Within digit somatotopy of the human somatosensory cortex using fMRI at 7T

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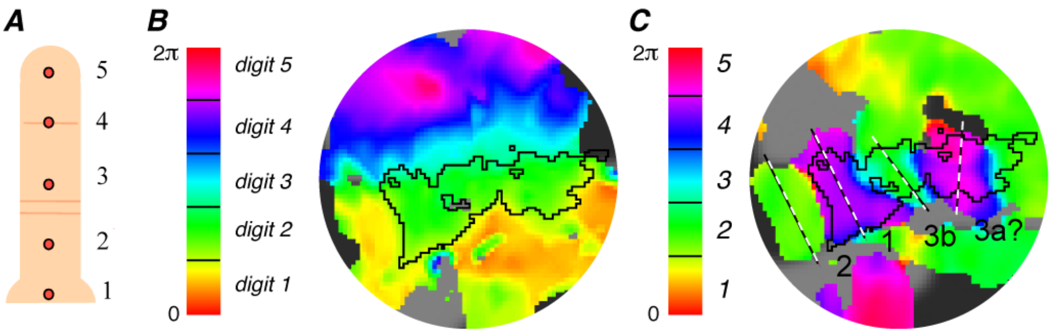
Introduction: The somatotopic representation of digits in the human primary somatosensory cortex (S1) has been extensively studied using fMRI (1). However the fine topography of the individual finger representations in S1 has not been explored in detail (2,3). We have previously used a 'travelling wave paradigm' to form a somatotopic map of all five digits in S1 (4). Here, we take advantage of the increased BOLD contrast-to-noise ratio and high spatial resolution achievable at 7T to measure the topographic organisation (base-to-tip) within the index finger representation in the primary somatosensory cortex in individual subjects with a travelling wave paradigm. The literature from primate physiology suggests that the proximal-to-distal mapping of the receptor sheet in the finger is reversed at the boundaries between areas 3b, 1, and 2 (5).

Methods: A 'travelling wave' paradigm was used to localize regions of the cortex responding to tactile stimulation along the phalanx of the index finger of the left hand. A supra-threshold 50 Hz stimulation was delivered to ~1mm^2 of the skin at five locations along the left index finger (Figure 1A) using 5 independently controlled piezo-electric devices. Each location was sequentially stimulated for 4s of a 20 s cycle either from proximal-to-distal (1 to 5) or from distal-to-proximal (5 to 1), with 12 cycles being collected per scan. Functional scans were repeated 8 times, alternating between proximal-to-distal and distal-to-proximal ordering. Scanning was performed on a 7T Philips Achieva system with 16-channel SENSE receive coil on three subjects, each scanned twice to assess reproducibility of patterns. In addition all subjects had undergone a previous session in which a somatotopic map of all 5 digits of the hand was acquired. fMRI data were acquired at 1.5 mm isotropic resolution using multi-slice, single shot gradient echo EPI (28 axial slices, FOV 192 x 150 mm, TE=25 ms, SENSE factor=3, TR=2 s) and image-based shimming (5). High resolution T2*-weighted data (0.5 mm in-plane, 1.5 mm slice thickness) were acquired with the same slice prescription, allowing registration to an anatomical reference volume for flat mapping. fMRI data were analysed using Fourier analysis to calculate the coherence and the phase of the best-fitting 1/20 Hz sine wave at each voxel. The proximal-to-distal and distal-to-proximal scans were combined to cancel the haemodynamic delay (4), such that the phase value of the average time series corresponds to the mapping of the proximal-to-distal index finger representation. Statistical maps and the index finger ROI were transformed onto flattened representations of the cortex.

Figure 1: (A) Schematic of index finger showing the positions (1-5) of stimulators on the index finger. Flattened representations of the cortex for subject 1 showing (B) left hand digit somatotopy map with index (digit 2) ROI outlined with black line (C) proximal-to-distal somatotopy. Dashed black-white line: putative limits within somatotopic areas.



Results: An orderly pattern of activation was revealed within the index finger representation in the primary somatosensory cortex of two of the subjects scanned. Figure 1B shows the representation of the 5 digits of the Subject 1's left hand, from which the index finger ROI was defined. Figure 1C shows a thresholded map (*coherence*>0.35) of the phase of the BOLD response overlaid on a flattened patch for Subject 1. The color bar indicates mapping of the phase of the BOLD response to the stimulated location on the index finger. The dashed black and white lines represent the borders of the different subdivisions of S1. These have been defined assuming mirroring of proximal-distal representations in adjacent sub-regions (5), which fall in the cortical area corresponding to the representation of the index finger in S1 (solid black line identified from the digit mapping experiment (7)). Subject 2 also showed a similar pattern of proximal-to-distal reversals. Assessing the spatial extent, it was found that the representation of the digit tip (defined from phase values of location 5) spanned 4.5 ± 1.0 mm and of the base (defined from phase values of locations 1 and 2) 3.2 ± 0.6 mm, whilst the tip-base separation was measured to be 5.4 ± 1.5 mm, average across area 1 and 3b and subjects 1 and 2. The third subject scanned did not display a clear succession of adjacent mirrored representations, Figure 3. However the maps of proximal-distal representation obtained in the two sessions on this subject were very similar (compare Fig. 2A and B). Similar reproducibility was found in the data from the other two subjects.

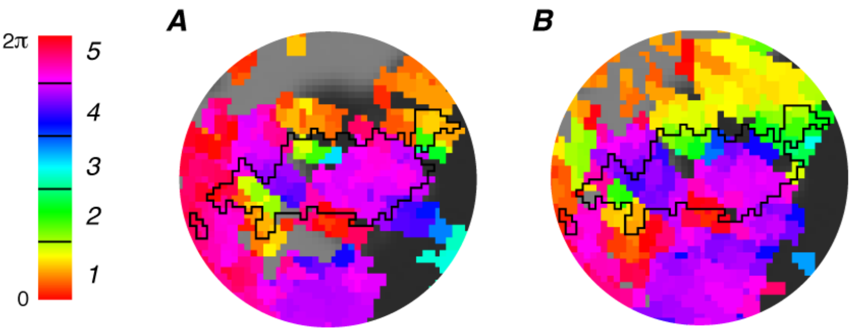


Figure 2: Flattened representations of the cortex for subject 3 showing activation map for the index proximal-to-distal representation in two different sessions (A) and (B).

Discusion: We have demonstrated within digit somatotopy of the primary somatosensory cortex at the individual-subject level using fMRI with 1.5 mm isotropic voxels at 7T. For two of the three subjects scanned we found an organized somatotopy within the cortical area corresponding to the index finger, with phase reversals in the map which are consistent with the mirrored representations in the adjacent sub-regions 3a/3b/1/2. These results are consistent with electrophysiology experiments conducted in monkeys (5). The third subject did not exhibit an orderly map, which could be divided into subregions. However the somatotopic maps from two scanning sessions on different days are consistent for all subjects, demonstrating the reproducibility of 'within-digit' somatotopic mapping at 7T.

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