Oscillations in Human Orbitofrontal Cortex During Even Chance Gambling

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***Abstract*— Evaluating value and risk as well as comparing expected and actual outcomes is the crux of decision making and reinforcement based learning. In this study, we record from stereotactic electroencephalograph depth electrodes in a human subject in numerous areas in the brain. We focus on the lateral and medial orbitofrontal cortex while they perform a gambling task involving betting on a high card. Preliminary time-frequency analysis shows modulations in the 5-15Hz band that is well synced to the different events of the task. These oscillations increase in both high betting scenarios as well as in losing scenarios though their effects cannot be decoupled. However, the activity between lateral and medial orbitofrontal cortex is a lot more homogenous than previously seen. Additionally, the timing of some of these oscillations occurs before even a response in the visual cortex. This evidence hints that these areas encode priors that influence our decision in future statistically ambiguous scenarios.**

I. Introduction

Risk assessment is a fundamental part of our lives. The brain seamlessly assesses the value and risk of different options before choosing a behavior. It then adapts future strategies based off of comparing actual and expected outcomes. This processing of risk and reward occurs across many areas in the brain including orbitofrontal cortex (OFC), ventral medial prefrontal cortex (vmPFC), and anterior cingulate cortex, among other regions[1-4]. The OFC has a broad set of functions ranging from sensory integration to reward evaluation to decision making and predictions[3-4]. In addition, the medial portion is linked with reward outcomes while the lateral portion is linked with punishments [5,6]. Although the areas involved are well understood, the specific involvement of each and how they relate to each other are not fully understood with few if any electrical recordings from human subjects.

Neural signals from these areas can be obtained in a number of different forms. The most common methods to probe the human brain include electroencephalography (EEG), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and electrocorticography (ECoG). Each have their own drawbacks. Each of these methods has at least poor spatial resolution, poor temporal resolution, or recording sites away from the neural sources [7].

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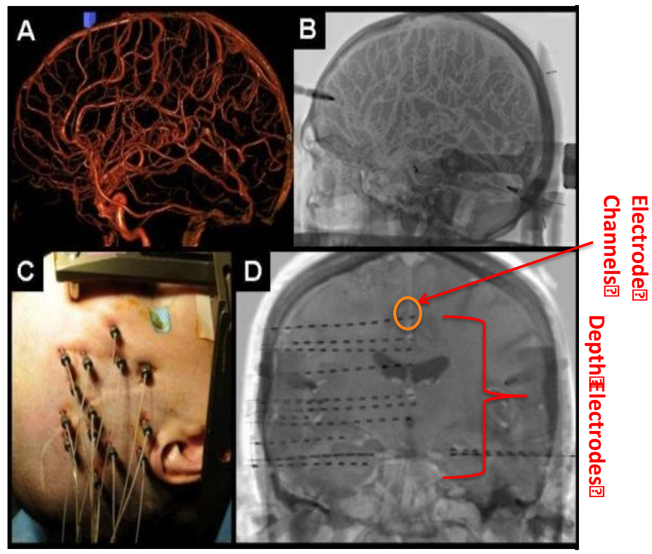

Figure 1. Placement of multiple depth electrodes using SEEG. (A) and (B) show preoperative MRI and angiograms that assist safe electrode placement during surgery. (C) shows 14 electrodes at the skin surface while (D) shows theintraoperative imaging of the electrodes within the brain.

Data for this study is collected instead using stereotactic EEG (SEEG) depth electrodes while epilepsy patients who meet specific medical criteria perform a gambling task. This approach offers millisecond temporal resolution along with thorough coverage of the brain including recording sites in shallow and deep structures that are inaccessible with traditional methods[8]. The task itself (originally designed in [9]) instructs subjects to play a game of high card against the computer and to bet fake money on having the higher card. This preliminary study focuses on the depth electrode recordings from OFC in order to analyze its function during this gambling task.

II. Methods

A. Study Subjects

One subject was recruited who has undergone SEEG depth electrode implantation for the purpose of epileptic focus localization. The patients typically have had trouble with foci localization with less invasive means, like scalp

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EEG and thus need a more invasive procedure. After the operation, a member of the research team independent of the clinical staff approached the patient to describe the research and the task. The subject enrolled voluntarily and provided informed consent under guidelines approved by the Cleveland Clinic Institutional Review Board.

B. Electrical Recordings

The SEEG depth electrode (PMT Corporation, MN, USA) implantation is performed at Cleveland Clinic using stereoscopic cerebral angiograms co-registered with three dimensional MRI scans (Fig. 1) [8]. The preoperative MRI and angiogram are used during surgery to plan out electrode insertion trajectories to avoid vascular structures to minimize the risk of a bleed. The recordings are performed on site in the Epilepsy Monitoring Unit and sampled at 2kHz through the Nihon Kohden 1200A EEG diagnostic and monitoring system (Nihon Kohden America, Foothill Ranch, CA, USA). The subject has 13 electrodes implanted each with 10 contacts. The contacts are platinum based, 2mm in length, and spaced 1.5mm apart. Five of these contacts are located in the OFC as annotated by the clinical team at Cleveland Clinic. Three of these contacts are located in the lateral portion while the other two are located in the medial portion.

C. Behavioral Task

The behavioral task is displayed to the subject through a computer monitor affixed to a mechanical rig with a moveable arm from the InMotion2 ARM Interactive Therapy System (Interactive Motion Technologies, Watertown, MA, USA) which the subject operates in order to play the game. The task is presented using Monkeylogic [10,11], an extension to Matlab (Mathworks, Natick, MA).

The task is effectively a game of high card (Fig 2). The subject first moves the cursor on screen to the center by moving the robotic arm. Once there, their card is shown. The cards throughout that trial are even and range between 2 and 10. They are also always drawn randomly with replacement. After a delay, a high bet of $20 and a low bet of $5 are shown. The subject then moves the cursor to one to signal their choice. After a random 250-500ms delay, the computer's card is shown. If the subject's card is higher, the respective bill is displayed to indicate the reward. If the card is lower, then the bill is shown with a red X to indicate loss. If the card is the same, text indicating a draw is shown.

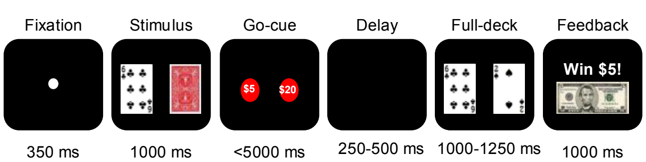

Figure 2. Time course for the gambling task. 350 ms after centering the cursor using the robotic arm, the subject is shown their card. They are then instructed to select either the $5 or $20 bet. The computer's card is revealed after a random 250-500ms delay and then the reward or penalty is shown based on the cards.

C. Data Analysis

The SEEG depth electrodes give local field potential activity. Time-frequency properties are analyzed with spectrograms generated from the Chronux toolbox for Matlab [12]. Chronux uses a multi-taper method to estimate the power spectrum of a signal based on slepian functions. A sliding window of 300ms is used with a 100ms step size. The time-bandwidth product of 2 is used allowing for 3 tapers for estimation.

The power spectrogram is generated for each trial and channel. The powers are normalized by comparing in trial power with the power during a baseline period before each trial begins. The values shown will always be in terms of percent change from the baseline activity. These then can be averaged across all trials of a specific type and about a specific event to produce a stereotyped spectrogram. This study focuses on the responses of the OFC surrounding the betting and outcome of the even chanced 6 card. The responses of the lateral and medial OFC are averaged across the electrodes that are located in their regions.

III. Results

A. Subject Performance

The subject successfully completed 162 trials of the gambling task (Fig 3). The subject plays almost optimally (in the sense of maximizing expected reward) by always betting high with an 8 or 10 card and almost always betting low with a 2 or 4 card. The only exception is a single high bet with a 4 card. For the 6 card, the subject bets high 46% of the time.

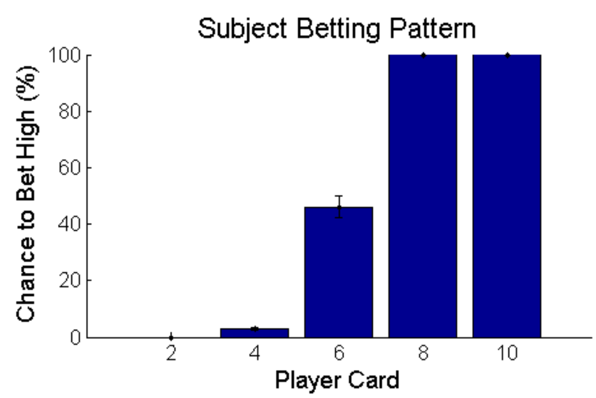

Figure 3. Subject's betting pattern. The subject played almost optimally by betting high with a high card (8,10) and betting low with a low card(2,4). The subject bet high 46% of the time with a 6 card. Error bars represent standard errors.

B. Time Frequency Analysis - Player Card

Event synced spectrograms in Figure 3 show the differing responses to being shown a 6 card sorted by whether or not the subject bet high or low. Both conditions in the medial and lateral OFC show a distinct modulation between 5 and 15 Hz. The peak in medial OFC oscillation occurs 200ms after the peak in later OFC oscillations. Additionally for both areas, the peak in trials where the subject bet low occurs

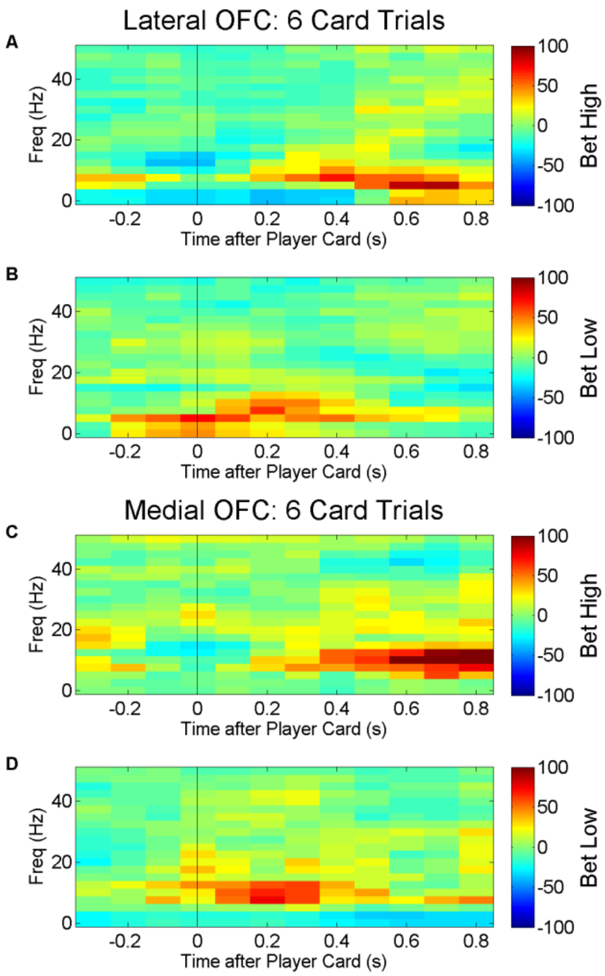

Figure 4. Spectrograms of power in orbitofrontal cortex when the player's card is revealed. (A) and (B) show lateral OFC response for high and low bets respectively while (C) and (D) show the same for medial OFC. A prominent change in 5-15Hz oscillations is present in all cases but comes much earlier when the subject ends up betting low.

500ms before the peak in trials where the subject ended up betting high. This increase in 5-15Hz oscillation even starts before the actual card is shown.

C. Time Frequency Analysis - Computer Card

In order to look at responses related to outcome evaluation, we create event synced spectrograms showing the different cases in what the patient bet and whether the patient won or lost (Fig 5,6). Draws are not included in this analysis. The same modulations in 5-15Hz oscillations can be seen starting after revelation of the computer's card. The trials where the subject had more money on the line result in a larger increase in 5-15Hz power. Additionally, the trials where the subject lost money also had a larger increase in power. In fact, the trials with both a low bet and a win had a decrease in power for both medial and lateral OFC.

Between the two regions, the timings in this case were similar though the lateral OFC tended to exhibit less power. This can be seen in the lateral OFC's drop in power being more significant than the medial OFC's in the case of winning low bet trials. Additionally, the increase in power for losing a high bet extends to higher frequencies up to 20Hz for the medial OFC.

IV. Discussion

All the spectrograms show a consistent modulation in the same 5-15Hz frequency band across all trial types as well as both lateral and medial OFC. This activity codes both information about how someone is likely to bet as well as their evaluation of the outcome. In both cases, a larger bet regardless of winning or losing money is correlated with a higher power in both areas' responses. However, this relationship cannot be separated from the correlation between power and whether the subject won or lost. For example, there is no obvious way to distinguish between the oscillations of winning a large amount or losing a small amount in these areas.

Between the medial and lateral OFC, there is little difference in their activity to distinguish between them other than their timing. Despite previous work linking medial OFC more with rewards and lateral OFC more with punishments [5,6], we see no evidence of this dichotomy here. This could mean the roles of the different areas of OFC are more homogenous than previously expected. However, one explanation is the size and proximity of the electrode contacts to cause activity from one area to bleed into recordings from another resulting in much more heavily correlated signals. Regardless, this analysis was performed on only one subject and more subjects need to be studied before drawing any concrete conclusions.

One particularly interesting finding is the early timing of the responses to the player card being shown. The window size of 300ms would explain a slip of up to 150ms, however these start as early as 200ms prior to the card being shown. Furthermore, comparing these timings to visual cortex peak response times of 300-400ms (not shown), it is obvious that these increases in power precede any visual responses. If these oscillations come before any information of the current card, this implies that they must instead encode some form of a prior, such as some history dependent information that influences the current trial's bet. This activity is thus more of a predictor of future decisions for seemingly stochastically driven choices.

V. Conclusion

This study is an initial look into depth electrode recordings in human behavioral experiments. A small subset of the trials and a small subset of the electrodes are enough to provide interesting results leaving us many avenues for future research. Future work will be focused on analyzing the gambling task as a whole as well as looking at different decision making areas and at these areas across multiple subjects. Additionally, the simultaneous nature of this setup also allows for network-based analyses to assess the different functional connections between these areas.

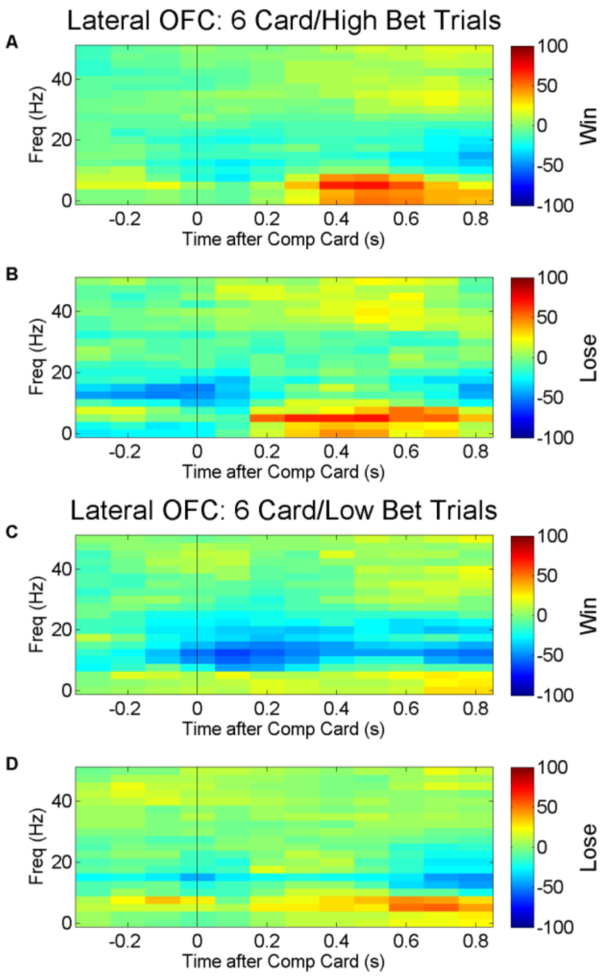

Figure 5. Spectrograms of power in lateral orbitofrontal cortex when the computer's card is revealed. (A) and (B) show the response for winning and losing a high bet respectively. (C) and (D) show the same for winning and losing a low bet. The same 5-15Hz oscillation is present. The strength varies both with winning versus losing as well as betting high versus betting low. The winning of the low bet trial even has a marked decrease in power.

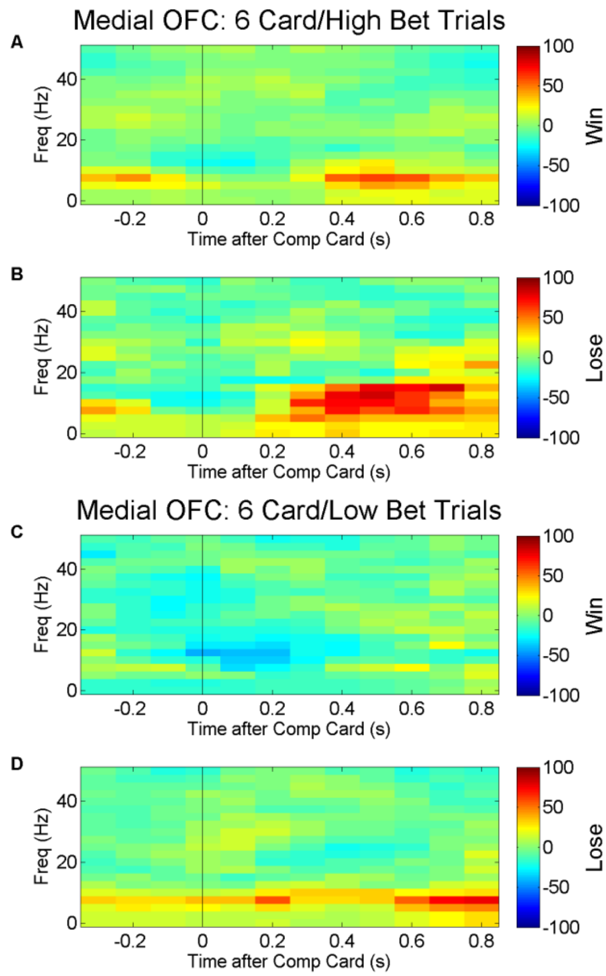

Figure 6. Spectrograms of power in medial orbitofrontal cortex when the computer's card is revealed. (A) and (B) show the response for winning and losing a high bet respectively. (C) and (D) show the same for winning and losing a low bet. The same 5-15Hz oscillation is present with some additional response up to 20Hz in the case of losing a high bet. The strength varies both with winning versus losing as well as betting high versus betting low.

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