The influence of perception bias on behavioral characteristics during the interpretation of bistable sensory information

Alexander Kuc
Baltic Center for Artificial Intelligence and Neurotechnology
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
kuc1995@mail.ru

Vladimir Maksimenko
Neuroscience and Cognitive Technology Lab
Innopolis University
Republic of Tatarstan, Russia
Baltic Center for Artificial Intelligence and Neurotechnology
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
maximenkovl@gmail.com

***Abstract*—In this paper, an extended experimental paradigm was proposed related to the interpretation of bistable images, Necker cubes. In addition to the classic image of the Necker cube, we shown its mirror projection, which provided left-oriented and right-oriented cubes with a perspective from above and below. We showed a perception bias regarding to the perspective from above, which was confirmed by a lower reaction time, as well as its disappearance with high ambiguity of sensory information.**

***Index Terms*—Necker cube, ambiguous images, cognitive task, perceptual bias, behavioural estimates**

I. Introduction

Perception is the most important function of the brain that helps us interact with each other and with the environment. Perception reflects the identification and interpretation of sensory data to understand the information presented. The study of neurophysiological mechanisms of the process of perception of sensory information is an important and actual task both from a fundamental point of view [1] and from a practical point of view in the development of brain-computer interfaces [2] and systems for monitoring the cognitive state of a person [3].

It is believed that the processing of visual information by the brain combines bottom-up and top-down components. The bottom-up component reflects sensory processes that focus our attention on the features of stimuli and process sensory information in the visual cortex [4], [5]. The top-down component relies on internal processes and uses information stored in our memory. The role of the top-down component increases when the observer encounters ambiguous sensory information [6]. When an observer looks at a completely ambiguous image, different interpretations of this image involuntarily switch under the action of an internal top-down component [7]. However, in some cases, the observer may have a tendency to interpret sensory data in a certain way. For example, when interpreting a bistable image of a Necker cube, observers demonstrates a certain inclination in favor of an image with a perspective from above (FA) [8]. This may reflect a kind of everyday statistics: we usually look at objects from above more often than from below.

Little is known about the subjectivity of perception in purposeful behaviour when subjects make decisions regarding the interpretation of the Necker cube. In this paper, we expanded our previous experimental paradigm [9] by showing the classical drawing of the Necker cube and its mirror projection, providing left and right orientation of stimuli with both a perspective from above (FA) and a perspective from below (FB). We tested how perspective (FA vs FB) affects the behavioural results of the subjects.

II. Materials and methods

A. Experiment

To conduct an experimental study, we recruited a group of volunteers consisting of 20 subjects aged 18 to 26 years ($M = 19.8$, $SD = 2.4$) with normal or normalized visual acuity. The subjects were placed in a comfortable chair in front of the monitor screen. The monitor displayed bistable images, Necker cubes [10], with different levels of ambiguity and orientation. The ambiguity and orientation of the images depended on the balance between the contrast of the inner edges. To do this, we introduced the control parameter $a = g/255$, where g is the brightness of the inner edges in the gray palette. We used a set of images of the Necker cube with the parameter a = 0.15, 0.25, 0.4, 0.45, 0.55, 0.6, 0.75, 0.85. Such a set of images can be divided on the one hand into stimuli with a high level of ambiguity (HA, a = 0.4, 0.45, 0.55, 0.6) and with a low level of ambiguity (LA, a = 0.15, 0.25, 0.75, 0.85). On

This work is supported form the President Grant (project MD-2824.2022.1.2, NSh-589.2022.1.2) and the Ministry of Science and Higher Education of the Russian Federation (Baltic Federal University Program of Development within the Priority2030 Program)

979-8-3503-0574-6/23/$31.00

the other hand, left-oriented (a = 0.15, 0.25, 0.4, 0.45) and right-oriented (a = 0.55, 0.6, 0.75, 0.85) visual stimuli [11]. In addition, all stimuli were mirrored around the horizontal axis. Thus, the experimental set consisted of 16 stimuli: 8 cubes with different contrast of internal edges, presented with two possible orientations (0 degrees and 180 degrees rotation). The subjects were instructed to determine the orientation of each demonstrated Necker cube and report their decision using a two-button joystick. The whole experiment lasted about 40 minutes. During the experimental sessions, cubes with a predefined parameter a were randomly demonstrated 400 times, each cube with a certain ambiguity, orientation and projection was presented about 25 times.

B. Protocol

During the experimental sessions, we formed a protocol. For each visual stimulus, we evaluated the behavioural response by measuring the reaction time (RT), which corresponded to the time elapsed from the presentation of the stimulus to pressing the button. For each participant of the experiment, we calculated the error rate (ER) as the percentage of erroneous responses. The correctness of each response was assessed by comparing the actual orientation of the stimulus with the response of the subject.

C. Analysis of experimental data

We performed a statistical analysis at the group level for the median RT value using three within-subject factors: the level of ambiguity, orientation and perspective. The main effects were evaluated using the analysis of variance (ANOVA) with repeated measurements [12]. For post-hoc analysis, we used either the t-criterion for dependent samples or the Wilcoxon criterion for dependent samples, depending on the normality of the distribution. The normality of the distribution was verified using the Shapiro-Wilk test. The statistical analysis was carried out using the SPSS Statistics software.

III. Results

We observed significant main effects of $ambiguity$ and $orientation$. There were also significant main effects of the interaction of $perspective * orientation$ and $ambiguity * perspective * orientation$. The impact of other factors on RT was negligible.

Post-hoc analysis showed that RT for HA stimuli was higher than RT for LA stimuli ($p < 0.001$). Studying the main effect of $orientation$, it was noticed that the subjects reacted faster to the right-oriented stimuli than to the left-oriented stimuli ($p = 0.01$). Studying the effect of the interaction of $orientation$ and $perspective$, it was found that RT depends on orientation differently depending on perspective. For the classical image, RT didn't differ between left-oriented and right-oriented stimuli. For the mirror image, the RT values for left-oriented stimuli exceeded the RT value for right-oriented stimuli ($p = 0.003$). Finally, a significant effect of the interaction of all factors indicated that RT changed between left-oriented and right-oriented stimuli depending on their ambiguity and perspective. Post-hoc analysis showed that RT for HA stimuli didn't differ between orientations on both perspectives. For LA stimuli, RT differed between orientations in different ways depending on the perspective. For the classical drawing, the subjects reacted faster to left-oriented LA stimuli than to right-oriented stimuli. For the mirror image, the subjects reacted faster to right-oriented LA stimuli than to left-oriented stimuli.

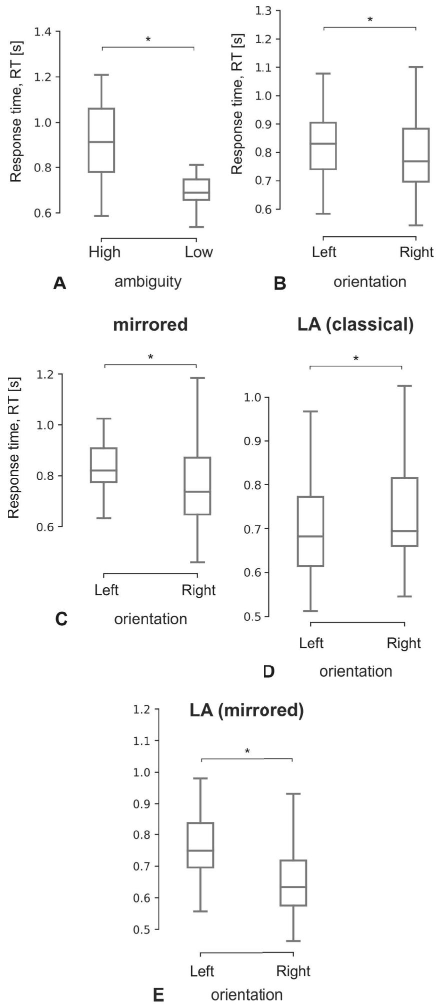

Fig. 1. Analysis of reaction time to experimental stimuli.

IV. Conclusion

In this paper, we have studied the influence of the perspective of a visual image on the process of perception of this image from the point of view of behavioural reactions. We proposed an extended experimental paradigm for the interpretation of bistable images, Necker cubes, in which mirror projections were added in addition to classical images. It has been shown that when the Necker cube is viewed purposefully, the response time to images with an FA perspective is lower than for images with an FB perspective. With high ambiguity, this difference decreases, which indicates a change in the strategy of processing stimuli. In future studies, we plan to identify EEG biomarkers that identify these changes in the processing of visual stimuli and explain the bias in the perception of sensory information.

REFERENCES

[1] A. Kuc et al., "Sensor-level wavelet analysis reveals eeg biomarkers of perceptual decision-making," Sensors, vol. 21, No. 7, pp. 2461, 2021.

[2] V. A. Maksimenko et al., "Nonlinear analysis of brain activity, associated with motor action and motor imaginary in untrained subjects," Nonlinear Dynamics, vol. 91, pp. 2803-2817, 2018.

[3] A. Batmanova et. al., "Predicting perceptual decision-making errors using EEG and machine learning," Mathematics, vol. 10, No. 17, pp. 3153, 2022.

[4] C. G. Richter et al., "Top-down beta enhances bottom-up gamma," Journal of Neuroscience, vol. 37, No. 28, pp. 6698-6711, 2017.

[5] L. Melloni et al., "Interaction between bottom-up saliency and top-down control: how saliency maps are created in the human brain," Cerebral cortex, vol. 22, No. 12, pp. 2943-2952, 2012.

[6] X. Fan et al., "The bottom-up and top-down processing of faces in the human occipitotemporal cortex," Elife, vol. 9, pp. e48764, 2020.

[7] L. Parkkonen et al., "Early visual brain areas reflect the percept of an ambiguous scene," Proceedings of the National Academy of Sciences, vol. 105, No. 51, pp. 20500-20504, 2008.

[8] J. Kornmeier, R. Wörner, A. Riedel and E. L. Tebartz, "A different view on the necker cube-differences in multistable perception dynamics between asperger and non-asperger observers," PLoS One, vol. 12, No. 12, pp. e0189197, 2017.

[9] A. K. Kuc, V. A. Maksimenko, M. V. Khramova and A. E. Hramov, "Study of sensory information processing depending on visual stimulus complexity based on multichannel EEG signals," Informatsionno-upravliaiushchie sistemy, No. 1, pp. 73–80, 2020.

[10] A. K. Kuc et al., "Monitoring brain state and behavioral performance during repetitive visual stimulation," Applied Sciences, vol. 11, No. 23, pp. 11544, 2021.

[11] V. A. Maksimenko et al., "Dissociating cognitive processes during ambiguous information processing in perceptual decision-making," Frontiers in Behavioral Neuroscience, vol. 14, pp. 95, 2020.

[12] V. A. Maksimenko et al., "Effect of repetition on the behavioral and neuronal responses to ambiguous Necker cube images," Scientific Reports, vol. 11, No. 1, pp. 1-13, 2021.