

High-Density Optical Mapping of the Human Somatosensory Cortex

Christoph H. Schmitz^{1,2}, Stefan P. Koch¹, Jan Mehnert^{1,3}, Susanne Holtze¹, Christina Habermehl¹, Arno Villringer^{1,3,4,5}, Helmuth Obrig^{1,3,4,5}

¹Berlin Neuroimaging Center, Charité University Hospital, Dept. of Neurology, Berlin, Germany, ²NIRx Medizintechnik GmbH, Berlin, Germany, ³Max Planck Institute for Cognitive and Brain Sciences, Leipzig, Germany, ⁴University Hospital, Day Care Clinic for Cognitive Neurology, Leipzig, Germany, ⁵Berlin School of Mind and Brain, Berlin, Germany

Introduction

Diffuse optical imaging (DOI) assesses the vascular-metabolic response by detecting changes in cortical hemodynamics. DOI is non-invasive and requires no exposure to radiation, magnetic fields or contrast agents. It is portable and allows a flexible handling in a clinical diagnostic, prognostic and rehabilitative environment.

While limited spatial resolution is considered the major methodological shortcoming it has been shown recently that retinotopic activations to eccentric stimuli can be differentiated in human visual cortex [1]. Here we investigate whether high resolution DOI is applicable to somatotopic representations and whether somatosensory areas can be functionally differentiated from the precentral motor representations.

Methods

Stimulation Procedure:

The 1st finger and the 5th finger of the left hand were vibro-tactily stimulated (10 blocks, pseudo-random stimulus order, stimulus duration 4 s, separated by baseline periods of 16 s – 24 s).

Prior to vibro-tactile stimulation, each subject performed a self-paced finger tapping of the left hand (10 repetitions, same block design).

Imaging Setup:

30 optical fibers were arranged over the right peri-central area in a rectangular grid. 900 (30 sources x 30 detectors) simultaneous optical data channels at a rate of 1,9 Hz using the DYNOT 232 optical tomography imager (NIRx Medical Technologies, NY, USA) were acquired.

Anatomical MRI scans were recorded for all subjects with fiducial markers placed at the corner positions of the optical fiber array.

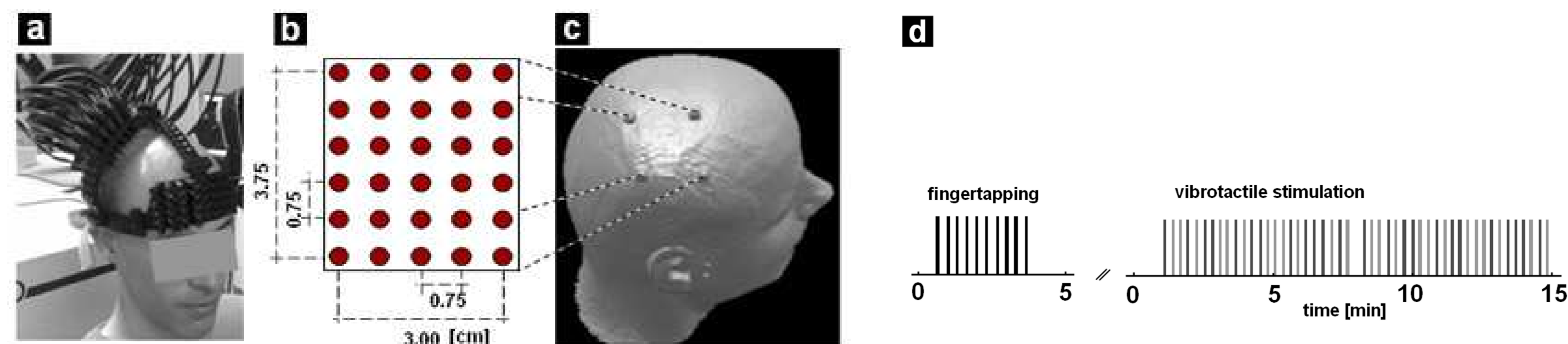


Figure 1 Experimental design. (a) Subjects wore an open scaffolding fiber optic holder. Optical fibers were individually spring loaded to maintain a mild constant pressure onto the skin to provide stable optical contact. (b) The optical probes form a rectangular array of 30 fibers with inter-optode distance of ~0.75cm. (c) After NIRS acquisition, subjects received an anatomical MR scan with fiducial marks positioned at the corner of the probe array. (d) Subjects underwent two separate sessions, a finger tapping task and vibrotactile stimulation.

Image Reconstruction:

Volumetric image time series of oxy- and de-oxy-hemoglobin concentration changes were reconstructed using the approach described in [2]. The reconstruction algorithm employs the relative difference-method for inverting the image operator, which is obtained from finite-element-method (FEM) solving of the diffusion equation on an anatomical head model.

Mapping:

MR images were segmented using SPM8 (The Wellcome Trust Centre for Neuroimaging at the University College London, UK) to obtain the gray matter topography and corresponding fiducial marker positions.

A general linear model (GLM) was applied to the optical data and the result volume was subdivided into concentric shells parallel to the optical head model surface. Extracerebral layers and deep brain structures were excluded and the optical data from the remaining layer were integrated (approx. 10-15 mm below the model head surface). The resulting image maps were then projected onto the anatomical data.

Results

GLM-based analysis revealed a functional activation during both finger tapping and vibrotactile stimulation.

The tapping response is located anterior to the central gyrus, both somatosensory responses are located posterior to the central gyrus, with the 1st finger response positioned inferior to the 5th finger activation. The actual distance between the three activated brain areas (10 mm) allows an estimation of our optical image resolution.

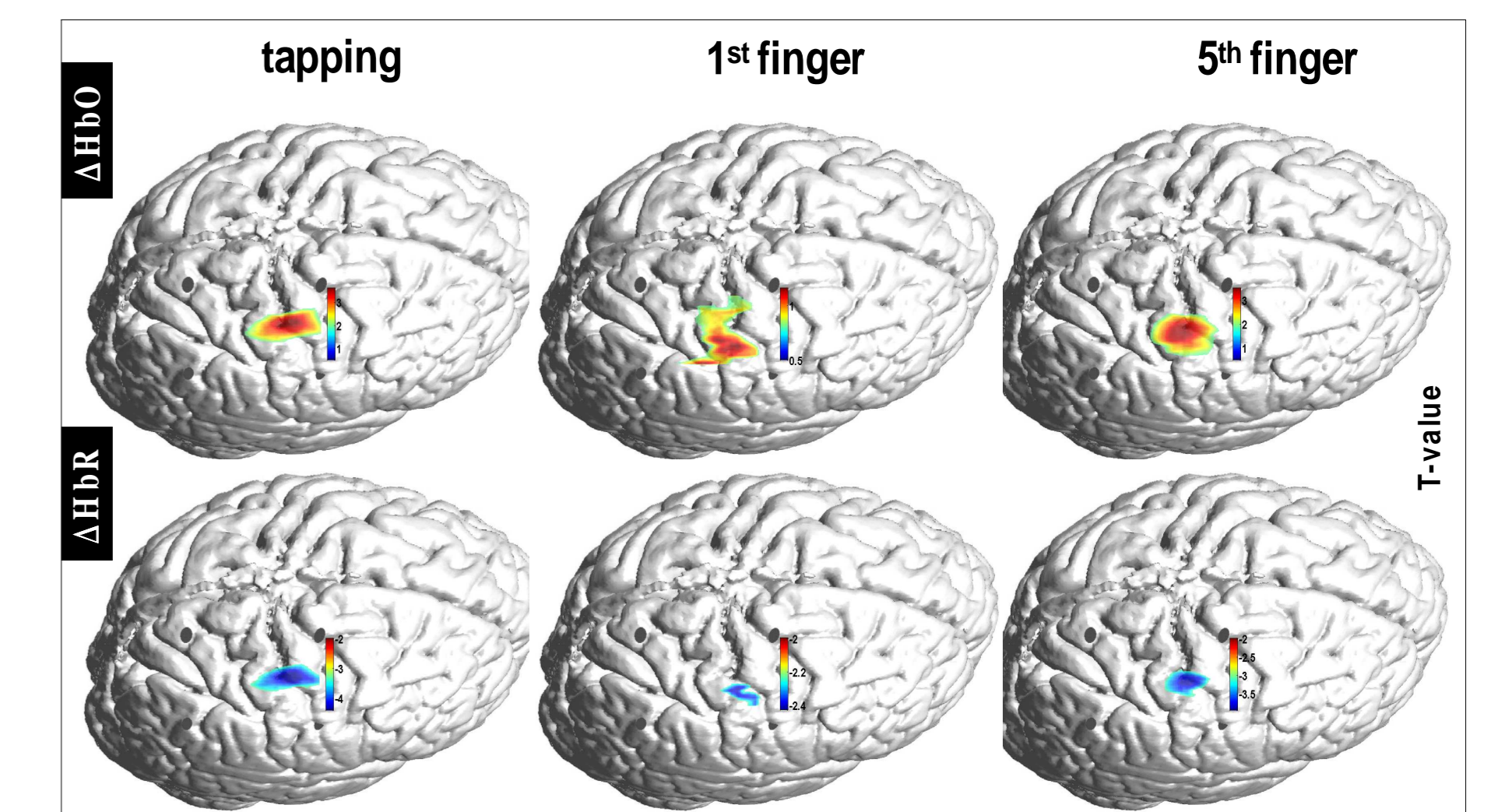
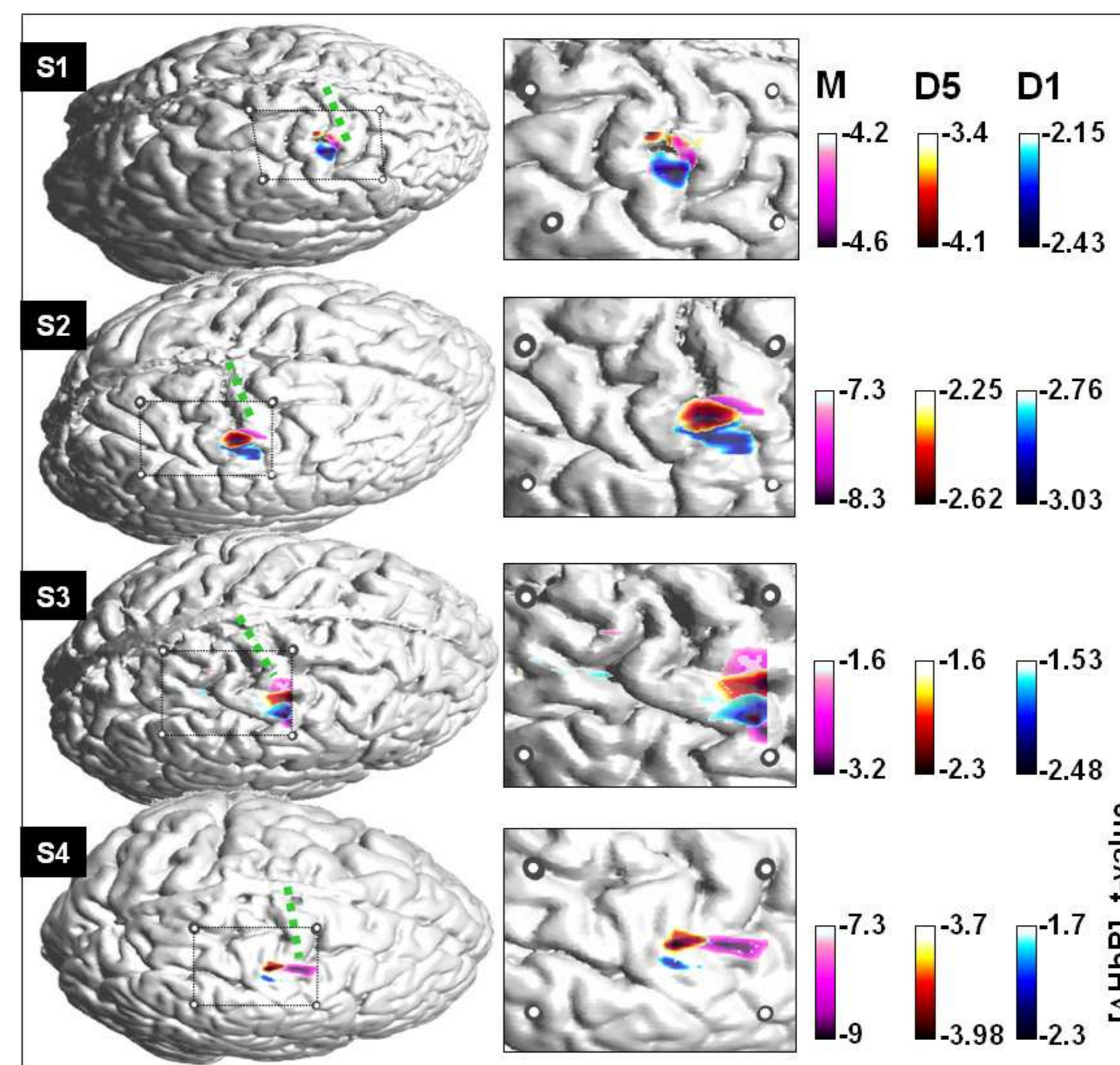


Figure 3 Activation maps for three conditions and two Hb states overlaid on cortical anatomy. Plotted are the t-values obtained from the GLM calculation, which were consistently thresholded within each Hb state (HbO: $t > 0.5$; HbR: $t > -2.0$).

Figure 2 Activation maps for finger tapping and vibrotactile finger stimulation. First column: individual cortical anatomy of the 4 subjects (S1-S4). Circles represent the positions of the fiducial marks. These allow locating the cortical area covered by the optical array. The array covers the pre- and postcentral gyrus. Precentral gyrus is denoted with a green dotted line. HbR T-maps for finger tapping (pink) and vibrotactile stimulation of 1st (blue) and 5th (red) finger, respectively, were superimposed on the anatomical image. Middle column: Magnified section of the probe array with underlying anatomical structures and thresholded T-values.

Conclusions

Our results show that diffuse-optical high-density imaging is able to localize and discern somatotopic activation to vibrotactile stimulation of different fingers. As expected by homuncular organisation of the somatosensory cortex the hemodynamic response to vibrotactile stimulation of the 1st finger was localized more inferior compared to the 5th finger. Both were detected posterior to motor activation. Mapping onto the individual's anatomy indicates pre-central motor activity and post-central somatosensory responses. These findings are in good agreement with fMRI studies that have investigated the human somatosensory system [3-5] and prove that functional optical techniques can yield high-resolution maps of functional cortical anatomy. We estimate the achievable separation of functional activation of our technique to be better than 10 mm.

References

- [1] Zeff, B.W., White, B.R., Dehghani, H., Schlaggar, B.L. & Culver, J.P. (2007), 'Retinotopic mapping of adult human visual cortex with high-density diffuse optical tomography', Proc Natl Acad Sci, vol. 104, no. 29, pp. 12169-74.
- [2] R.L. Barbour, H.L. Graber, Y. Pei, S. Zhong, and C.H. Schmitz, "Optical tomographic imaging of dynamic features of dense-scattering media," J. Optical Society of America A, Vol. 18, pp. 3018-3036 (2001).
- [3] Kurth, R., Villringer, K., Mackert, B.M., Schwemann, J., Braun, J., Curio, G., Villringer, A. & Wolf, K.J. (1998), 'fMRI assessment of somatotopy in human Brodmann area 3b by electrical finger stimulation', Neuroreport, vol. 9, no. 2, pp. 207-12.
- [4] Kurth, R., Villringer, K., Curio, G., Wolf, K.J., Krause, T., Repenthin, J., Schwemann, J., Deuchert, M. & Villringer A. (2000), 'fMRI shows multiple somatotopic digit representations in human primary somatosensory cortex', Neuroreport, vol. 11, no. 7, pp. 1487-91.
- [5] Ruben, J., Schwemann, J., Deuchert, M., Meyer, R., Krause, T., Curio, G., Villringer, K., Kurth, R. & Villringer A. (2001), 'Somatotopic organization of human secondary somatosensory cortex', Cereb Cortex, vol. 11, no. 5, pp. 463-73.1