Using T_1 map to guide functional MRI study of ipsilateral somatosensory cortex in awake non-human primates

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Introduction

A precise knowledge of functional organization in the neocortex relies on comparisons between functional mapping and anatomical structures. In classical neuroscience, such comparisons were often made between electrophysiological recording of neural response and postmortem histological staining of myelin [1]. MRI can augment this knowledge with comparisons between BOLD fMRI and structural MRI such as T_1 mapping that reveals cortical myeloarchitecture [2]. In particular, previous anatomical studies suggest that interhemispheric somatosensory connections are spatially heterogeneous, and they end in specific myelin-poor bands in the cortical area 3b, which is part of primary somatosensory cortex (SI) of the non-human primate common marmoset [1]. This structural organization suggests that ipsilateral functional responses may also center on these myelin-poor zones, but this possibility was not explored in previous functional imaging studies [3-5]. We therefore study ipsilateral responses in awake marmosets, with a methodological advance in combining high-resolution BOLD fMRI with T_1 mapping.

Methods

All fMRI measurements were performed in awake adult marmosets that were trained but received no pharmacological agents (n = 3, age = 1.5 yr). Each animal was first anesthetized with 2% isoflurane to take 3D MRI of the head scalp. The animal then went through 3 weeks of acclimatization process. Animal head was secured rigidly by one top and one bottom helmet pieces starting from the 3rd week of acclimatization and throughout the real MRI sessions. The 3D shapes of the helmet were designed to tightly fit the 3D shape of head, which was obtained from the 3D MRI.

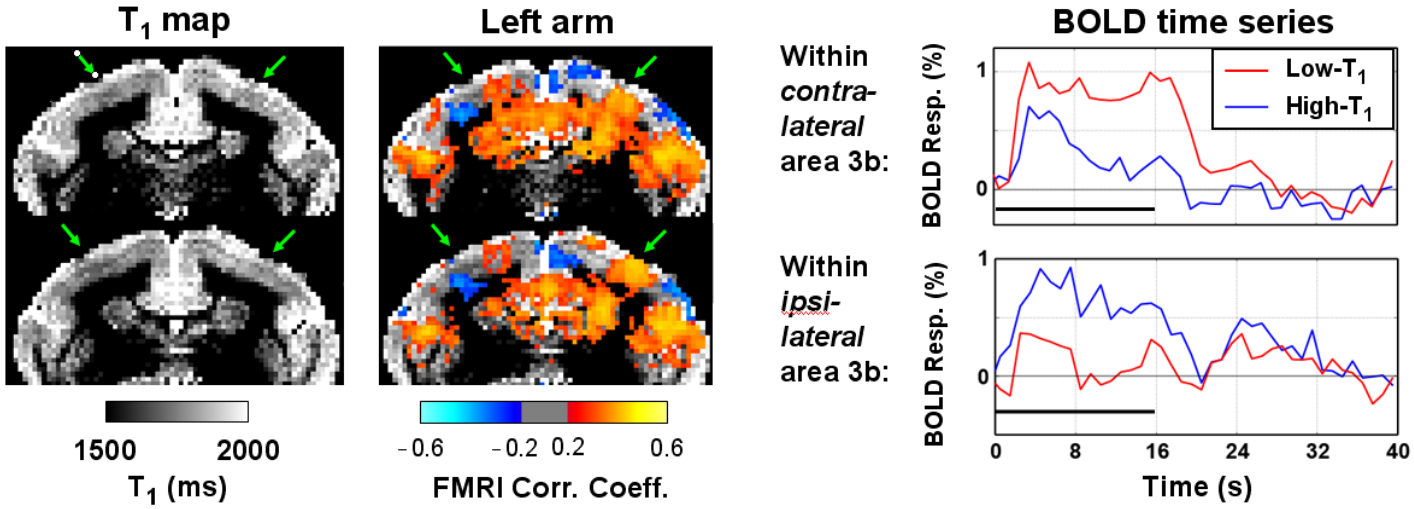
A 7-Tesla scanner was used with a two-element receive-only surface coil array. FMRI BOLD imaging used 2D gradient-echo EPI in 7 coronal slices (TE: 20 ms; TR: 1000 ms; thickness: 0.7 mm; field-of-view: 21×27 mm; resolution: 0.35 mm). T_1 mapping was conducted using nearly identical EPI sequence so that T_1 map and fMRI data had identical geometrical distortions and so were spatially co-registered. T_1 mapping used an inversion pulse (180˚), 90˚ excitation angle, and 12500 ms TR. T_1 was computed from images taken at 3 different inversion times (150, 1500 and 4700 ms).

Electrical stimulation of peripheral nerves was delivered by pairs of electrode pads placed across each arm. Two types of stimulus design were used to elicit strong ipsilateral responses in SI. The first comprised 2 s of stimulation followed by 24 s of no stimulation. The second comprised a 16 s block that comprised 0.5-1.5 s epochs with stimulation randomly mixed with 0.5-1.5 s epochs without stimulation, followed by 24 s of no stimulation. During the time stimulation was on, electrical pulses (1.5 mA, 400 us) were delivered with a 50 Hz repetition frequency.

Results

The figure below shows two coronal slices across the area 3b of SI. In the middle of area 3b, T_1 map shows a low-T_1 zone (green arrows) that is flanked on both medial and lateral sides by a high-T_1 band. The two high-T_1 bands agree with the two myelin-poor bands reported by histological staining [1]. , indicating that T_1 map can reveal fine details of cortical myeloarchitecture [2].

The fMRI correlation coefficient map overlaid on top of the T_1 map shows positive (orange) and negative (blue) BOLD responses to left arm stimulation. The BOLD response map was significantly asymmetric. The contralateral response (right side) was significant and centered on the low-T_1, myelin-rich zone (green arrow) of area 3b, whereas ipsilateral response (left side) was weaker and centered on a high-T_1, myelin-poor band (on medial side of green arrow). The BOLD time series in regions drawn based on the T_1 map also showed stronger contralateral response in low-T_1 than in high-T_1 regions, but ipsilateral response stronger in high-T_1 than in low-T_1 regions. Results similar to the figure were found in all 3 marmosets.



Conclusion and Discussion

Our results show an unprecedented spatial mismatch between contralateral and ipsilateral representations of the same arm in cortical area 3b. Cortical myeloarchitecture, which is indirectly probed by T_1 mapping, serves as anatomical reference that landmarks this spatial mismatch, such that ipsilateral response centers on a myelin-poor band, and contralateral response centers on a myelin-rich zone. These results are consistent with anatomical studies that showed transcallosal projections ending at the two myelin-poor bands [1]. However, no such mismatch has been reported in previous studies [3-5], presumably because our fMRI study of ipsilateral responses is the first to use guidance from T_1 maps.

References

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