intensity of 1.5mA.

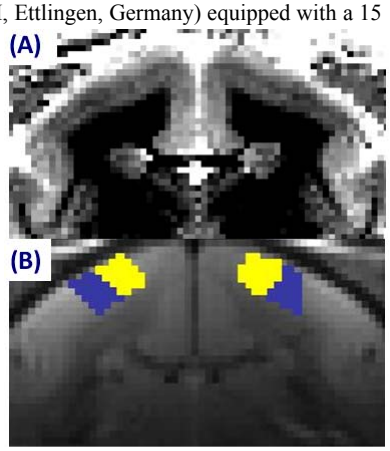

Fig. 1. (A) T_1 map and (B) EPI image of a coronal slice. Blue and yellow regions denote low T_1 and high T_1, respectively.

Results

From the T_1 map (Fig. 1A), we manually outlined four regions-of-interest (ROIs) within area 3b of SI: the low-T_1 regions (blue in Fig. 1B), and the high-T_1 regions (yellow in Fig. 1B), contralateral and ipsilateral to stimulation. The BOLD responses were positive in all four ROIs. For low-T_1 regions, responses were much stronger in contralateral than in ipsilateral. For high-T_1 regions, however, response amplitudes were roughly equal in contralateral and ipsilateral (Fig. 2). Results from the four experiments were: I) Contralateral and ipsilateral responses had very different relationships to stimulus frequency. Contralateral response increased monotonically with frequency, whereas ipsilateral response was weak at low frequency, and became significant only at high frequency (> 25 Hz).

II) Only the contralateral response in low T_1 sustained until long stimuli ended, whereas responses in all three other ROIs were transient such that they reduced sharply within ten seconds, even for a long stimulus (Fig. 2).

III) As stimulus intensity increased, transient responses in all four regions, as well as the sustained response in contralateral low-T_1, all increased in amplitude, but such increase was very small in ipsilateral low-T_1 (Fig. 2).

IV) For each of the four regions, when both arms were stimulated, the BOLD response was stronger than when only the arm on contralateral side was stimulated. This increase in response, however, was larger for the high-T_1 regions than for the low-T_1 regions.

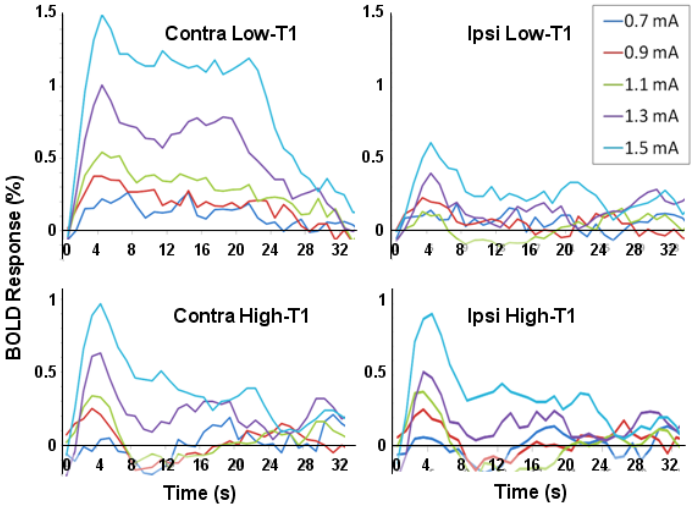

Fig. 2. FMRI responses in the four regions of interest to 20 s long, 50 Hz stimulation at five different current intensities (0.7~1.5 mA). Stimulus lasted from 0 s to 20 s.

Discussion and Conclusions

One methodological advance in the present study is to combine fMRI with T_1 mapping, which is useful since spatial variations of T_1 often correspond to the cytoarchitecture in cortical gray matter [4]. In area 3b of marmoset SI, regions mapped to the hand receive denser thalamic inputs than nearby regions, and have higher myelin density and lower T_1 values [5]. Hence, we use T_1 map to demarcate, in area 3b of SI, the zones that receive direct thalamic inputs encoding somatosensory information from the hand.

Consistently with previous studies [1-2], the ipsilateral SI response is much weaker and more transient than the contralateral SI response. Furthermore, we found interesting differences between the low-T_1 (high-myelination) and the high-T_1 (low-myelination) zones. In high-T_1 regions, which receive little direct thalamic inputs of somatosensory signals from hands, contralateral and ipsilateral fMRI responses are similar in amplitude and relationships with stimulus parameters, suggesting that they are driven by similar, presumably corticocortical, neural inputs. On the other hand, in low-T_1 regions the ipsilateral fMRI response is weaker than contralateral, consistently with the dominance of thalamic inputs in these regions. The higher response to bilateral than to unilateral stimulation suggests that the corticocortical neural inputs that underlie the ipsilateral neural response facilitate the neural responses to direct thalamic inputs. This facilitation effect is stronger in high-T_1 than in low-T_1 regions, consistent with the larger proportion of corticocortical projections at higher T_1.

References

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