Investigating somatotopy in SI and SII with high resolution multiband fMRI at 7T

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TARGET AUDIENCE: Physicists and neuroscientists interested in using multiband techniques and applications to fMRI.

PURPOSE: fMRI has been used to provide a detailed map of the somatotopic representation of fingertips in the human primary somatosensory cortex (SI) [1], located in the posterior bank of the central sulcus, and also provides the spatial resolution required to resolve within-digit somatotopy [2]. However, finger somatotopy in human secondary somatosensory cortex (SII), located in the parietal operculum on the ceiling of the lateral sulcus, has not been explored in detail. For example, a previous fMRI study (Ruben *et al*) [3] using coarse spatial resolution (4 mm isotropic) could not resolve the representation of the fingers in SII. Until recently, a limitation in implementing high-resolution fMRI studies of somatosensory cortex has been the long times need to acquire slices covering both SI and SII. Multiband (MB) acquisition, in which multiple slices are imaged simultaneously, provides a way of overcoming this problem and thus reducing the volumar acquisition time.

AIM: To apply multiband (MB) acquisition at 7T to achieve simultaneous coverage of SI and SII in a high spatial resolution fMRI study of somatotopy using a travelling wave paradigm.

METHODS: Three subjects participated in this study, which was performed at 7T using a 32-channel receiver coil (NOVA Medical). Each subject participated in two fMRI scan sessions, one session to generate somatotopic maps of the 5 fingertips of the left hand (right hand, subject 3) and a second scan session to localize regions of the cortex corresponding to tactile stimulation of the left face, index, middle and ring fingers, and left foot (right site, subject 3). In each scan session, vibrotactile stimulation (30 Hz) was delivered to the skin using independently controlled piezo-electric devices. A 'travelling wave' paradigm was used to sequentially stimulate each location for 4s of a 20 s cycle either in a forward (from the thumb to the little finger; or face-index-middle-ring-foot) or backward (from little finger to the thumb; or foot-ring-middle-index-face) ordering. Functional scans consisting of 10-12 cycles were repeated 6 times, alternating between forward and backward order.

Data Acquisition: fMRI data were acquired using multi-slice gradient echo–echo planar imaging (GE-EPI) with the following parameters: TR= 2 s, TE= 25 ms, FA=75^{o}, FOV=192x162 mm^{2} (APxRL). A SENSE factor of 2.5 was used in the RL direction and a multiband excitation factor of 2, yielding 52 slices with a 1.5 mm isotropic spatial resolution. High-resolution structural T2*-weighted images (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 surface rendering.

Data Analysis: fMRI data were analyzed using Fourier analysis in mrTools (http://www.cns.nyu.edu/heegerlab) to calculate the coherence and phase of the best-fitting 1/20 Hz sine wave at each voxel. The forward and backward scans for each experiment were combined to cancel the haemodynamic delay. Statistical maps were rendered onto surface representations of the cortex and displayed at a coherence threshold c > 0.4.

RESULTS: Fingertip somatotopic maps showed a clear orderly pattern of phase variation in the posterior bank of the central sulcus, corresponding to the representation of the fingers in SI, for all three subjects scanned. Figure 1A shows the representation of the 5 fingertips of Subject 1's left hand; within SI the representation from little finger to the thumb is in the medio-lateral direction. However, no clear fingertip somatotopic pattern was found in SII for any of the subjects scanned, the travelling wave paradigm in fact produced little response in SII due to the overlapping activity of digits. The face-hand-foot mapping paradigm revealed finger representations within SI (Figure 1B) consistent with the fingertip mapping results. The representation of the face can be seen in the posterior wall of the central sulcus, inferior to the representation of the fingers, and the foot is seen in the medial wall of the anterior parietal lobe. A somatotopic arrangement can also be seen in SII within the parietal operculum, with the representation of the foot being more medial with respect to the representation of the fingers.

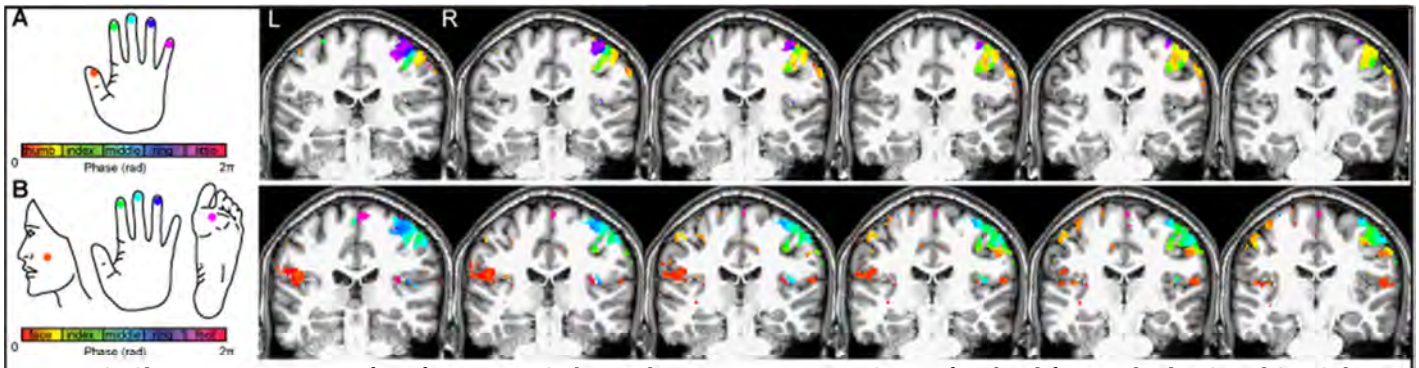

Figure 1A: Clear somatotopic maps for 5 fingertips in SI, but no digit separation seen in SII; 1B:face-hand-foot resolved in SI and SII. Color bar indicates phase of BOLD response. Maps are shown using a coherence threshold c>0.4.

DISCUSSION: The fingertip mapping paradigm revealed a clear somatotopic representation within SI, but not in SII for all three subjects. We used a travelling wave paradigm to locate regions of the brain which preferentially respond to stimulation of a given finger, hence the travelling wave paradigm is less effective at identifying neural populations with wide receptive fields. The absence of a finger somatotopic map suggests that the representations of the individual fingers largely overlap in SII. The face-hand-foot mapping showed a somatotopic arrangement in SII, with representations of the face, hand and foot ordered from lateral to medial, in agreement with previous fMRI experiments and electrophysiology in primates [4].

CONCLUSION: The use of multiband acquisition at 7T has allowed the simultaneous mapping of SI and SII with higher spatial resolution (1.5 mm isotropic) than has previously been achieved. Even at a spatial resolution of 1.5 mm, the representation of individual fingers within SII cannot be resolved. However clear separation of body areas of the face-hand-foot is revealed in SII.

References. [1] Besle *et al* J Neurophysiol 109:2293-2305,2013 [2] Sanchez-Panchuelo *et al* J Neurosci.7;32(45):15815-22, 2012 [3] Ruben *et al* Cereb Cortex (2001) 11(5) 463-473[4] Huang *et al* Journal of Neuroscience Methods 169 (2008) 76-83.