Correlates of Attention in the Cingulate Cortex During Gambling in Humans

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***Abstract*— People make decisions multiple times on a daily basis. However, some decisions are easier to make than others and perhaps require more attention to ensure a positive outcome. During gambling, one should attempt to compute the expected rewards and risks associated with decisions. Failing to allocate attention and neural resources to estimate these values can be costly, and in some cases can lead to bankruptcy. Alpha-band (8–12 Hz) oscillatory power in the brain is thought to reflect attention, but how this influences financial decision making is not well understood. Using local field potential recordings in nine human subjects performing a gambling task, we compared alpha-band power from the cingulate cortex (CC) during trials of low and high attention. We found that alpha-band power tended to be higher during a 2 second window after a fixation cue was shown in low attention trials.**

I. INTRODUCTION

Alpha-band oscillatory power, a dominant variety of oscillation in the human brain [1], is thought to reflect the temporal structure of one of the most basic cognitive processes — attention. With a mean frequency of approximately 10 Hz, the amplitude of alpha-band oscillations has been found to be associated with suppression of activity [2]. In cases where this suppression occurs in task-irrelevant regions, the result is a focusing of attention that allows distracting stimuli to be ignored [2]. When it occurs in task-relevant regions, it can produce reduced or altered attention and performance [3].

Patients with depression and schizophrenia often suffer from attention deficits and cannot concentrate well during tasks, and the cingulate cortex (CC) is highly important in these disorders [4], [5]. Studies have reported hypo-activation in the rostral division of the anterior CC during a Stroop test, which measures distraction [6], a conflict decision making (Go/NoGo) task [7], an oddball task in which an unexpected stimulus is presented [8], and emotion recognition tasks [9]. Reduced anterior CC activity in patients with schizophrenia plays an important role in the development of deficits in different cognitive domains, such as attention, working memory, verbal production, response monitoring, and inhibition [10].

In this study, we examine the relationship between attention during decision making and alpha-band power in the cingulate cortex. We exploit a unique data set collected from medically refractory epilepsy patients being invasively monitored for surgery via stereo-electroencephalography (SEEG) [11]. SEEG provides comprehensive coverage of the brain, from shallow to deep structures, in a three-dimensional arrangement recorded over hundreds of channels with a temporal resolution of milliseconds. Using SEEG recordings in nine human subjects performing a gambling task [12]–[15], we analyzed alpha-band oscillations ($8-12$ Hz) in the CC during. We identified trials of low and high attention based on how quickly each subject moved during fixation (*i.e.*, trials where attending to the fixation cue took longer were associated with low attention and vice versa). We then compared the alpha-band power in the CC during a 2 second window after a fixation cue was shown for trials of low and high attention. We found differences in alpha-band power between low and high attention trials across the majority of subjects. Namely, the power was higher when the subject took longer to initiate their movements (and thus was presumably paying less attention).

II. METHODS

A. Subjects

Subjects were patients at the Cleveland Clinic with medically intractable epilepsy who had undergone SEEG recordings in order to localize the seizure focus. In this study, aside from the behavioral experiments, no alterations were made to the patient's clinical care, including the placement of the electrodes [11]. Subjects enrolled voluntarily and gave informed consent under criterion approved by the Cleveland Clinic Institutional Review Board. A total of nine subjects

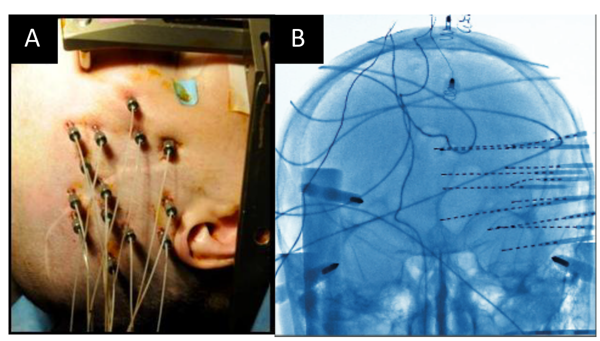

Fig. 1. Imaging fusion and placement of multiple electrodes using the SEEG method. **A:** Photograph showing 14 electrodes at the skin surface. **B:** Fluoroscopy image of an SEEG-implanted subject (coronal view with eyes facing forward). Note the precise parallel placement, with tips terminating at the midline or dural surface.

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Table 1. Subject Information

Patient ID	Sex	Age	# Contacts in cingulate cortex
P6	M	26	2 (L Post)
P7	F	41	3 (R Post)
P10	F	31	1 (R Post)
P12	F	53	5 (R Ant), 3 (R Post)
P13	F	60	1 (L Post), 2 (R Post)
P15	F	36	3 (R Ant), 2 (L Mid), 3 (R Post)
P16	F	23	2 (L Post), 2 (R Post)
P17	F	32	2 (L Post)
P21	M	28	3 (L Ant), 3 (L Post)
Totals			**37**

volunteered to perform the task. Details on contact locations within the CC of these nine patients are noted in Table 1.

B. Neural recordings - Stereoelectroencephalography

The advantage of using SEEG methodology is its capability in accessing large-scale networks by providing precise human brain data, from cortical to sub-cortical areas, in a three-dimensional fashion. In routine placement of depth electrodes, burr-holes that are each 15 mm in diameter are required for safe visualization of cortical vessels, and therefore only a small number of electrodes are placed. SEEG placement, however, uses several small drill holes (1.8 mm in diameter), allowing many electrodes to be inserted.

Since direct visualization of the cortical surface is not possible with small drills (Fig. 1), the SEEG technique may require detailed pre-procedural vascular mapping using pre-operative imaging with magnetic resonance angiography (MRA) and cerebral angiography. The mapping procedure is performed under fluoroscopy using general anesthesia. The number and location of implanted electrodes are pre-operatively planned based on a hypothesis of the location of the epileptogenic zone (EZ). This hypothesis is formulated in accordance with non-invasive pre-implantation data such as seizure semiology, ictal, and inter-ictal scalp EEG, MRI images, PET and ictal single-photon emission computed tomography (SPECT) scans. Thus, the implantation strategy has the goal of accepting or rejecting the pre-implantation EZ hypothesis. Using strict techniques, this procedure is safe and minimally invasive [13]. In this preliminary study, we elected to only analyze contacts in the cingulate cortex due to its role in attention.

C. Gambling Task

Subjects performed the gambling task in their Epilepsy Monitoring Unit room [14]. The task was displayed via a computer screen and the subjects interacted with the task using an InMotion2 robotic manipulandum (Interactive Motion Technologies, USA). The manipulandum is controlled by the subject's hand and allows for two-dimensional planar motion, which translated directly to the position of a cursor on the screen.

The gambling task (Fig. 2) is based on a simple game of high card where subjects would win virtual money if their card was higher than the computer's card. At the beginning of each trial, the subject was instructed to move a cursor, via the planar manipulandum, to a central fixation target. After a random delay (mean = 1.58 sec, std = 0.77 sec), the subject was shown their card $(2, 4, 6, 8,$ or $10)$, which was randomly chosen from a uniform distribution (subjects were given the distribution of cards *a priori*). The computer's card was initially hidden. The screen then showed the subject two choices: a high bet ($\$20$) or a low bet ($\$5$). The subject had 6 seconds to select one bet with the cursor. Following the bet selection, the computer's card, which was also chosen randomly, was revealed. After a variable delay of $1.3 - 1.55$ sec, the final screen depicted the amount won or lost. After a variable inter-trial-interval averaging 1 sec, the subject was then instructed to move the cursor to the central fixation location as the subsequent trial start.

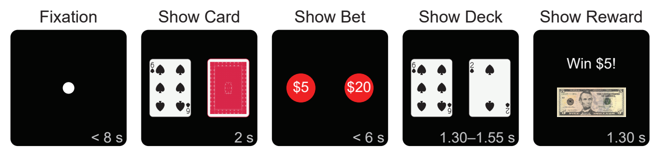

Fig. 2. Timeline of gambling Task. After fixation, subjects were shown their card for 2 sec. Once the bets were shown, subjects selected one of the choices and then were shown the computer's card following a delay. Feedback was provided afterwards by displaying the amount won or lost.

D. Data Analysis

All electrophysiological and behavioral analyses were conducted offline using custom MATLAB scripts. Differences in the neural responses between low and high attention task conditions during the 2 seconds after a fixation cue was presented were examined using a non-parametric cluster statistic. Specifically, alpha-band time series were constructed for each trial and time-locked to when the player began the fixation task. Then the alpha-band signals for low attention trials were compared to those for high attention trials, as defined in the next section. To see if alpha-band signals for each group were statistically different, we used a non-parametric cluster-based test [16]. Clusters are defined as a set of adjacent time windows whose activity is statistically different at a specified level between the two trial types.

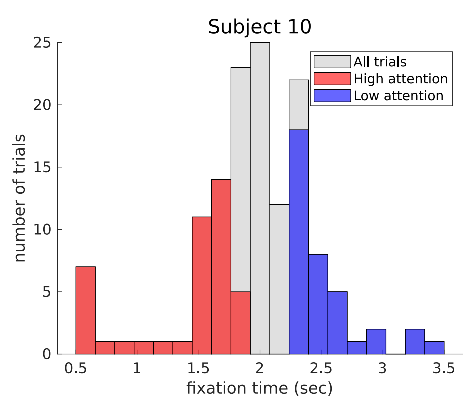

Fig. 3. Example of identified high and low attention trials, using the time to fixation distribution.

Table 2. Subject Fixation Time

Patient ID	Total Trials	**High attention trials time to fixation** mean ± std (sec)	**Low attention trials time to fixation** mean ± std (sec)
P6	162	0.65 ± 0.00	1.14± 0.36
P7	142	1.50 ±0.37	2.12 ± 0.08
P10	126	1.44 ± 0.38	2.60 ± 0.49
P12	119	1.20 ± 0.43	2.77 ± 1.10
P13	150	0.65 ± 0.00	1.86 ± 0.46
P15	137	1.26 ± 0.44	2.27 ± 0.21
P16	115	0.65 ± 0.00	2.46 ± 1.32
P17	140	1.85 ± 0.21	2.66 ± 1.13
P21	159	0.65 ± 0.00	1.42 ± 0.22

1) Identifying low versus high attention trials: To identify low and high attention trials, we looked at the time between when the subjects received the fixation target cue and when the cursor was in the central fixation location. We defined this as the time to fixation (TF). The fastest 30% of the TF distribution for a subject were labeled as high attention trials, while the slowest 30% were labeled as low attention trials. Figure 3 shows an example TF distribution for a single subject, and table II-D.1 shows the average TF for low and high attention trials for each subject. Trials with likely movement artifacts during the TF (seen as abnormally high deviations in the voltage data) were removed.

2) Computing alpha spectral power: SEEG data were preprocessed by subtracting a 10 second moving average on each channel to eliminate voltage drift. Additionally, 60 Hz electrical noise and higher harmonics were filtered out. We calculated the power between $8-12$ Hz using the MATLAB `bandpower` function (Signal Processing Toolbox) applied to a moving window of width 500 ms. The window was shifted by 10 ms for each estimate. Contacts within each sub-region (*i.e.*, anterior or posterior cingulate cortex) were averaged together.

3) Non-parametric cluster statistical test: Significant differences between the neural response data in the cingulate cortex are defined by a non-parametric cluster statistic run on data aggregated from trials for all relevant subjects [16]. This test considers the dependency between adjacent time-frequency windows in order to avoid over-penalizing with multiple comparison corrections. For each time window in the alpha-band time series, a null distribution was created by shuffling high and low attention labels 1000 times within each subject. Within each shuffle, the average difference between the reshuffled low and high attention alpha-band power was calculated. A p-value was assigned for each window by comparing the difference acquired from the true labels with the distribution of differences acquired from the shuffled labels. Clusters were formed by grouping adjacent time windows with p-values below a desired threshold ($p < 0.25$).

III. Results & Discussion

We applied our methods to nine patients with recordings from the cingulate cortex executing the gambling task. In total, 15 different combinations of patient and subregion were recorded from. Of these, 10 had differences in alpha-band power between the low and high attention trials within the

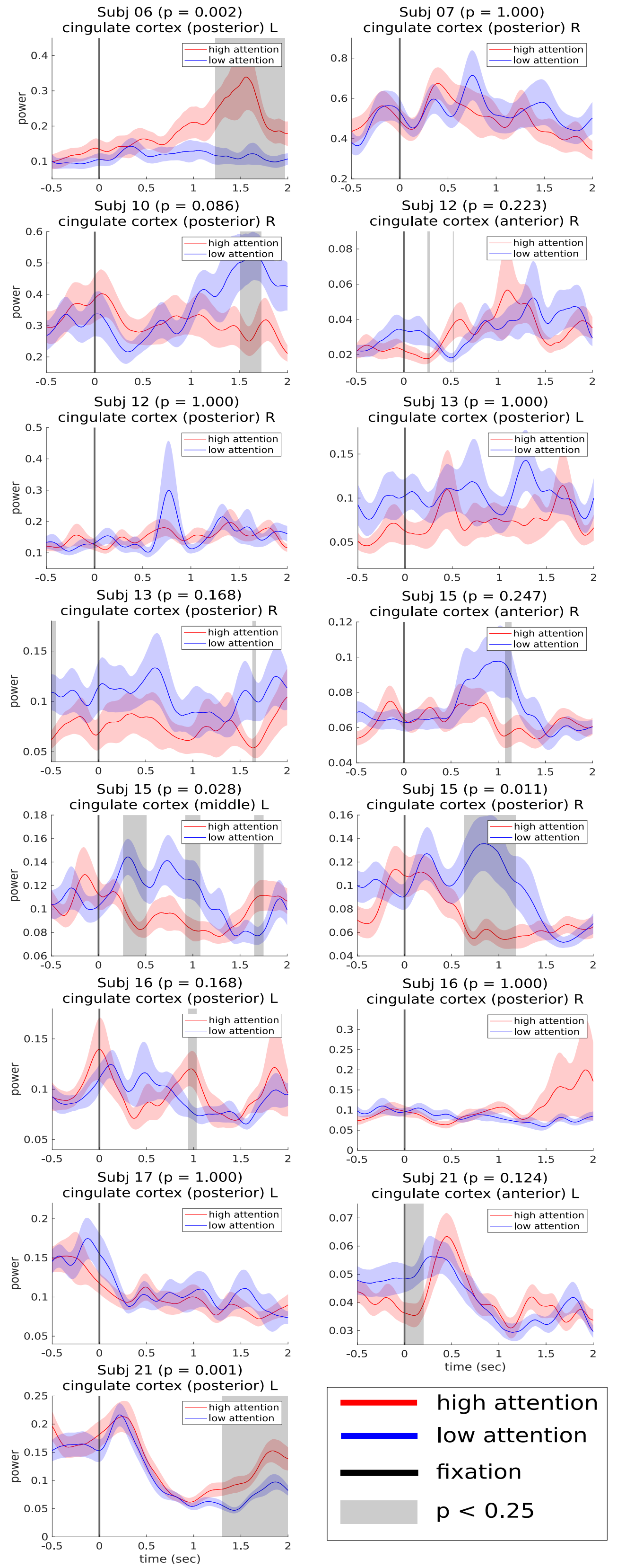

Fig. 4. Alpha-band power over time for low attention (blue) versus high attention (red) trials. Gray shaded regions indicate a difference between low and high signals with $p < 0.25$. The given p-value is the lowest achieved in each region in the window shown. The solid black line at time 0 indicates the start of the fixation task.

two second window of interest following the fixation cue (Fig. 4). Many of these ($6/10$) showed increased alpha-band power during trials where TF took longer than normal (low attention trials). This is in agreement with previous literature that showed attention deficits associated with reduced CC function, as well as an association between alpha-band power and local suppression [3]. Two patients (P06 and P16) however showed the opposite trend, with higher alpha-band power in high attention trials, and one patient (P21) showed opposite trends in anterior and posterior cingulate cortex. Although the small sample size of subjects and trials do not allow us to separate the two attention conditions with high statistical significance, we can state that the data provides some support for the idea that higher alpha-band power in the CC indicates a lower attention state as measured by time to complete a simple fixation task.

The goal of this study was to find if time to fixation is a viable metric of attention and investigate how attention influences decision making. This study reviewed the alpha-band power in the CC during a time window during fixation. Alpha-band is associated with inhibiting distractions. That is, higher alpha-band power is associated with the subject's eyes being closed or even day-dreaming. We found that during fixation, trials with higher alpha-band power were usually associated with longer fixation times. This attention metric may be too coarse. For example, some subjects moved the cursor to the center target before fixation (as seen in Fig.3 with fixation times around 0.5 sec). However, these trials may not reflect high attention. Later studies will compare regions associated with visual attention and motor attention with fixation times to see if there are differences in the alpha-band power. By comparing time to fixation to visual attention and motor attention, we hope to see if time to fixation influences how an individual makes decisions.

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