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Studying the interaction between top-down and bottom-up processes during ambiguous perception

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***Abstract*—There is a view that the brain processes sensory information through the interaction between two types of processes, bottom-up and top-down. Bottom-up processes originate in the sensory areas at the earlier processing stages and process the stimulus details. Top-down components occur in the anterior cortical sites carrying information about the internal state of the subject, their mental state, and experience. Modern neuroscience relates bottom-up components with the high-frequency EEG rhythms, while low-frequency rhythms subserve the top-down ones. The interaction between the top-down and bottom-up processes attracts the attention of scientists worldwide, but numerous important questions remain unresolved. In this lecture, we address this issue by using an ambiguous stimuli paradigm, Necker cubes. When the Necker cube is unambiguous, the contrast of the inner edge defines its orientation, left or right. When the cube is unambiguous, the morphology of inner edges barely defines orientation. We suppose, that in the first case, the observer uses bottom-up mechanisms to process the cube's morphology. In the latter case, they mostly rely on top-down mechanisms. Thus, manipulating the image ambiguity, we expect the prevalence of the bottom-up processes over the top-down and vice versa.**

***Index Terms*—ambiguous stimuli, Necker cubes, visual perception, top-down processes, bottom-up processes**

I. Introduction

There is a view that the brain processes sensory information through the interaction between two types of processes, bottom-up and top-down [1], [2]. Bottom-up processes originate in the sensory areas at the earlier processing stages and process the stimulus details. Top-down components occur in the anterior cortical sites carrying information about the internal state of the subject, their mental state, and experience. Modern neuroscience relates bottom-up components with the high-frequency EEG rhythms [3], while low-frequency rhythms subserve the top-down ones [4]. The interaction between the top-down and bottom-up processes attracts the attention of scientists worldwide, but numerous important questions remain unresolved. In this lecture, We address this issue by using an ambiguous stimuli paradigm, Necker cubes. When the Necker cube is unambiguous, the contrast of the inner edge defines its orientation, left or right. When the cube is unambiguous, the morphology of inner edges barely defines orientation. We suppose, that in the first case, the observer uses bottom-up mechanisms to process the cube's morphology. In the latter case, they mostly rely on top-down mechanisms. Thus, manipulating the image ambiguity, we expect the prevalence of the bottom-up processes over the top-down and vice versa.

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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 of them gave their written informed consent in advance. All participants were familiar with the experimental task and had not participated in such experiments in the last 6 months. The experimental studies were conducted in accordance with the Helsinki Declaration.

B. Task

We used Necker cube images as ambiguous visual stimuli [5]. They have transparent internal edges defining the stimulus orientation [6]. The control parameter (a) sets the stimulus orientation and ambiguity. Thus it divides images into two groups: high-ambiguity (HA) and low-ambiguity (LA) [7]. During the experiment, participants perceive the cubes with varying degrees of ambiguity in random order. They receive instruction 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). For each stimulus, we measure the response time (RT), passed from the presentation moment to the moment of choice. We excluded wholly ambiguous stimuli; therefore we suppose that subject defines orientation based on the morphology of the inner edges. We treat the response as correct if the pressed button reflects the orientation, defined by the control parameter. Thus, we evaluate the error rate (ER) as a percentage of the errors.

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C. EEG analysis

EEG signals were recorded using the monopolar registration method and the classical extended 10-10 layout. 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 cup adhesive electrodes placed on a Tien–20 paste. Typically, the resistance values varied in the range of 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).

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. After the EEG preprocessing procedure, we excluded some trials due to high-amplitude artifacts. The recorded EEG signals were segmented into 4-second recordings, where each recording was associated with a single Necker cube demonstration, including a 2-second interval before and a 2-second interval after the Necker cube demonstration.

We calculated the spectral power for each trial in the frequency range 4-40 Hz using the Morlet wavelet [8]. 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 prestimulus state (from -1.5 to 0 s) and the activity associated with the stimulus processing (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 [9].

III. Results

The participans responded faster to LA stimuli (M=0.86s, SD= 0.24) than to HA stimuli (M=1.09s, SD= 0.3): $t(19) = 5.83, p < 0.001$. ER was higher for HA stimuli (M=8.95%, SD= 11.5) than for LA stimuli (M=1.65%, SD= 2.6): $Z = 3.5, p < 0.001$.

Contrasting ERSP during HA and LA stimuli processing for 0.5 s, post stimulus onset, we observed a significant positive cluster with $p = .0089$ extended from the stimulus onset to 0.15 s in the θ-frequency band $7.25 - 8.5$ Hz and included midline central (Cz), right fronto-central (FC), and right fronto-temporal (FT) sensors. Another significant cluster with $p = 0.0049$ extended from approximately 0.02 s to 0.2 s in the β-frequency band $23 - 23.8$ Hz and included the midline occipital (O2), right parietal (P4), and parieto-central (CP4) sensors.

IV. Conclusion

We found that high ambiguity induced higher anterior EEG power in the. θ-band for 0.15 s post-stimulus onset. In line with previous studies, we treated it as a biomarker of top-down control [10]–[12], e.g., the prevalence of expectations and prior experience in ensuring correct perception when the sensory information is inconclusive [13].

High ambiguity also caused higher EEG power in the β-band over the occipito-parietal electrodes for 0.02–0.2 s post-stimulus onset. Previously, this activity was linked to the interaction between occipital and parietal cortical regions, necessary for stimulus disambiguation [14].

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