Mapping human somatosensory cortex with fMRI at 7 T: travelling wave and event-related paradigms

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Introduction

Functional MRI can be used to reveal the topographic organization of sensory cortical areas (c.f. 1-3). Here, we took advantage of the increased BOLD contrast to noise ratio at 7T to measure the topographic representation of the digits in somatosensory cortex with a travelling wave paradigm, and to characterise the temporal and spatial properties of responses to vibrotactile digit stimulation with an event-related design, at 1mm isotropic resolution.

Methods

Scanning was performed on a 7T Philips Achieva on 4 subjects in two scanning sessions; one in which we used an event-related design to characterize the haemodynamic response to digit stimulation, and one in which somatotopic mapping was performed to find the topographic representation of the individual digits using a travelling wave paradigm (5). The tactile stimulus was delivered to the digit tips of the left hand using 5 independent piezoelectric devices each vibrating at a frequency of 30 Hz. For the event related paradigm all digits were simultaneoulsy stimulated for an ON period of 3 s with random inter-stimulus intervals of 18, 19 or 20 s. Functional scans consisted of 12 trials (228 s) and were repeated three times. In the traveling wave paradigm the stimulus was applied sequentially to each digit for 3 s, with an off period of 1.8 s between stimulation of different digits, resulting in a wave of activity travelling across cortical regions containing a somatotopic map of the hand. Each functional scan (24s cycle, 10 repeats; total time 240s) was repeated three times for forward ordering (thumb to little finger) and reverse ordering (little finger to thumb). 22 axial slices at 1mm isotropic resolution were acquired using GE-EPI (TR= 2.4s,TE =25ms, FOV=192x72mm^2). Outer volume suppression was used to prevent fold-over in the (L-R) phase-encode direction. Field maps and T_1-weighted MPRAGE image data were acquired at the end of each session with the same resolution and slice prescription as the EPI data to allow subsequent distortion correction and registration of the fMRI data to a reference volume. fMRI data from the event related design were analyzed by stimulus-locking the event-related responses at each voxel (4). An estimated timecourse of the the concatenated individual scans was generated by multiplying the estimated haemodynamic response with the stimulus convolution matrices. Statistical activation maps were computed from the amount of variance in the original fMRI time course that is accounted for by the estimate, r^2 = 1-variance(residual)/variance(original), where the residual was the difference between the estimated and original timecourses. Fourier analysis (5) of the travelling wave data was used in a voxel-wise calculation of the coherence and the phase of the best fitting sinusoid to the time series at the stimulus repetition frequency (0.042 Hz). The phase of the response corresponds to the delay with respect to the onset of the stimulus cycle, and therefore the spatial location of the stimulus (which digit) on the hand. All data were transformed onto flattened representations of the cortex using custom software (6).

Results and Discussion

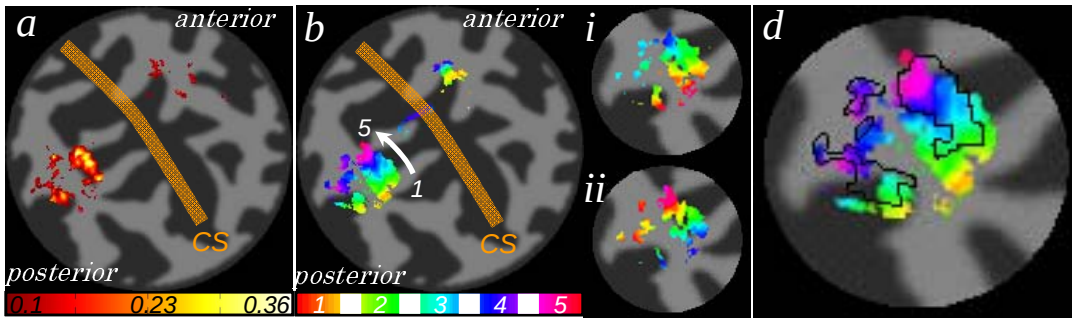

Figure 1: Flattened representations of the cortex showing (a) activation map for the event-related paradigm (threshold r^2>0.1) and (b) the average of the (i) forward and time-reversed (ii) reverse travelling wave thresholded phase maps: The colour bar indicates the phase value corresponding to digits. (Colours in (i) and (ii) are different) (d) Zoomed image (b) with the black line indicating the extent of the event related activation map at a threshold r^2>0.1.

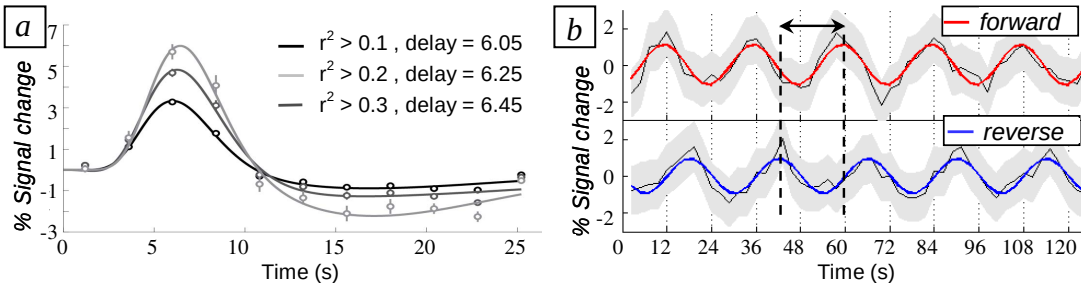

Figure 2: **(a)** Haemodynanmic response time courses from the event related paradigm for an ROI spanning all digits. Data (symbols) and fitted hrf (solid line) are shown at three different r^2 thresholds. (b) Time series (5 cycles) from digit 2 region for the forward and reverse (time-reversed) travelling wave. Red and blue lines, sinusoidal fits. Arrow marks the delay time (12 sec).

Similar activation patterns were found in the primary somatosensory cortex for both the travelling and event-related paradigms. Figure 1 shows the flattened representation of the cortex with functional data overlaid. The phase maps of the BOLD response from the travelling wave paradigm reveal an orderly pattern of activation, which is reversed when the order of digit stimulation is reversed. Taking the average (b) of the forward (i) and time-reversed reverse (ii) travelling wave data cancels the haemodynamic delay and therefore directly shows the mapping of digits 1-5 with increasing phase. (Colour bar shows mapping of the BOLD response phase to the identity of digit stimulated.) The extent of the event related map (a) for a threshold r^2>0.1 is shown (d) superimposed on the travelling wave map. A region of interest (ROI) corresponding to the phase map shown in (d) - extending through the whole cortical depth was used for comparison with the event related paradigm. This ROI (covering all digits) extends over 863 mm^3 and the intersection with the event related map has dimensions 326 mm^3 (r^2 > 0.1) 96 mm^3 (r^2 > 0.2) and 34 mm^3 (r^2 > 0.3), respectively. The mean time course of event related data extracted from this overlapping ROI is shown in Fig. 2a (symbols) for the given thresholds. The solid lines represent the corresponding fits to the haemodynamic response function (Glover, 1999). The estimated haemodynamic delay is only slightly affected by choice of thresholds. Here, we restricted the ROI to appropriate phase values to look at responses for each individual digit. The estimated haemodynamic delay does not vary substantially across digits (namely 6.3, 6.35, 6.05, 6.0 and 5.5 s from digit 1 to 5 respectively for r^2 > 0.1), and slight changes were found with cortical depth (delays appearing larger in grey matter voxels closer to the CSF than white matter boundary). The estimated haemodynamic delay from the travelling wave paradigm (Figure 2 b) was found to be in good agreement with the delay obtained from the event-related paradigm. The results indicate that high resolution fMRI at 7 T using a travelling wave paradigm provides a robust and efficient approach to detailed somatotopic mapping.

References

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