High-resolution imaging of fast neural activity in the brain with Electrical Impedance Tomography

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Abstract: We present the first EIT images of evoked physiological activity in the primary somatosensory cortex (S1) obtained with intracranial planar electrode array. Images were validated using intrinsic signal optical imaging (ISOI) and current source-sink density analysis (CSDA). Detailed high-resolution spatiotemporal connectivity of the brain cortex was reconstructed with ≤200µm and ≤2ms.

1 Introduction

There is great interest in imaging functional connectivity in the brain using methods such as functional MRI and optical imaging, but no technique currently exists that could image neural activity over milliseconds throughout the whole brain. Electrical impedance tomography has the potential to image neural activity throughout the brain by recording impedance decreases due to the opening of ion channels during neuronal depolarization [2]

2 Methods

EIT images of evoked physiological activity in the cerebral cortex were reconstructed using the data collected with a 30-electrode epicortical planar array, 7x5mm, placed over primary somatosensory cortex (S1); activity was elicited by mechanical whisker stimulation in the anaesthetised rat.

ISOI was recorded together with simultaneous local field potentials, and further CSDA analysis were undertaken and directly compared with EIT images.

Functional connectivity was then extracted from impedance images using dynamic analysis, and connectivity maps in the whisker barrel cortex were computed for two separate whisker groups.

3 Results

Impedance images showed somatotopically separate activity, which was validated with intrinsic optical imaging. Simultaneous electrophysiological recordings revealed correlation between EIT and current source-sink density analysis for activity onset time (r=0.6, P<0.001), peak amplitude (r=0.9, P<0.001), and depth of activity onset (815±80 um deep for both methods). Functional connectivity was extracted from impedance images using dynamic analysis, revealing the depth of largest lateral spread at 450±40 um.

The trajectory of neural activity, imaged throughout S1 with a resolution of ≤200µm and ≤2ms, entered at layer IV and passed to extragranular layers over ~3 ms; the greatest lateral spread, up to 1.5 mm, occurred in supragranular layers, predominantly along barrel rows (figure 1).

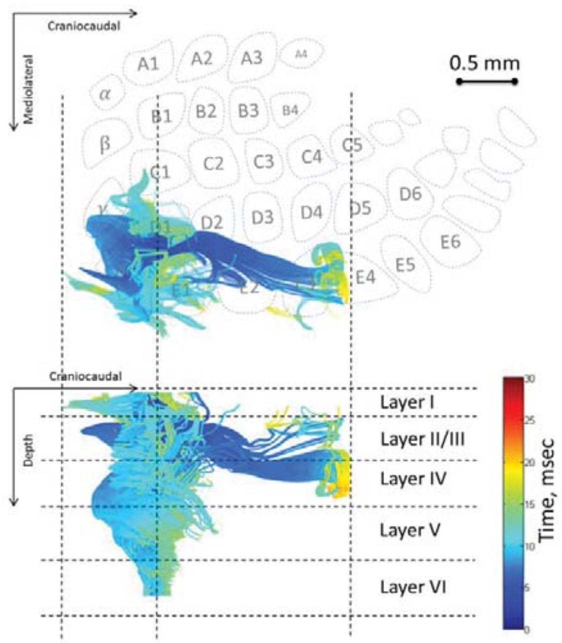

Figure 1: Functional connectivity in the somatosensory cortex of the rat in response to mechanical stimulation of a group of four whiskers ($\gamma, \delta, E1,$ and $D1$). Activity is shown in two isometric views. The top view, superimposed with the map of whisker barrel cortex (top figure), shows lateral propagation of activity to adjacent whisker barrels along the rows. The side view (bottom figure) displays the interlaminar propagation across layers: activity comes in the middle of layer IV, propagates into supra- and infra-granular layers within the stimulated barrels, and then spreads to adjacent whisker barrels predominantly through layers II/III. Timing of activation over milliseconds is colour-coded.

4 Conclusions

Our results demonstrate that EIT can image neural activity throughout the mammalian cerebral cortex with reduced invasiveness, greater resolution and imaging volume (70 mm^3) than other methods. Modelling indicates similar resolutions are feasible throughout the entire brain so that this technique, uniquely, has the potential to image functional connectivity of cortical and subcortical structures.

References

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