System for Integrated Neural Imaging, Recording and Stimulation

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Introduction: Modern neurotechnologies have enabled recording and stimulating local or distributed neural activity, as well as imaging the whole-brain functional and structural patterns. However, these tools are currently being used separately along parallel research tracks. Further advancement in brain science calls for innovative ideas to establish a new system that allows for simultaneous acquisition and joint analysis of neural imaging, recording and stimulation for applications in both humans and animal models. Here we discuss our ongoing research in designing new instrumentation and developing new analysis methods to integrate high-resolution structural magnetic resonance imaging (MRI), diffusion MRI tractography, functional MRI and electroencephalography (EEG).

Materials and Methods: Preliminary studies were done on the human brain. For individual brains, the anatomy was captured through the combined use of susceptibility-related magnitude and phase images and diffusion-weighted images with high spatial and angular resolution, respectively; the functional organization was revealed through the integration of simultaneously acquired functional MRI and EEG when subjects were in the resting state (i.e. not engaged in any overt task). Both structural and functional information was combined to build a comprehensive brain connectome that not only depicted detailed connections among anatomically specific brain regions but also assigned to each region and each connection unique "spectral signatures" indicating their differential involvement in network activities over a variety of temporal scales.

Results and Discussion: Fig. 1 shows some example brain images that depict the anatomy, axonal pathways, spatial activity pattern and spectrally informed cortical parcellation. Fig. 2 shows example connectional diagrams for which structural MRI defined nodes, diffusion MRI identified connections, functional MRI measured the connectional strength and EEG provided spectral signatures to render colors. Collectively, these results demonstrate a proof of concept for a promising research direction of integrated imaging and recording for non-invasively mapping the brain's structural and functional organization.

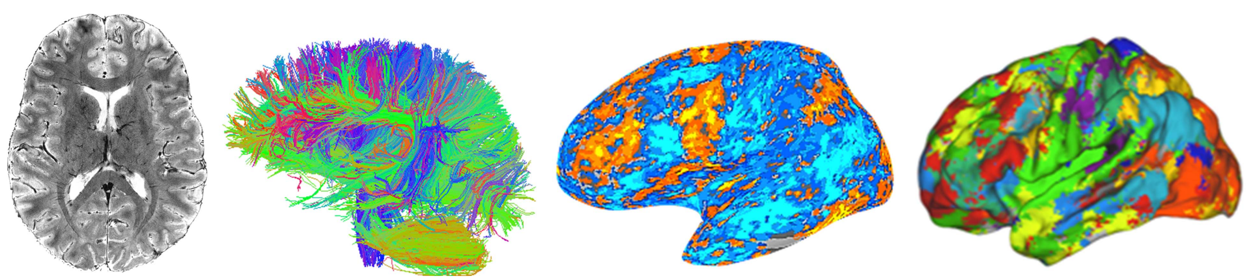

Figure 1. From left to right are T2*-weighted high-resolution structural MRI, diffusion tractography, instantaneous resting state fMRI activity and fMRI-EEG informed cortical parcellation of spectral signatures of neural activity.

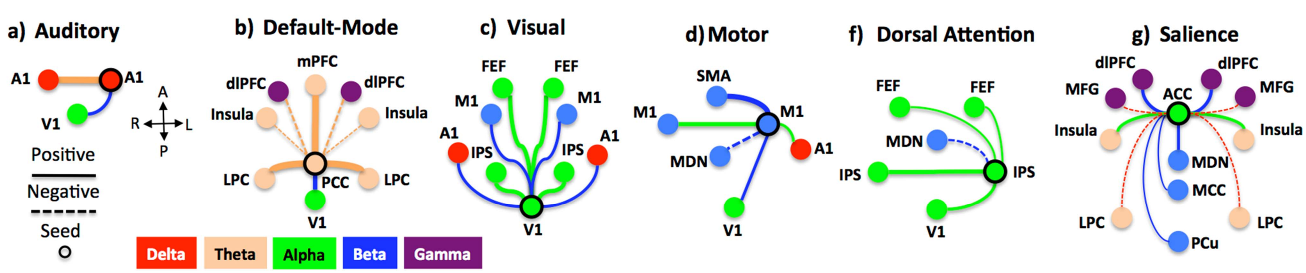

Figure 2 Spectrally color-coded functional connectivity for auditory, default-mode, visual, motor, dorsal attention and salience networks. Colors represent different frequency bands that contribute most to the activity at each region (solid circle) and the interaction between regions (solid or dashed line for positive or negative connectivity). Line thickness represents the connectivity strength.