A Study on Bistabel Preception and Its Origin in Human's Brain

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Studying functionality of different regions of the brain is an important part of neuroscience. In the task of bistable perception, there is a rotating cylinder which can be seen rotating both clockwise and counterclockwise. In six trials with two volunteers, EEG signals are acquired. In each trial, a playback of bistable perception is played for five minutes and direction of rotation is received. Further the signals' noise and artifacts are eliminated. The dataset collected is used for classification using 13 features including six in time domain and seven in frequency domain. The regions of superior temporal gyrus (STG), superior parietal lobe (SPL), and angular gyrus (ANG) effecting the signals recorded by electrodes of Ft8, Cp3, and Cp4 have the most important role in bistable perception.

Keywords—neuroscience, electroencephalography, biostable perception, STG, SPL, ANG, machine learning

I. INTRODUCTION

Decisions are often informed by several aspects of a problem, each guided by different sources of information. In many instances, these aspects are combined to support a single judgment. For example, an observer might judge the distance of an animal by combining perspective cues, binocular disparity and motion parallax. In other instances, the aspects are distinct dimensions of the same object. For example, the animal's distance and its identity as potential predator or prey. The neuroscience of decision-making has focused largely on perceptual decisions, contrived to promote the integration of noisy evidence over time toward a categorical choice about one stimulus dimension

Here, we develop a task in which the participant views one visual stimulus and makes two decisions about the same object. There is a moving cylinder created by two planes of dynamic points moving in opposite directions. The participant has to choose whether the cylinder is moving to the right or left.

II. MATERIALS AND METHODS

A. Code

Using Psychtoolbox-3 [1] in MATLAB a code is programmed in order to run the test for each volunteer and collect desired data. The test contains a five-minute block of bistable rotating cylinder playback (Fig. 1). The user's sense of direction in the bistable rotating cylinder is obtained and recorded through arrow-keys. The times that the user senses a difference in the direction perceived, are saved in a .txt format to be used for EEG signal processing and classification. Moreover, some information such as the volunteer's name, age, and also the number of the trial is asked at the beginning of the test and stored as heather in the .txt file.

B. Signal Acquisition

The data used in this experiment is recorded by a 32 channel electroencephalography (EEG) electrodes. In this experiment, a total of two subjects (a man and a woman at the same age) who wear the headwear and are included in the analysis; each one participating in a 15 minute experiment in three 5-minute trials, with a 2-minute rest between each two trials. Subjects' feedback is recorded as left or right indicating clockwise or counterclockwise rotation with the exact time of change in decision. In order to avoid artifacts originated from movements, the subjects are constrained to move just a finger to push a button and not have any other movements.

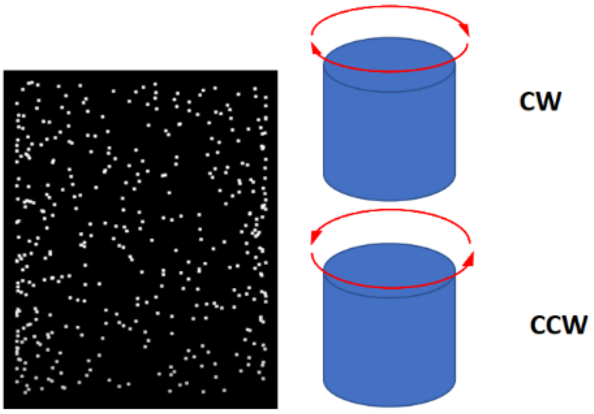

FIG. 1. BISTABLE ROTATING CYLINDER

C. Pre-processin

In the pre-processing phase "Makoto's preprocessing pipeline" was used with following steps using MATLAB's EEGLAB toolbox.

1. Removing low frequency waves using a High-pass filter with the cut-off frequency of 1 Hz.
2. Removing 50 Hz line noise using a Notch filter with the cut-off frequency of 49 & 51 Hz.
3. Correcting continuous data using Artifact Subspace Reconstruction (ASR) without removing any channels. (Fig. 2)
4. Re-reference the data to average.
5. Decomposing the data using ICA algorithm (ruica option). (Fig. 3)
6. Generate probabilistic IC labels and removing bad components from data (we removed maximum of 2

muscle components with probability of 60% or higher) (Fig. 4)

7. Epoching the data 1 second before and 2 seconds after each task event.

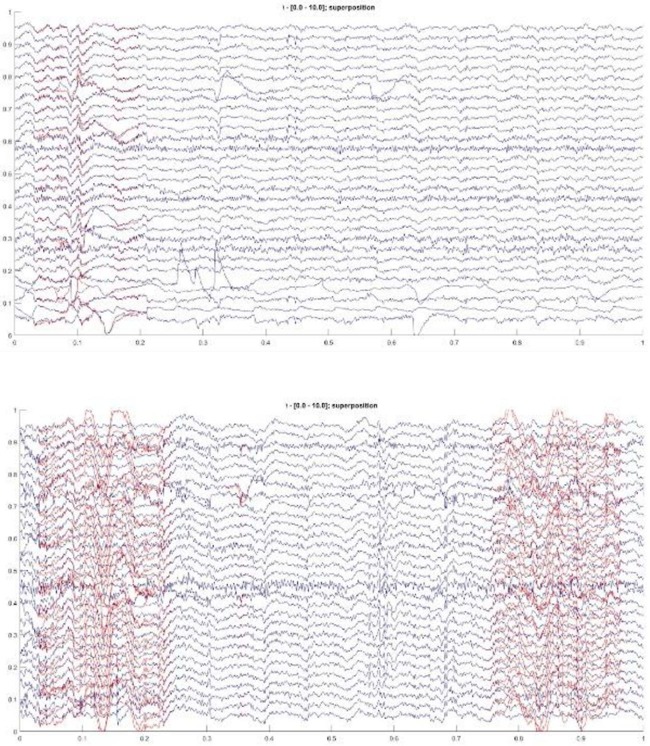

FIG. 2. CORRECTING CONTINUOUS DATA USING ARTIFACT SUBSPACE RECONSTRUCTION (ASR)

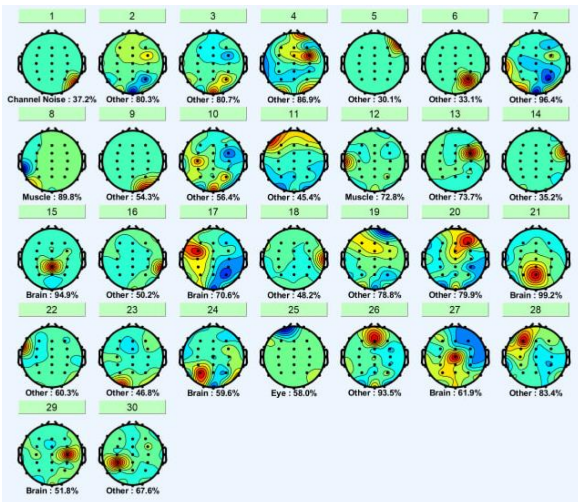

FIG. 3. DECOMPOSING THE DATA USING ICA ALGORITHM

D. Classification

First, further preprocess is done by removing the first 15 events due to the shorter duration than two seconds and multiple overlaps. 13 features including seven in time domain and six in frequency domain is extracted. Using Shannon's Entropy as a feature in frequency domain caused the model to classify all inputs as one class. Time domain features include mean amplitude, amplitude variance, Skewness, Kurtosis, Entropy (Shannon), Entropy (log energy), and mean squared and frequency domain features include mean frequency, frequency variance, skewness, kurtosis, entropy (log energy), and mean squared

As the training set, 50 events are used and the rest of the dataset (20 or 21 remaining events) is being considered as validation set. Furthermore, Support Vector Machine (SVM) classifier is used to classify the clockwise and counterclockwise responses for each channel separately.

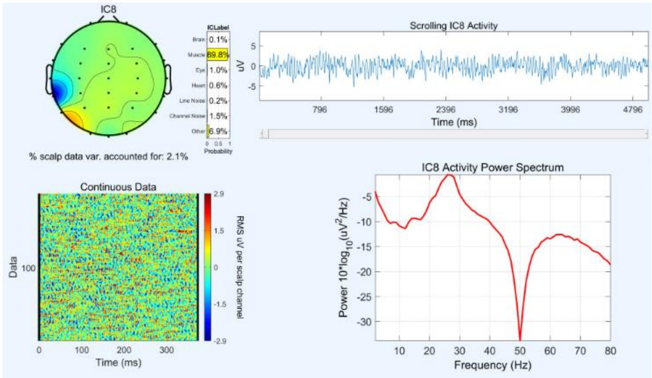

FIG. 4. GENERATE PROBABILISTIC IC LABELS AND REMOVING BAD COMPONENTS FROM DATA

III. RESULTS

Table I indicates the accuracy of classification of each electrode's signal. It can be seen that some electrodes have higher accuracy in comparison to others. By analyzing these electrodes and the regions of the brain underlying them, the parts of the brain responsible for the task of bistable perception can be studied.

TABLE I. SUBJECT A CHANNEL ACCURACIES (IN PERCENT)

Fp1	**Fp2**	**F7**	**F3**	**Fz**	**F4**	**F8**	**Ft7**	**Fc3**	**Fcz**
58.53	48.78	58.53	48.78	43.90	58.53	53.65	48.78	48.78	48.78
Fc4	**Ft8**	**T7**	**C3**	**Cz**	**C4**	**T8**	**Tp7**	**Cp3**	**Cpz**
51.21	58.53	46.34	51.46	41.46	43.90	53.65	51.21	56.09	48.78
Cp4	**Tp8**	**P7**	**P3**	**Pz**	**P4**	**P8**	**O1**	**Oz**	**O2**
51.21	46.34	46.34	43.90	48.78	48.78	48.78	51.21	48.78	51.21

TABLE II. SUBJECT B CHANNEL ACCURACIES (IN PERCENT)

Fp1	**Fp2**	**F7**	**F3**	**Fz**	**F4**	**F8**	**Ft7**	**Fc3**	**Fcz**
34.14	34.14	48.78	41.46	48.78	43.90	51.21	48.78	53.65	43.90
Fc4	**Ft8**	**T7**	**C3**	**Cz**	**C4**	**T8**	**Tp7**	**Cp3**	**Cpz**
48.78	51.21	51.21	56.09	43.90	60.97	46.34	39.02	56.09	43.90
Cp4	**Tp8**	**P7**	**P3**	**Pz**	**P4**	**P8**	**O1**	**Oz**	**O2**

60.97	48.78	48.78	58.53	43.90	51.21	48.78	43.90	51.21	48.78

IV. Disussion

As we discussed in the course and according to our further studies, we can come up with some expectations about the areas of the brain contributing to this perception task. Areas in the occipital lobe of the cortex are associated with vision primary analysis. The dorsal pathway contributes to motion perception and the ventral pathway is related to object identification. The prefrontal cortex is where these two pathways join. We can predict that some parts in the dorsal pathway affect the subject's perception of the direction. A special part of this pathway, which is considered to be associated with motion detection, is the MT area. It is expected that this part contributes to the results of this task strongly. Moreover, other parts of the parietal cortex and frontal cortex must have effects on how the subject observes the rotation direction.

As shown in Table I, the electrodes F8, Ft8, C3, Cp3, and Cp4 indicated higher accuracy rate in comparison to other electrodes. Based on this table, it can be inferred that the regions responsible the most for the task of bistable perception are central and frontal regions of the brain. The regions of brain underlying electrodes F8, Ft8, C3, Cp3, and Cp4 are respectively the left inferior frontal gyrus (IFG), precentral gyrus and anterior superior temporal gyrus (STG), postcentral gyrus, posterior supramarginal gyrus (SMG) and superior parietal lobe (SPL), the angular gyrus (ANG) and superior parietal lobe (SPL) [2].

The IFG region is mostly responsible for language comprehension and production which clearly indicates the absence of any meaningful relationship between the bistable perception task and F8 electrode [3]. The precentral gyrus is the part of the brain responsible for executing voluntary movements [4]. Furthermore the signal captured by the Ft8 electrode can also originate from anterior STG [2]. fMRI analysis has evidenced a link between insight-based problem solving and activity in the right anterior superior-temporal gyrus, specifically in relation to the sudden flash of understanding [5]. This evidence shows the role of the electrode Ft8 and also one of the probable origins of direction understanding in this task. The postcentral gyrus contains the primary somatosensory cortex, a significant brain region responsible for proprioception through various somatic sensations [6]. This shows the sense of pressure while pushing the keys which indicates the absence of meaningful relation between the signal of C3 electrode and the direction understanding. The supramarginal gyrus (SMG) is activated for phonological processing during both language and verbal working memory tasks [7]. The superior parietal lobule (SPL) is involved with spatial orientation, and receives a great deal of visual input as well as sensory input from one's hand [8]. This shows the key role of the SPL region in the understanding direction of rotation with spatial orientation. It can be deduced that the Cp3 electrode's signal and the it's origin has an important role in the task. The right angular gyrus (ANG) has been associated with spatio-visual attention. It may allocate attention by employing a bottom-up strategy which draws on the area's ability to attend to retrieved memories [9]. For example, the angular gyrus plays a critical role in distinguishing left from right by integrating the conceptual understanding of the language term "left" or "right" with its location in space [10]. Furthermore, the angular gyrus has been associated with orienting in three dimensional space, not because it interprets space, but because it may control attention shifts in space [11]. The importance of the ANG and SPL regions in the task shows the importance of the Cp4 electrode.

In conclusion it can be said that in the task of bistable perception the regions of STG, SPL, and ANG of the brain are responsible. The neural activities of these regions are recorded by the electrodes of Ft8, Cp3, and Cp4 respectively. The accuracy of classification in the signals captured by these electrodes are 58.53%, 56.09%, and 60.97%.

V. Further research

In this part, we discuss further research domains related to our principal aim. In order to analyze the effect of the functionality of mentioned probable regions in rotating direction perception, one way is to stimulate various parts of the brain and test the subject's performance during the same task.

Noninvasive brain stimulation (NIBS) refers to a set of technologies and techniques with which to modulate the excitability of the brain via transcranial stimulation. Two important modalities of noninvasive brain stimulation are transcranial magnetic stimulation (TMS) and transcranial current stimulation (tCS). The second modality includes transcranial direct current stimulation (tDCS) and transcranial alternating current stimulation (tACS) (Fig. 5)[12].

A. *tDCS*

This technique was the first modern tCS technique developed and has received the most attention to date. tDCS involves the application of a low-amplitude, direct current (typically 0.5–4 mA) to the scalp via electrodes. Electric current flows from the negatively charged cathode to the positively charged anode, penetrating the skull and modifying neuronal transmembrane potentials in the current path. The effect is to modulate the excitability of a given region and alter the probability of firing an action potential. The effect of tDCS on the brain depends on several factors, including electrode location, intensity, duration, electrode size, electric field orientation, and the activity of the stimulated brain region [13]. The cortex underlying the anode typically becomes more excitable, whereas the cathode site has decreased excitability.

1. Advantages [15]:

   Modulates spontaneous neuronal activity in polarity dependent fashion

   Site-specific effects that are perpetuated throughout the brain

   Significant effects on high order cortical processes like decision making, memory, language, sensory perception, pain

   Useful in emotional regulation and visuospatial attention – up- and down regulation of different brain regions

   Small currents that do not evoke action potentials

2. Disadvantages [15]:

   Low spatial resolution

   High potential for placebo effect

Hard to define localization of the electrodes

Large variability in effects between individuals

Factors to do with hormones and fatigue levels likely to interact with tDCS

Enhancing mental function in one area can negatively impact another

B. tACS

This technique is similar to tDCS, but the current alternates at a frequency specified by the operator. This can alter the oscillatory frequencies in the brain regions being stimulated [14]. Given the role of abnormal oscillatory activity in a wide variety of pathological conditions, there is optimism that tACS may be able to normalize pathological oscillatory patterns with therapeutic effect. tDCS and tACS have not been investigated to the same extent as TMS as a clinical tool to date, yet their low cost and ease of use warrant further investigation into possible therapeutic uses [12].

1. Advantages [15]:

   May offer novel method to improve subjective sleep quality after a night with poor sleep

   Allows for modulation of brain oscillations

   Causally link brain oscillations of a specific frequency range to cognitive processes

   If specific frequencies associated with a cognitive function are known, tACS can be applied at that exact frequency.

   Modulate basic motor and sensory processes as well as higher cognitive processes like memory, ambiguous perception, decision making

   Direction insensitivity of stimulation

   Higher skin perception threshold during stimulation

2. Disadvantages [15]:

   Does not have a conventional cathode so up- and downregulation of different brain regions is not well-understood

   Experiments that require inhibition of particular brain regions are out of reach

   Lack of electrophysiological evidence

   Intracranial current density varies between people

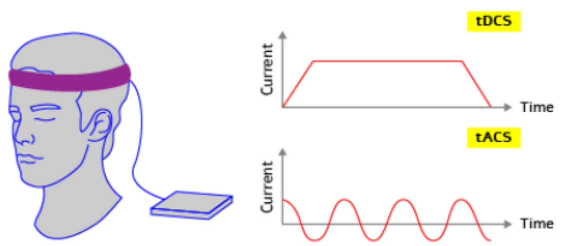

FIG. 5. TDCS VS. TACS [15]

C. Hypothesis

Further experiments must be performed in order to come up with a conclusion about the effective brain region in perception of the direction of the rotation object. Based on the discussed brain stimulation techniques and the results of our experiment, we can stimulate the three mentioned probably-effective regions of the subject's brain independently in three distinct experiments using tDCS technique and simultaneously record the EEG signals and analyze the performance of the subject during the task. This approach can lead to much more reliable conclusions about the classification and also enhanced accuracy.

VI. References

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