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Python Workshop Course - Final Project

Introduction

This project aims to replicate findings from the study titled *"High gamma activity distinguishes frontal cognitive control regions from adjacent cortical networks"* published in Cortex (2023). This important research investigates the distinct roles of various oscillatory activities, including high gamma, low gamma, and beta activities, within the lateral frontal cortex during cognitive tasks that necessitate attentional switching. Utilizing electrocorticography (ECoG), the study explores how these activities differentiate frontal cognitive control regions from neighboring cortical networks during verbal tasks requiring attentional switching.

Our replication focuses on comparing the oscillatory frequency changes observed while participants engage in 2 distinct tasks: a simple counting (1-20) and a task that alternates between counting and reciting the alphabet (1, a, 2, b, etc., up to 20). The goal is to reaffirm the conclusions of the original study regarding the functional distinctions within the lateral frontal cortex facilitated by various gamma and beta activities.

Methods

Complete data were available for 13 patients, with a total of 59 electrodes included in the analysis. The recorded data previously underwent signal preprocessing, including re-referencing, down-sampling, and noise filtering. The data were then bandpass filtered into 6 frequency bands (delta: 1-4Hz theta: 4-8Hz, alpha: 8-12Hz, beta: 12-30Hz, low gamma: 30-70 Hz, high gamma (HG): 70-250Hz), and instantaneous power in each band was computed.

According to the paper's methods section, we trimmed 1sec from each end of task trials to remove periods affected by reaction time, since onset and offset markers were manually recorded. In addition, to focus the analysis on the most demanding portions of the tasks, in the hard condition trials a further 3sec from the beginning of each trial was excluded.

To quantify task-related neural activity changes across task difficulty, we computed the percentage of signal change (PSC) for the first pair of conditions (hard vs. easy, we didn't apply the analysis on easy vs. rest condition), and for each frequency band separately. This metric identified electrodes that showed power modulations in response to increased cognitive demand.

To evaluate the statistical significance of PSC for each electrode, a permutation approach was used. Power time series from all trials in each condition were concatenated into a loop, and trial markers were randomly shifted to generate surrogate datasets while preserving trial lengths and temporal correlations. This process was repeated 10,000 times (100,000 in the original paper, but according to our supervisor it is not necessary), and produced a null distribution against which statistical significance was determined. This process lasted 3.32 hours.

Results & Discussion

Identifying significant task-related power changes

We examined the significant power modulations across various frequency bands (Figure 1a). These findings are directly compared with the original findings presented in Figure 2b of the referenced paper. While our results largely align with those from the original study for most frequency bands, discrepancies were noted particularly in the decrease in high gamma activity (5.1% vs 1.7%) and the increase in low gamma activity (22% vs 20.3%). These differences are attributed primarily to the rotation examination method employed in our study, which introduces randomness in data analysis and can influence the distribution and calculation of p-values. Such methodological variations can lead to slight but significant discrepancies in statistical outcomes, especially in studies where the orientation and order of data processing are crucial for interpreting neural activity.

Our results:

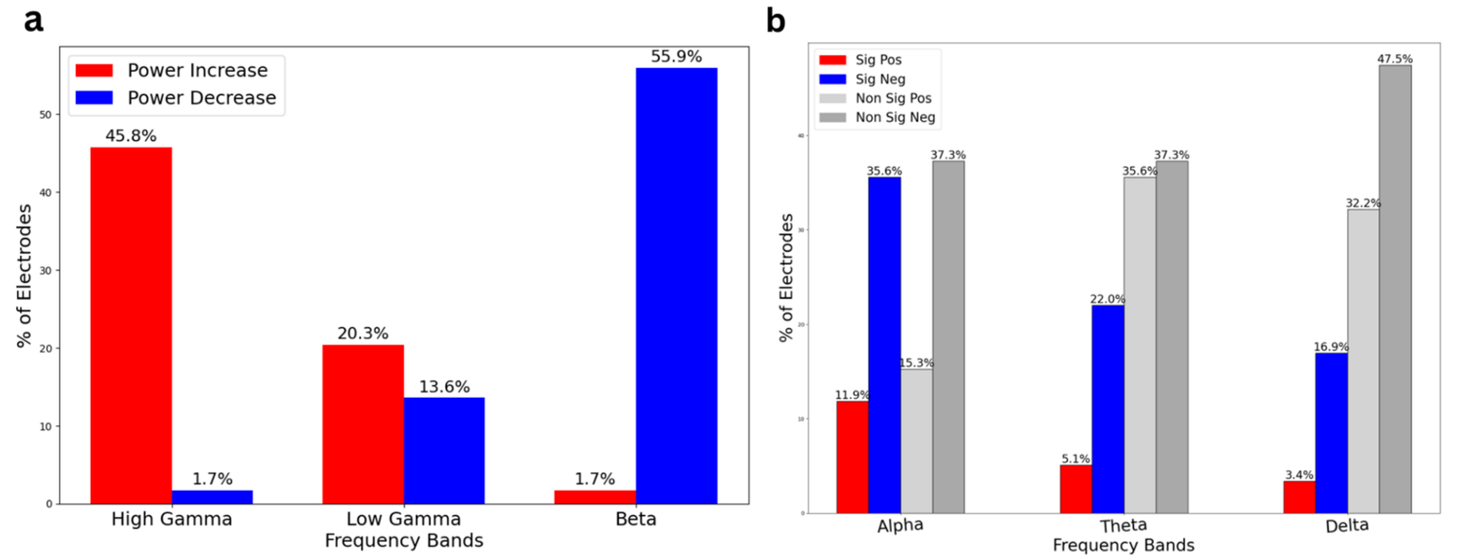


Fig 1 - (a) Proportion of electrodes (out of a total of 59) showing significant power modulations for each of the frequency bands. (b) Proportion of electrodes showing significant and non significant power modulations for the remaining 3 frequency bands: Alpha, Delta, Theta

Results from the paper:

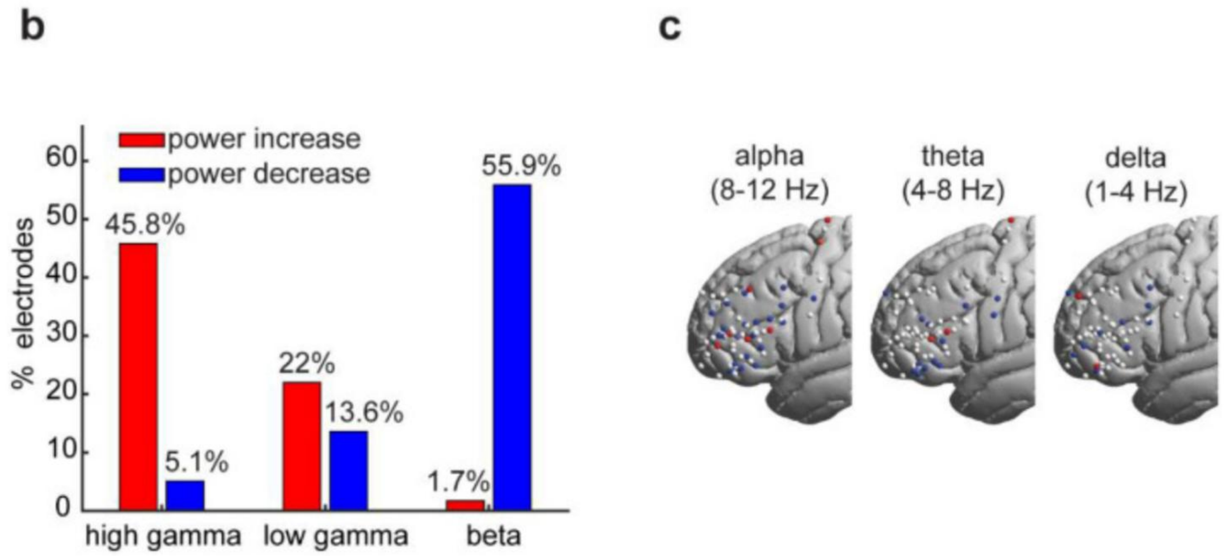


Fig. 2. Switch > count spectral power modulations. (b) Proportion of electrodes (out of a total of 59) showing significant power modulations for each of the frequency bands. (c) Proportion of electrodes showing significant and non significant power modulations for the remaining 3 frequency bands: Alpha, Delta, Theta

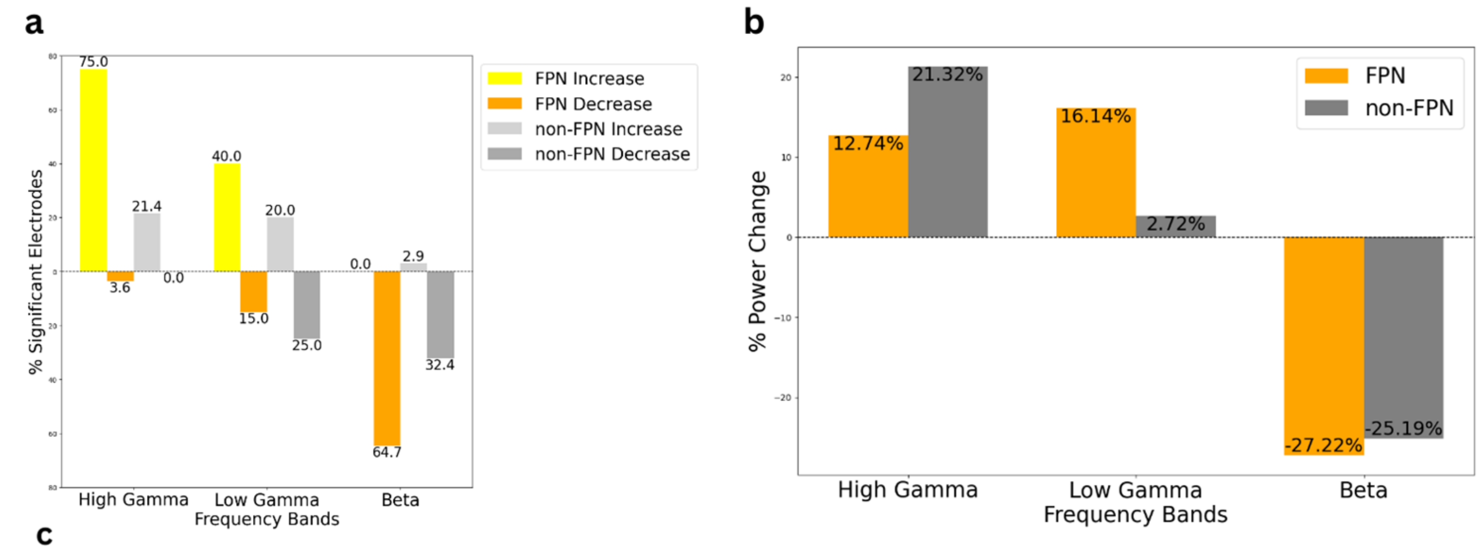
To further explore potential variabilities, our study presented another bar graph depicting the proportion of electrodes showing significant and non-significant power modulations across the Alpha, Delta, and Theta frequency bands (Fig.1b), which were not explicitly quantified in the original publication. Given the discrepancies noted in High Gamma, Low Gamma, and Beta activities, it is reasonable to speculate that similar variations might exist for these additional frequency bands. Although the original paper's results provide only a visual representation of electrode placements and power modulations (Fig. 2c), comparing it with our results reveals a pattern consistent with our findings despite not providing exact values. In these frequency bands (Alpha, Delta, and Theta), the majority of electrodes demonstrated non-significant changes (p-value>0.05), with a lesser but still present proportion showing significant increases and decreases (p-value<0.05).

Power modulations within and outside the FPN

Transitioning to a broader perspective of our findings, the next analysis was focused on the percentage of electrodes showing significant power changes within and outside the Frontoparietal Network (FPN).

The replicated results of our study (Fig. 2a) generally align with the original study's findings detailed in Figure 3c of the original paper. Although the overall trends closely match, slight variations in the percentages of power increase and decrease across different frequency bands were observed. These discrepancies are reflective of the expected outcomes from the rotation method used in our analysis.

<u>Our results:</u>



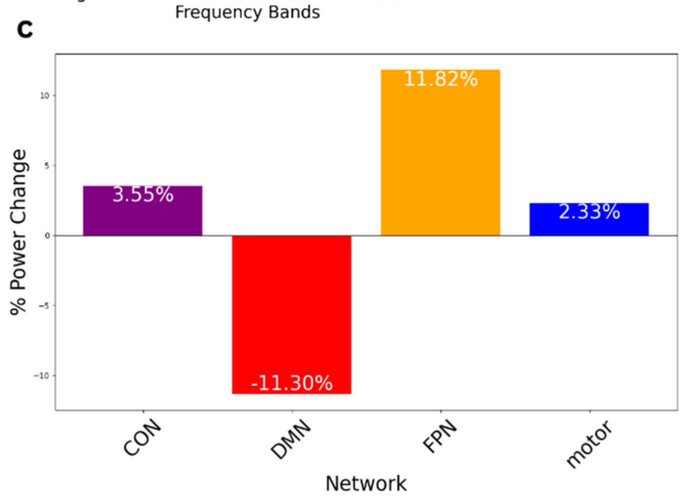
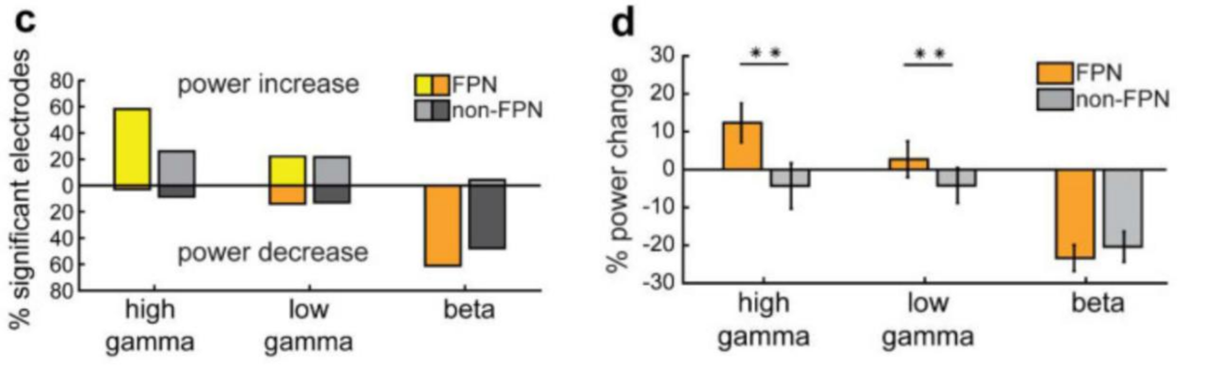


Fig 2 - (a) Percentage of electrodes showing significant power modulations out of all electrodes located within (yellow and orange) and outside (light and dark grey) the FPN. Lighter colored bars (above the zero line) show percentage of electrodes with power increases. Darker colored bars (below the zero line) show percentage of electrodes with power decreases. (b) Average power modulations of all electrodes within and outside the FPN for each frequency band for the switch > count contrast. (c) Average power modulations of all electrodes within each network for the switch > count contrast.

Results from the paper:



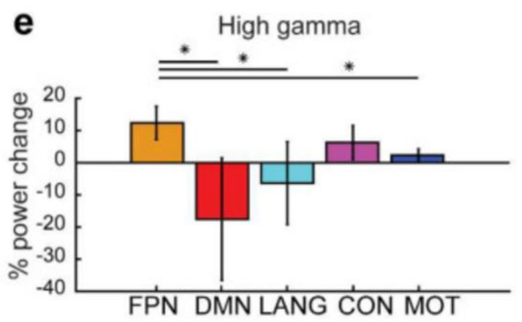


Fig. 3. (c) Percentage of electrodes showing significant power modulations out of all electrodes located within (yellow and orange) and outside (light and dark grey) the FPN. Lighter colored bars (above the zero line) show percentage of electrodes with power increases. Darker colored bars (below the zero line) show percentage of electrodes with power decreases. (d) Average power modulations of all electrodes within and outside the FPN for each frequency band for the switch > count contrast. (e) Average power modulations of all electrodes within each network for the switch > count contrast. Error bars denote SEM. ⋆⋆p = .01, ⋆p < .05 one-tailed (linear mixed effects).

In the final phase of our analysis, we aimed to replicate the linear mixed effects modeling approach described in the original study for analyzing power modulations within and outside the FPN and across various networks, as detailed in Figures 3d and 3e of the original paper. Unfortunately, replicating these models proved challenging due to the need for precise assumptions about model components and dataset completeness, which are often not fully detailed in publications. Consequently, we focused on approximating the analysis by examining the average power modulations of all significant electrodes within and outside the FPN for each frequency band and across each network during the switch > count task.

Unlike the original study, our approach did not employ mixed linear effects modeling, meaning we did not account for the dependencies between electrodes within individual subjects. This simplification allowed us to proceed with the available data but may have influenced the results by treating electrodes as independent observations rather than nested within subjects.

Unfortunately, we were unable to include the language network (LANG) in our replication due to the absence of necessary data.