2021 5th Scientific School Dynamics of Complex Networks and their Applications (DCNA) | 978-1-6654-4283-1/21/$31.00 ©2021 IEEE | DOI: 10.1109/DCNA53427.2021.9586879

Effect of prehistory on the ambiguous stimuli processing in the human brain

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***Abstract*—To model the picture of the external environment, the brain uses data coming from the sensory system. However, it is believed that the brain's representation of the external environment is formed not only by sensory information, but also by a priori knowledge, the so-called predictions. This work considers how the previous sensory information (sensory prehistory) influences the processing of the current visual stimuli. Bistable images of the Necker cube with varying degrees of ambiguity were used as visual stimuli. We found EEG biomarkers possibly reflecting the effect of prehistory on the brain state and the ongoing stimulus processing.**

***Index Terms*—ambiguous visual stimuli, EEG, wavelet transformation**

I. Introduction

Analyzing neural activity in the brain is a popular task that combines physics, mathematics, neurophysiology, etc. It includes but not limited to the study of epileptic seizures [1], motor imagery [2], and cognitive functions [3]. Along with the fundamental meaning, progress in these field may facilitate the development of both passive [4] [5] [6], and active brain-computer interfaces [7].

An important topic in neuroscience is studying mechanisms that the brain uses to interact with the external environment. It is believed that the formation of the brain's representation of the external environment occurs not only due to incoming sensory information, but also due to a priori knowledge, called predictions. [8] [9]. Information processing is organized hierarchically: low levels detail the information, while high levels interpret the information as a whole. In this concept, predictions are usually considered by scientists as high-level processes that act on mechanisms at a lower level in the processing hierarchy.

The literature shows that the formation of stimuli patterns occurs due to top-down expectations [10] [11] [12]. The brain correlates these patterns with external factual information [13]: patterns are transmitted from high levels to low levels, while signals going in the opposite direction encode the corresponding errors [14]. Thus, predictive signaling reflects top-down processes, and predictive error signaling represents bottom-up processing. These processes are interdependent and always interact with each other [15].

In this work, the subjects were consistently presented with bistable visual stimuli with different levels of ambiguity. We have considered the neurophysiological mechanism of brain processing of these visual stimuli. We analyzed how the ambiguity of the previous visual information affects the processing of the current visual stimulus by the brain. We hypothesized that the previous stimulus might modulate the subject's expectation and, therefore, influence the processing of the next stimulus.

II. Methods

A. Participants

The experiments involved twenty healthy subjects (16 men and 4 women) aged 20 to 36 years with normal or adjusted to normal visual acuity. All the subjects were instructed and familiarized in detail with the experimental task, and also signed an informed consent before the start of the experimental sessions. All participants of the experiment confirmed that they had not participated in such experiments for the last 6 months. The works on the experiment were conducted in accordance with the Helsinki Declaration and approved by the local research ethics committee of Innopolis University.

B. Task

The Necker cube was used as an ambiguous visual stimulus. All images were divided into two groups: images with high degree of ambiguity (HA stimuli) and images with low degree of ambiguity (LA stimuli). The entire experiment lasted about 40 minutes for each participant, including short EEG recordings at rest before and after the main part of the experiment [16]. During the experiment, subjects perceived the cubes with varying degrees of ambiguity presented on the screen in random order. Participants in the experiment were instructed

This work is supported by Russian Science Foundation (project 19-12-00050)

to determine the orientation of each Necker cube and report their choice using the joystick (the left button corresponds to the left orientation of the image, the right button corresponds to the right orientation of the image). To assess the behavioral response of the subjects, we measured the reaction time to each visual stimulus (RT). RT was calculated as the time elapsed from the moment the visual stimulus was presented to the moment the subjects pressed the button.

C. EEG recording

To register EEG signals, we used the method of monopolar registration, as well as an extended classical scheme of the arrangement of electrodes 10-10. We recorded 31 signals with two reference electrodes A1 and A2 on the earlobes and a ground electrode N just above the forehead.The signals were obtained using Ag/AgCl adhesive electrodes. The electrodes were attached to the surface of the head using Tien–20 paste (Weaver and Company, Colorado, USA). Increasing the conductivity of the skin, as well as reducing its resistance, was carried out using an abrasive gel "NuPrep" (Weaver and Company, Colorado, USA).

We monitored the resistance of the electrodes throughout all the experimental sessions. Typically, these values did not exceed 2-5 kΩ. For amplification and analog-to - digital conversion of EEG signals, an electroencephalograph "Encephalan-EEG-19/26"(Medikom MTD company, Taganrog, Russian Federation) with several EEG channels and a two-button input device (keyboard) was used.

D. EEG preprocessing

The raw EEG signals were filtered by a bandpass filter with a finite pulse response with cut-off points of 1 Hz and 100 Hz and a 50 Hz notch filter using an integrated hardware and software package. The removal of eye blinking and heartbeat artifacts was performed by independent component analysis (ICA) using the EEGLAB software. Since artifacts with high amplitudes were present on the EEG recordings, we excluded the tests where such artifacts were present. As a result, out of the initial 400 trials, we left 320.

We divided the received EEG signals into equal segments of 4 seconds in length. Each such segment contained an EEG recording associated with the demonstration of one Necker cube, including a 2-second interval before and a 2-second interval after the demonstration of the Necker cube.

We grouped the cubes LA and HA based on the ambiguity level of the previous cube. In addition, we took into account the ambiguity of the cube represented by two cubes earlier (the second is the previous one). Finally, we have formed four conditions for the HA and LA stimuli: condition 1 – both previous cubes have a low level of ambiguity (LA-LA); condition 2 – the first previous cube has a low level of ambiguity, and the second previous cube has a high level of ambiguity (HA-LA); condition 3 – the first previous cube has a high level of ambiguity, and the second previous cube has a low level of ambiguity (LA-HA); condition 4 – both previous cubes have a high level of ambiguity (HA-HA). We leveled the number of EEG recordings for all conditions. As a result, 16 records were considered for each condition.

E. EEG analysis

We calculated the spectral power for each trials in the frequency range 4-40 Hz using the Morlet wavelet. The number of cycles (n) was defined as $n = f$, where f is the frequency of the signal. The wavelet analysis was performed in the Matlab environment using the Fieldtrip toolkit. Intervals of 0.5 seconds on each side of the record were reserved for calculating the power of the wavelet. As a result, we considered the power of the wavelet at the interval of 3 s, including the prestimul state (from -1.5 to 0 s) and the activity associated with the stimulus (from 0 s to 1.5 s). For the resulting wavelet power, we considered the event-related spectral perturbations (ERSP) (visual stimulus demonstration) using the baseline correction [stimulus – baseline]/baseline.

III. Results

The analysis of behavioral responses showed that the ambiguity of the previous visual stimulus affected the time that the subject spent on identifying the current image. The response time was lower if the previous and current visual stimuli had the same level of ambiguity. Based on these results, we compared the prestimulus activity between condition 1 and condition 4. We found a significant negative cluster in the frequency range of 16 - 18.75 Hz, localized in the occipital and parietal regions of the brain (O2, Pz, CPz channels). The spectral power of this cluster in condition 4 was higher than in condition 1.

IV. Conclusion

We analyzed the response time and cortical activity at the sensor level in a group of subjects during ambiguous visual stimuli classification task. A cluster in the pre-stimulus state was found to correlate with the effect of previous visual stimuli on the processing of the current visual stimulus. At the same time, there were no significant differences between the conditions either for the time of presentation of the current Necker cube, or for the ratio of orientations of the current visual stimuli. Thus, we conclude that the observed change in spectral power was caused only by the ambiguity of the previous stimulus, but not by the duration of the experiment or the current orientation of the stimulus.

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