Electrophysiological Correlate of fMRI Resting-State Networks in Macaques

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Target Audience Neuroscientists, fMRI Researchers

Purpose Although resting-state fMRI signal correlation has been widely used to infer functional connectivity and network organization of the brain[1], its neural correlate remains unclear. By analyzing correlation of band-limited power (BLP), several electrophysiological studies have suggested that the fMRI correlations may have contributions from neuronal oscillations at specific frequency bands[2-4]. However, consensus about the relative importance of the different frequency band appears to be lacking[2-4], while a dominant role of individual frequencies in the fMRI correlations, seems inconsistent with the fact that regional-specific fMRI correlations persist across various brain states characterized by dramatic changes in oscillatory activity[5]. Here, we revisited this issue by analyzing large-scale electrocorticography (ECoG) data acquired under various brain conditions using a data-driven method.

Methods We recorded ECoG signals from 4 macaques using subdural electrode grids (128 channels) implanted over almost the entire left hemispheric surface (Fig 1a). The animals were studied during eyes-closed wakefulness, sleep, ketamine/medetomidine anesthesia, and propofol anesthesia. We applied a time-frequency transform to raw signal of each electrode to derive spectrograms, after which power level normalization and global mean removal were performed. The resulting spectrograms were also averaged within conventional frequency bands (i.e., δ, θ, α, β, and γ bands) to generate different BLPs. Subsequent correlation analysis was based on a data-driven method previously used for fMRI network extraction[6]. Briefly, an inter-electrode cross-correlation matrix was first calculated based either the broadband power variation or BLP at individual frequencies. K-means clustering was then applied to classify the matrix's rows/columns, which represent seed-based correlation maps, into multiple groups based on their similarity. The rows/columns were then averaged within groups to generate patterns of ECoG power co-variations.

Results Clustering analysis found 8 groups of electrodes showing strong broadband power co-variaiton over the frontal, precentral-temporal, paracentral, superior temporal, supramarginal, parietal, occipito-temporal, and occipital cortex during eyes-closed wakefulness (Fig. 1c). Conditions of the ketamine anesthesia, propofol anesthesia, and sleep all resulted in very similar correlation patterns (Fig. 1d-f), although their raw ECoG signal were very different. These patterns are strikingly similar to 8 of 11 fMRI resting-state networks (RSNs) in anesthetized macaques reported previously[7] (Fig. 1b). The same clustering analysis on different BLPs gave largely similar results independent of frequency band (Fig 2).

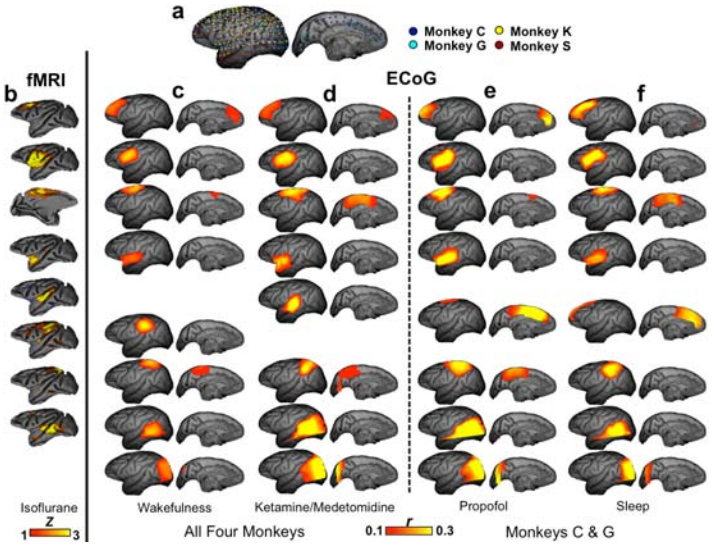

Fig. 1 A comparison between the fMRI RSNs[7] and correlation patterns of ECoG broadband power under four brain conditions.

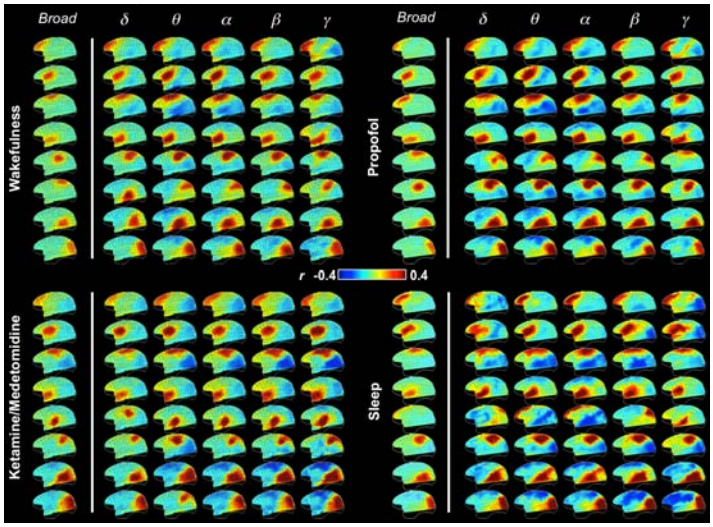

Fig. 2 Correlation patterns derived from ECoG BLPs at different frequency bands

Discussion The results confirm and extend earlier studies that found an electrophysiological correlate to fMRI signal correlation during rest.[2-4]. Interestingly, our data-driven approach found that the co-variation patterns of the electrophysiological signals are robust across various states of consciousness, despite strong changes in the raw signals and their spectral characteristics. Moreover, similar ECoG networks were found across BLP frequency bands, suggesting that neuronal activity characterized by a broadband spectral feature, rather than oscillatory activity at specific frequency bands, underlies the fMRI-derived networks.

Conclusion Spontaneous fMRI signals reflect region-specific correlations in broadband power of electrophysiological signals, which are robust against brain state transition characterized by significant electrophysiological and behavioral changes.

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