Delineation of eloquent cortex via resting state functional connectivity as measured by functional magnetic resonance imaging and the electrocorticogram

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Introduction

Question

Is it possible to delineate the boundaries of functionally distinct cortical areas simply using fluctuations in the activity of the resting brain using electrocorticography (ECoG) or functional magnetic resonance imaging (fMRI)?

Background

When evaluating a patient for neurosurgery it is critical to identify areas necessary for one cognitive functions such as language that must be preserved. The clinical “gold standard” for identifying functional areas is direct cortical electrical stimulation (DCES). DCES is an effective but invasive and time-consuming procedure that requires optimal cooperation from the patient and has a risk of triggering seizures. A possible alternative in non-invasive and time-consuming procedure that requires optimal cooperation from the patient and has a risk of triggering seizures. A possible alternative to direct cortical stimulation is to group areas according to “functional connectivity” (FC), which is the degree to which the activity in one of the two areas provides information about activity in the other. ECoG and fMRI are two widely used techniques for detecting functional connectivity. Previous work using ECoG (No et al., 2013) describes the FC of a region, but their results were confounded by distance, which is strongly negatively correlated with FC. Here we test the utility of ECoG and fMRI FC for delineating functional boundaries while controlling for distance.

Methods

Participants

*Participates with drug resistant epilepsy undergoing evaluation for epilepsy surgery

DCES Data

Pairs of neighboring electrodes stimulated using standard clinical parameters and tasks (DCES) were grouped into distinct categories such as word generator, visual fixation, or any language, clear, and ambiguous. “One” indicates that no function was detected by stimulation.

Resting State ECoG Data

- Assesses how the participant was aware but insensible with eyes closed (0-7 min)
- Tapped at 50 Hz for 10 min and referenced to an electrode screwed into the skull. Offline re-reference the bipolar pair.
- High-gamma band power (HGBP) was extracted using a 100 ms moving window, a discrete Fourier transform, and two Slepian tapers. Power from 40-200 Hz was log transformed and averaged across each window (spurious frequency from 60 Hz line noise).

Resting State fMRI Data

- Assessed how the participant was aware but insensible with eyes closed (0-7 min)
- One or two 200 s stimulus sequences: visual stimulation (stimulus on), visual stimulation (stimulus off), visual stimulation (stimulus on), visual stimulation (stimulus off), visual stimulation (stimulus on).
- T2* GE EPI, 3D Echo Planar Imaging (EPI), TR/TE=3,000/20 ms, flip angle=77, voxel size=3x3x3 mm, matrix size=64x64x48, 1 64 slices, 48-60 slices, averaging 46 slices.
- Motion BOLD (t) and mean of electrode location (BOLD signal for each electrode). Mean T1-T2* of the FC matrix and mean of electrode location (BOLD signal for each electrode).

Clustering

- Average and single linkage agglomerative clustering was used to group electrodes pairs according to either functional connectivity or the Euclidean distance between electrodes. The quality of the clustering was validated using mutual information (MI). MI is a measure of how much uncertainty is removed if one knows which cluster a pair of electrodes belongs to. A larger MI indicates that the connectivity and cluster adjacency matrices are more similar. MI is calculated as the relative entropy between probability distributions. A value of 1 indicates that the connectivity and cluster adjacency matrices are identical.

Choosing the Number of Clusters

- The quality of the clustering solution was measured via the mutual information (MI) between the connectivity and cluster adjacency matrices. The greater the value of MI, the closer the clustering solution approaches the ideal solution in which the block structure of the two matrices are identical. Note that “ambiguous” and “clear” are not fully considered as functional categories when computing MI.

Conclusions

- Resting state ECoG HGBP functional connectivity is greater than fMRI FC and is worse than ECoG functional connectivity for delineating functional regions.