Cortical boundaries revealed by T_1 mapping: comparison with fMRI in awake marmosets

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Introduction

The primary visual cortex (V1) has a high concentration of myelin in layer 4C, where long myelinated axons carrying thalamic inputs end at. Since myelin reduces tissue T_1, V1 can be distinguished by a thin dark layer in the middle of gray matter in T_1-weighted MR images. This anatomical boundary matches the boundary of V1 measured by functional magnetic resonance imaging (fMRI) during suitably designed visual stimuli (retinotopy) [1,2]. Such distinct anatomical features corroborating functional boundaries, however, were not yet reported for other sensory cortices. Here we use a new method based on inversion-recovery to measure T_1 maps in the awake marmoset. *Ex vivo* histological studies in marmoset revealed a higher concentration of myelin in primary somatosensory cortex (SI) – or at least in area 3b – than in abutting areas [3]. Thus, we investigate whether SI can be distinguished by T_1 measurements, and if so, whether the anatomical boundary matches the functional boundary of SI measured by fMRI during somatosensory stimuli.

Methods

Two marmosets were imaged awake after 3 weeks of acclimatization to body restraint. Each animal was positioned with its head secured rigidly by implanted head posts, and pairs of electrode pads were placed across its right arm and right leg. Electrical stimulation of peripheral nerves in both arm and leg was delivered in periodic repeats of epochs (1.5 mA 0.4 ms pulses at 40 Hz, each epoch 8 s on / 22 s off). A 7 Tesla Bruker scanner was used with a two-element receive-only surface coil array positioned over the head near the somatosensory cortex. A single 2D coronal slice (thickness: 1.0 mm; field-of-view: 25.6×32.0 mm; in-plane resolution: 0.2×0.25 mm) was prescribed at roughly 3 mm posterior to the anterior commissure. Local shimming was performed based on field map measurements. Functional MRI response was measured over the slice using a T_2*-weighted echo-planar (EPI) sequence (gradient-echo; TR/TE: 1000/25 ms). The significance of stimulus-evoked activation was measured as cross-correlation coefficients betweeen fMRI signal and stimulus time sequence. For T_1 map estimation, the same slice was measured with the same EPI parameters and shimming, only with inversion-recovery (IR) added into the EPI sequence with a much longer TR (TR/TE: 11000/25 ms). Data under 16 IR time values (sampled from 53.6 ms to 10875 ms with geometric factor 1.425) were fitted to a three-parameter, single-exponential T_1-recovery function [4]. A high-quality T_1 map was obtained within 45 minutes of measurement. The fMRI and T_1 map measurements were in good coregistration since they had identical geometric distortions, B_1 inhomogeneities and other artifacts.

Results

Two clusters of strong stimulus-evoked fMRI responses, one relatively medial (within purple to white lines) and one relatively lateral (within white to green lines), were observed in the dorsolateral cortex of left hemisphere (contralateral to stimulation). In comparison, the T_1 map on the same slice had a very symmetrical organization. The dorsolateral cortex of each hemisphere contained a distinct, relatively medial region (purple to white lines) with low T_1 values (greenish, ~1700 ms). The region lateral to it (white to green lines) had significantly higher T_1 values (reddish, ~1900 ms). The two regions were named SI and SII, respectively. Critically, the two fMRI response clusters were well separated by the T_1-defined SI–SII boundary, suggesting that they belonged to two cortical areas with different T_1 values. The lateral boundary of SII was in the lateral sulcus. Cingulate cortex was on the medial surface of hemisphere (below purple lines) and had high T_1 values (reddish). Weak responses were observed in the cingulate, but the SI-cingulate boundary was clear in both fMRI activation map and T_1 map. Results in another animal were similar.

Conclusion and Discussion

In this study, SI is identified based on its stimulus-evoked responses together with its significantly lower T_1 values compared to abutting SII and cingulate cortex. This is in agreement with higher myelin concentration in area 3b of marmoset SI [3]. As fMRI measures vascular signals and is spatial localization may not match the neural organization, T_1 mapping provides an extremely valuable, non-invasive measure of cortical architecture that is useful to aid interpretation of fMRI brain mapping results.

References

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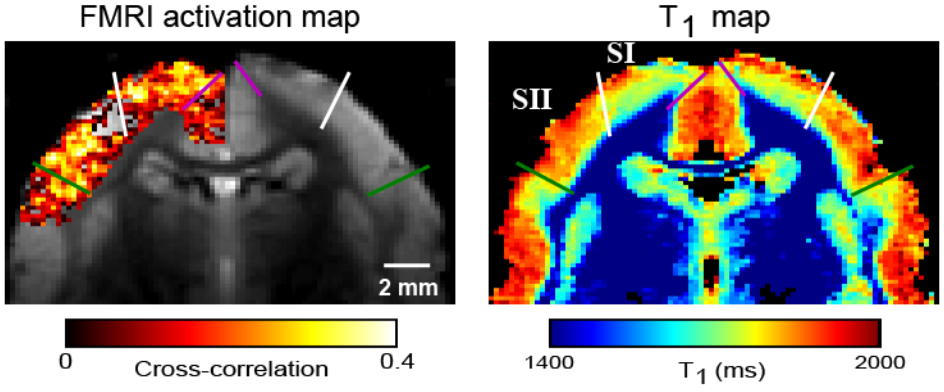

FMRI activation map and T_1 map measured on the same coronal slice (roughly slice A5.0 in atlas [5]) were compared directly. Purple, white and green lines were drawn at identical locations in two images. For clarity, only left cortex was shown in the activation map, although robust responses in right SII, thalamus and caudate were observed. Note that T_1 difference between cortex and white matter (blue) was much larger than the informative variations in cortical T_1.