2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

Alpha Power in the Cingulate Cortex reflects Accumulated Winnings During Gambling in Humans

Christopher Taylor[1], Macauley Smith Breault[2], Patrick Greene[2], Jorge Gonzalez-Martinez[3], and Sridevi V. Sarma[2], *IEEE Senior Member*

Abstract— **When making bets one's level of attention determines how much they may win. The cingulate cortex is a brain region associated with attention and may influence behaviors during gambling. With data gathered from the cingulate cortex in humans implanted with depth electrodes for clinical purposes while performing a gambling task of high card, we determine a relationship between neural correlates of attention and accumulated winnings. Specifically, we analyze how changes in alpha power (8-12 Hz) in the CC relate to accumulated winnings. We compared three subjects with different betting strategies: Reflexive (betting low on cards 2, 4, and 6), Logical (varying how they bet on card 6), and Illogical (betting randomly on all cards). We found that alpha power encodes attention in the cingulate cortex and relates to their accumulated winnings, especially in the illogical subject who had the least winning.**

I. Introduction

You are walking in a casino; it is roaring loud and other patrons are walking around you. When you sit at a gambling table and look at your cards, you attempt to focus. As the sound of the casino swings and people walk past you, your attention fluctuates. How will your attention affect how much you bet? Perhaps, if you are paying attention to the gambling task, you may win more money. In this study, we assessed to what extent this could be true.

Attention is defined as how one focuses on a task or object at hand [1]. It can be measured through multiple aspects such as behavioral and neural metrics. Common behavioral metrics used to measure attention in humans are eye movements, computer mice movements, and reaction times. By viewing eye movement, the study can gauge how participants fixated on specific locations of an image when first viewing [2]. They also displayed a relationship between mouse clicks and attention and how it related to print advertisements [2]. Finally, an individual's reaction time can be increased based on an incentive to complete a task [3]. This showed that monetary incentives bias subjects, motivating them to pay more attention.

A popular neural metric for attention is alpha power (8-12 Hz). It is typically measured using an electroencephalogram (EEG) from various regions of the brain [4]. Studies have found that decreased amplitudes of alpha power correlate with an increased state of attention [9]. One brain region of interest for attention-related research is the cingulate cortex. A study by Pardo et al. found that the cingulate cortex is associated with inhibiting responses and attentional conflict [5]. This relates to decision-making when a pattern is found within trials where subjects consistently get a high or low card during several player card epochs. The cingulate cortex is also associated with adjusting responses to external stimuli [6]. Those with attention deficit hyperactivity disorder are associated with impulsivity and inattention, which relates to subjects with low variation in alpha power in the cingulate cortex [6].

Even though attention manifests from the brain, the neural basis of attention is a challenging topic. This is because attention related regions, such as the cingulate cortex, are difficult to access due to their location. Most studies cannot achieve an accurate neural metric to measure of attention due to a lack of spatial resolution (such as EEG) or temporal resolution (such as functional magnetic resonance imaging (fMRI)) [7,13]. It is believed that attention is on the hundredth of a second scale which the fMRI is not capable of reading.

Based on this prior research, we were interested in studying how neural activity at a finer temporal resolution modulates with attention in the brain during decision-making. This required unprecedented invasive access to the cingulate cortex in humans during a complex decision-making task, such as a gambling task. We gained access to such a unique data set containing whole-brain recordings in humans by utilizing stereo electroencephalography (SEEG) technology. These subjects were being monitored invasively for clinical purposes. Recordings of local field potential (LFP) activity were taken while subjects simultaneously performed a gambling task by playing a game of high cards [7,8,9]. We used this data to test our hypothesis that attention would correlate to accumulative winnings.

By viewing changes in the subjects' reaction time and alpha power in the cingulate cortex within each trial, we were able to determine how varying level of attention is related to gambling bets and winnings. We focused our efforts on three subjects, who were characterized with different distinctive betting strategies (Reflexive, Logical, and Illogical) as identified in our previous study on this data [7,9,15]. We found that their monetary outcome is related to how logical their strategy was, where the most logical subject had the highest overall winnings. In addition, we found evidence of their behavioral strategy encoded in the cingulate cortex via alpha power.

[1] C. Taylor was with the Department of Electrical Engineering, Morgan State University, Baltimore, MD 21251 USA. He is now with the Department of Biomedical Engineering, Johns Hopkins University, Baltimore, MD 21211 USA (e-mail: ctayl131@jh.edu).

[2] M. Smith Breault, P. Greene, and S.V. Sarma are with the Department of Biomedical Engineering, Johns Hopkins University, Baltimore, MD 21211 USA. (e-mail: ssarma2@jhmi.edu).

[3] J. Gonzalez-Martinez is with the Epilepsy Center, University of Pittsburgh, Pittsburgh, PA 15213 USA.

978-1-7281-1178-0/21/$31.00 ©2021 IEEE

II. Methods

A. Subjects

The three subjects were patients at the Cleveland Clinic with medically intractable epilepsy who had undergone SEEG recordings to localize the epileptogenic zone (EZ). In this study, aside from the behavioral experiments, no alterations were made to their clinical care, including the placement of the electrodes [7]. Subjects enrolled voluntarily and gave informed consent under criteria approved by the Cleveland Clinic Institutional Review Board. All subjects volunteered to perform the task. Subjects were not medicated during this period which reduced chances of impairment.

B. Electrophysiological Recordings

Recordings of LFP activity were done using SEEG. The number and location of implanted electrodes are preoperatively planned based on a hypothesis of the location of the EZ. This hypothesis was 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. The implantation strategy then has the goal of accepting or rejecting the pre-implantation EZ hypothesis. Using strict techniques, this procedure is safe and minimally invasive [7,11]. Labeling of electrodes according to brain region was done by clinicians at the Cleveland Clinic using overlaid MRI and CT images. For this study, only interictal recordings taken from the cingulate cortex while the subject was performing the gambling task were used.

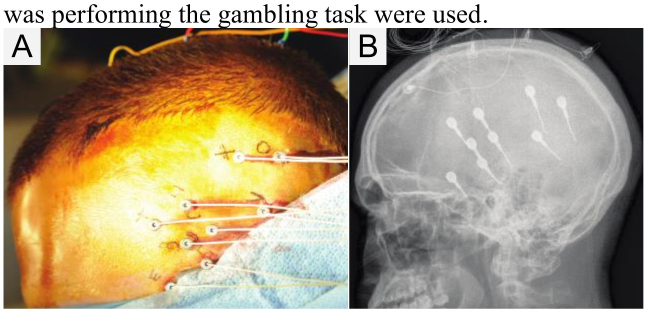

Figure 1. A. The clinical photograph displaying a human scalp where depth electrodes have been implanted. B. An X-ray of the same subject displaying the internal location of the depth electrodes relative to their skull.

C. Gambling Task

Subjects performed the gambling task in their Epilepsy Monitoring Unit room [7]. 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) was based on a simple game of high card, where subjects would win virtual money if their card was higher than the computer's card.

After a random delay (mean = 1.58 s, std = 0.77 s), 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 s 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 s, the final screen was shown, depicting the amount won or lost. After a variable inter-trial interval (mean = 1.75 s, std = 0.17 s), the subject was then instructed to move the cursor to the central fixation location as the subsequent trial start.

D. Data Analysis

Data analysis was completed offline using MATLAB. Our three subjects had distinctive strategies when it came to the game of high card. These strategies were broken down into three groups: Logical (Subject 17), Reflexive (Subject 7), and Illogical (Subject 16). Logical referred to betting high on cards 8 and 10 while betting low on cards 2, 4, and 6. Betting high on cards 8 and 10 while betting low on cards 2 and 4 are "logical" because they this strategy maximizes the expected reward and minimizes the variance of the reward or risk of reward by betting low on 6 cards. Reflexive follows a logical strategy but varied on 6 card trials, possibly due to the hot hand fallacy [7]. Illogical refers to the subject betting randomly high or low on all cards.

To analyze the neural data, we first extracted the alpha power as a time-series from LFP activity using the `bandpower` function in MATLAB between 8-12 Hz with a sliding window of length 500 ms and a 10 ms shift. We then normalized it by *z*-scoring the power data across the entire session. The alpha-band time series for each trial was time-locked to when the player began the fixation task. In this study, we focused on the cingulate cortex, as it was shared across our three subjects as well as for its involvement with attention from previous literature. We spatially averaged the normalized alpha power across electrodes within the cingulate cortex before temporally averaging within each epoch (see Fig. 2 for breakdown of epochs) within each subject.

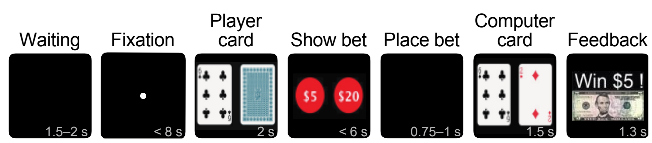

Figure 2. The gambling task was a game of high card. The trial is broken down into several periods called epochs. Each epoch varies in visual stimuli based on the trial's conditions. Each trial began with a Waiting period, were the subject waited for the icon to appear. This is followed by Fixation, where the subject uses a robotic manipulandum to guide a curser to the icon in the center. The player is shown their card (Player card). In this case, the subject's card has a 6 card. The betting options of $5 and $20 are displayed on the screen (Show bet). The subjects uses the manipulandum to make a bet. In this case, the subject bet $5. There is a short delay called Place bet before the computer's card is revealed during Computer Card. Here, the computer has a 2 card. Finally, the subject is shown Feedback, which displays the outcome of their trial. In this case, the subject's card is higher than the computer's card, so they won their bet of $5.

III. Results

A. Behaviors and cumulative winnings

Figure 3A displays a histogram of reaction times by the number of trials. This gives a general idea of the distribution of reaction time during Show bet. The Show bet epoch is relevant in that it is both a period of anticipation and movement, which we believe would designate a change in attention. The distributions show most subjects react within one second. The logical and reflexive subjects (17 and 7) have more trials less than a second, but they also reacted the slowest on some trials by taking more than three seconds. The illogical subject is more evenly distributed around one second. This indicates that illogical subject (16) may be "paying a constant amount of attention" during Show bet than the other subjects, who varied their attention during trials.

Figure 3B shows the accumulated winnings for each subject across all their trials. Subject 17, who bets logically, has the most financial gain per trial. Subject 16, the illogical subject, has the least gain. Subject 7 bet similarly to subject 17 but showed random betting around trial 50, resulting in substantial losses. They showed a hot handedness to a random pattern of cards, which may have influenced their betting and attention, resulting in their losses. They also have bad luck during the initial stages of the trial, indicated by the flat curve on their first few trials. When reviewing subject data, we confirm a trend of draws in the initial trials.

Figure 3B shows the accumulated winnings for each subject across all their trials. The logical subject (17) has the most financial gain per trial. The reflexive subject (7), who bet logically except on 6 card trials, showed random betting around trial 50, resulting in substantial losses. This subject was identified in a previous study as showing hot handedness [7]. This behavior influenced their betting and attention, resulting in the losses observed. The illogical subject (16) had the least gain. We also observed that this subject also received proportionally more trials with cards 2 and 4 (which are less likely to win on) in the beginning of the session compared to the other subjects. It is indicated in Figure 3B (right) by the flat curve between trials 1 and 50. However, we believe that this subject would have accumulated similar winnings if presented with a different set of cards in the beginning of the session.

Figure 3C shows accumulated winnings for each card group. The plot breaks down the cards into 3 groups: 2 or 4 (blue), 6 (grey), and 8 or 10 (red). Card variability was found by converting the amount bet ($5 or $20) into binary values (-1 or +1, respectively) and taking the cumulative summation for each card group. The logical and reflexive subjects (17 and 7) have a similar pattern of card variability, in that they bet $5 on cards 2 or 4 and $20 on cards 8 or 10. They differ for 6 cards where the logical subject (17) consistently bets $5 while the reflexive subject (7) randomly bet. This makes sense since subject 7 was shown previously to falls for hot hand fallacy and bet based on their winning streak [7]. As for the illogical subject (16), Figure 3C (right) shows a relatively flat slope for cards 6 and 8 or 10, indicating they bet both $5 and $20 intermittently. However, like the logical and reflexive subjects, this subject tended to consistently bet $5 when given cards 2 or 4.

B. *Alpha power variability within trials*

Figure 4 displays the distribution of alpha power during each epoch with trials divided into 3 cards groups: 2 or 4 (blue), 6 (grey), and 8 or 10 (red).

The logical subject (17) initially has high alpha power during Waiting, indicating low levels of attention. There is a dramatic decrease in alpha power as they begin to use the robotic manipulandum during Fixation. This means that they were paying more attention when they used the device. As the trials progressed, the subject maintains a stable alpha power, meaning they either had a set strategy throughout and performed based on reflex or maintained a constant level of attention throughout the session. Furthermore, this subject did not change their level of attention based on the card, as indicated by the consistent distribution of alpha power across epochs for all card conditions.

The reflexive subject (7) had the opposite experience during Fixation compared to logical subject (17). We believe this may be because this subject had previous experience with the robotic manipulandum performing another one of our behavioral tasks on a previous day. This additional experience allowed them to pay less attention when using the manipulandum compared to the other subjects who were experiencing the manipulandum for the first time. As subject 7 continued, their attention increased by way of the decrease in alpha power, particularly in cases where they received a 6 card. The lower levels of alpha indicate higher levels of attention due to the difficulty deciding which bet to choose on a 6 card, as supported by their betting strategy in Figure 3C (middle).

Subject 16 showed very little variability in their alpha power, both between epochs and cards. This indicates that they maintained constant amount of attention throughout the session irrespective of the trial conditions. Based on their overall winnings (Figure B (left)), it may be possible that they were not paying attention during the entire session. Their average alpha power does not vary despite their cards. This could be a reflexive action that may be like those who do not pay attention.

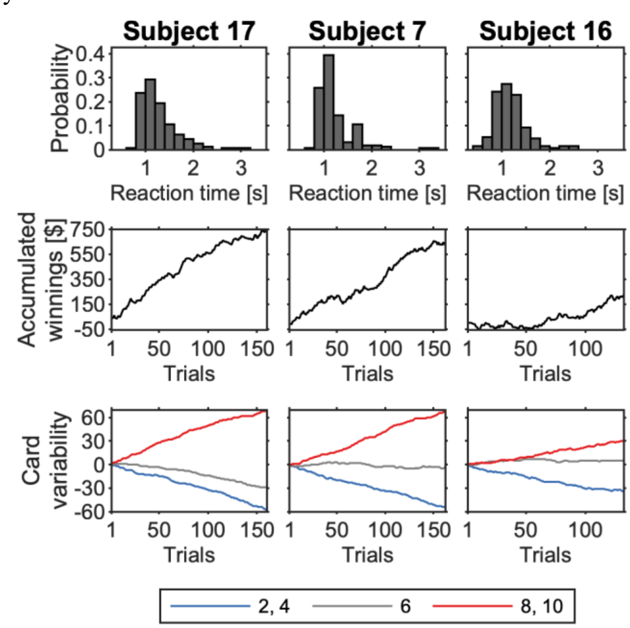

Figure 3. A. Histogram of the distribution of reaction times across all trials for each subject. B. Accumulatted winnings [in US dollars $] across trials for each subject C. Card variability across trials for each subject. Trials where the subject bet $5 were valued as -1, $20 were valued as +1. Then, the cumulative summation was calculated to get the Card variability seen on the y-axis. Trials were broken down based on the player's card, as indicated by the color of the lines: 2 or 4 (blue), 6 (grey), and 8 or 10 (red).

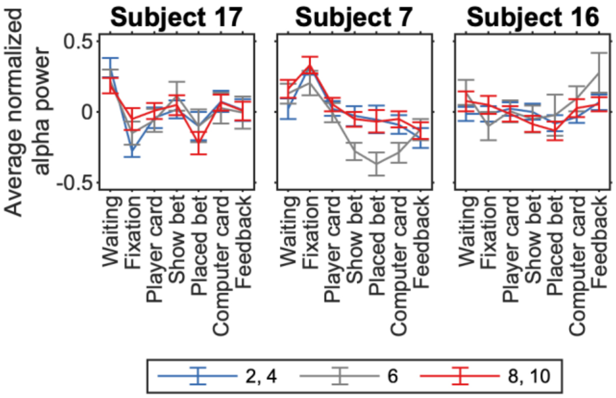

Figure 4. Distribution (mean ± SEM) of the normalized alpha power in the cingulate cortex during each epoch where each column shows a subject. The color of the lines indicates the card that the distribution was calculated for: blue for 2, 4 cards, grey for 6 card, and red for 8, 10 cards.

IV. Discussion

This study continues our previous research and relates alpha power in the cingulate cortex to attention [7,8,9]. We found a relationship between betting strategy and accumulated winnings, *i.e.*, the logical strategy tends to win more money. We used alpha power in the cingulate cortex as a neural metric to capture attention, where a decrease in alpha power means an increase state of attention [9]. The subject (7) who normally bet logically would modulate their attention when presented with an unexpected card. This was observed by the decrease in their alpha power but only for 6 card trials. Alpha power related to both attention and reflex when viewing subjects 17 and subject 16. Interesting, the logical and illogical subjects (17 and 16) both had relatively low average alpha power, meaning they were at a low state of attention. We pondered why this may be the case. Perhaps, both subjects were not paying attention but for different reasons. The logical subject (17) had a betting strategy for every card to their betting choice was always trivial while the illogical subject (16) did not need to pay attention because they were going to bet randomly no matter the card. Subject 16 is also interesting in that they had a combination of a bad logic and bad luck with cards [7,8].

A way to control for individual betting strategies in future experiments would be to give them the same sequence of cards, which was not for the data set explored in this study. Our next step is to look at other brain regions to see which are active with low variance in alpha power. This would demonstrate the involvement of regions other than the cingulate cortex in attention processes. We will also explore other frequency bands (such as theta, beta, and gamma) in a similar manner as we performed here to see if other frequency bands are encoding information related to decision-making and attention.

Acknowledgment

This work was supported by NSF (EFRI-MC3: #1137237) awarded to S.V.S. and J.A.G., NIH R01NS110423 awarded to S.V.S., and the ARCS Foundation awarded to M.S.B.

References

[1] Schefke, Tomasz, and Piotr Gronek. "Improving attentional processes in sport: defining attention, attentional skills and attention types." Studies in Physical Culture & Tourism 17, no. 4 (2010)

[2] Egner, Steffen, Stefanie Reimann, Rainer Hoeger, and Wolfgang H. Zangemeister. "Attention and information acquisition: Comparison of mouse-click with eye-movement attention tracking." Journal of Eye Movement Research 11, no. 6 (2018)

[3] Mir, Pablo, Iris Trender-Gerhard, Mark J. Edwards, Susanne A. Schneider, Kailash P. Bhatia, and Marjan Jahanshahi. "Motivation and movement: the effect of monetary incentive on performance speed." Experimental brain research 209, no. 4: 551-559. 2011

[4] Thut, Gregor, Annika Nietzel, Stephan A. Brandt, and Alvaro Pascual-Leone. "α-Band electroencephalographic activity over occipital cortex indexes visuospatial attention bias and predicts visual target detection." Journal of Neuroscience 26, no. 37:9494-9502. 2006

[5] Pardo, José V., Patricia J. Pardo, Kevin W. Janer, and Marcus E. Raichle. "The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm." Proceedings of the National Academy of Sciences 87, no. 1: 256-259. 1990

[6] G. Bush, J. A. Frazier, S. L. Rauch, L. J. Seidman, P. J. Whalen, M. A. Jenike, B. R. Rosen and J. Biederman, "Anterior Cingulate Cortex Dysfunction in Attention-Deficit/Hyperactivity Disorder Revealed by fMRI," Society of Biological Psychiatry, vol. 45, no. 12, pp. 1542-1552, 1999.

[7] Sacré, Pierre, Matthew SD Kerr, Sandya Subramanian, Zachary Fitzgerald, Kevin Kahn, Matthew A. Johnson, Ernst Niebur et al. "Risk-taking bias in human decision-making is encoded via a right–left brain push–pull system." Proceedings of the National Academy of Sciences 116, no. 4,1404-1413,2019

[8] Sacré, Pierre, Matthew SD Kerr, Kevin Kahn, Jorge Gonzalez-Martinez, Juan Bulacio, Hyun-Joo Park, Matthew A. Johnson et al. "Lucky rhythms in orbitofrontal cortex bias gambling decisions in humans." Scientific reports 6, no. 1: 1-10. 2016.

[9] Taylor, Christopher, Patrick Greene, Raina D'Aleo, Macauley Smith Breault, Cynthia Steinhardt, Jorge Gonzalez-Martinez, and Sridevi V. Sarma. "Correlates of Attention in the Cingulate Cortex During Gambling in Humans." In 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), pp. 2548-2551. IEEE, 2020.

[10] Johnson, Matthew A., Susan Thompson, Jorge Gonzalez-Martinez, Hyun-Joo Park, Juan Bulacio, Imad Najm, Kevin Kahn, Matthew Kerr, Sridevi V. Sarma, and John T. Gale, "Performing behavioral tasks in subjects with intracranial electrodes," Journal of Visualized Experiments, vol. e51947, pp. 1-6, 2014.

[11] Cossu, Massimo, Francesco Cardinale, Laura Castana, Alberto Citterio, Stefano Francione, Laura Tassi, Alim L. Benabid, and Giorgio Lo Russo. "Stereoelectroencephalography in the presurgical evaluation of focal epilepsy: a retrospective analysis of 215 procedures." Neurosurgery 57, no. 4 : 706-718. 2005

[12] Sklar, Samuel, Matthew Walmer, Pierre Sacre, Catherine A. Schevon, Shraddha Srinivasan, Garrett P. Banks, Mark J. Yates et al. "Neuronal activity in human anterior cingulate cortex modulates with internal cognitive state during multi-source interference task." In 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 962-965. IEEE, 2017.

[13] Logothetis, Nikos K., "What we can do and what we cannot do with fMRI.," Nature, vol. 453, pp. 869-878, 2008.

[14] van Diepen, Rosanne M., Lee M. Miller, Ali Mazaheri, and Joy J. Geng. "The role of alpha activity in spatial and feature-based attention." Eneuro 3, no. 5,2016.

[15] S. Gunaratnam, D. Talluri, P. Greene, P. Sacré, J. Gonzalez-Martinez and S. V. Sarma. “High Frequency Activity in the Orbital Frontal Cortex Modulates with Mismatched Expectations During Gambling in Humans,” 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Montreal, QC, Canada, pp. 1035-1038. 2020