Neuroscience 237 (2013) 161–169

CORRELATION BETWEEN THREE-DIMENSIONAL VISUAL DEPTH AND N2 COMPONENT: EVIDENCE FROM EVENT-RELATED POTENTIAL STUDY

B. LIU, [a,b]* X. MENG, [c] G. WU [c] AND J. DANG [a,d]

[a] *School of Computer Science and Technology, Tianjin University, Tianjin 300072, PR China*

[b] *Center for Neural and Cognitive Computation, Tsinghua University, Beijing 100084, PR China*

[c] *Department of Computer Science and Technology, Tsinghua University, Beijing 100084, PR China*

[d] *School of Information Science, Japan Advanced Institute of Science and Technology, Nomi 923-1292, Japan*

Abstract—In this paper, we investigated event-related potentials (ERPs) evoked by visual stimuli with different three-dimensional visual depths. Before the experiment, tests for binocular advantage and for sensitivity to three-dimensional depth were carried out, respectively. At the same time, it should be ensured that the distinguishing degree of different depths is big enough. After the qualified participants were selected, pictures with five different three-dimensional depths were presented to the participants who were asked to give a judgment of the depths. The behavioral results showed that under the five different depths, the participants had a very high accuracy of judgment. ERP results showed that in the time windows of 90–130 ms and 150–200 ms after the onset of visual target stimuli, P1 and N2 components appeared in the area from parietal to occipital regions. It was interesting that there existed a positive correlation between the amplitude of the N2 component and the absolute value of the depth. Meanwhile, time–frequency analysis results showed that, in the time window of 150–200 ms after the onset of visual target stimuli, a similar positive correlation between the time–frequency distribution and the absolute value of the depth was also found. Additionally, in the time window of 200–600 ms after the onset of visual target stimuli, the alpha waves evoked under the five different depths were almost the same, which reflected that the cognitive process of three-dimensional visual depth might be finished by 200 ms after the onset of visual target stimuli, when the brain is in a state of relaxation.

Key words: three-dimensional visual depth, depth perception, N2, positive correlation, ERP.

INTRODUCTION

Vision path is a common way of receiving outer information and the physical basis of obtaining spatial perception (Anzai et al., 1999). The human brain obtains its three-dimensional visual perception through binocular disparity and reconstructs the three-dimensional visual information in the visual cortex area by using relevant information such as the nuance difference and features of two pictures mapped into the retina (Barlow et al., 1967; David, 1996; Anzai et al., 1999; Palmer, 1999; Howard and Rogers, 2002; Parker, 2007; Didyk et al., 2011). Research on computer vision is based on the same principle; that is, submitting two-dimensional images into a computer and then obtaining a three-dimensional image by pattern-matching methods. However, because the visual cognitive process of the human brain is considered as a black box in this principle, problems such as excessive algorithm complexity and low accuracy occur. Therefore, it is necessary to study the three-dimensional visual perception of the human brain, so as to provide a theoretical basis and constraint condition in accordance with the neural activity mechanism for computer vision research (Ge et al., 2005).

Regan and Spekreijse (1970) first adopted the event-related potential (ERP) experiment method to study binocular depth perception. Random scatter diagram for the left and right eyes were constructed, respectively, and used as visual stimulus materials for binocular integration. Additionally, in order to avoid familiar-cues, squares, which had three angular disparities (10′, 20′ and 40′), were adopted as visual target stimuli. A positive-going ERP component was elicited at 94 ms and peaked at 160 ms after the onset of stimuli. The amplitude of this ERP component was slightly different under different angular disparities. Ge et al. (2005) adopted the self-made multi-channels VEP signal collection system and two sets of random dot stereograms to study and analyze the cortex potentials in the three-dimensional visual depth cognitive process. They found that the regions where the N2 wave was evoked involved in the primary and senior visual cortexes. It was suggested that the cognitive process of three-dimensional visual depth was a concerted integration of complicated information. Dave et al. (2004) found that the P1–N2 combination wave appeared in the occipital area when they studied the effect of corpus callosum in binocular integration, and the amplitudes of P1–N2 varied under different depth conditions.

*Correspondence to: B. Liu, School of Computer Science and Technology, Tianjin University, Tianjin 300072, PR China. Tel: +86-10-62781789; fax: +86-10-62781789.

E-mail address: liubaolin.china@gmail.com (B. Liu).

Abbreviations: ANOVA, analysis of variance; ERPs, event-related potentials; TFD, time–frequency distribution; TFR, time–frequency representation.

0306-4522/12 $36.00 © 2013 IBRO. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuroscience.2013.01.045

In addition, there exists a comfort zone for binocular integration. In this zone, the binocular integration is more natural, and the comfort zone might be different for different subjects (Barlow et al., 1967; Lambooij et al., 2007; Didyk et al., 2011). Furthermore, the human eyes can only easily distinguish the two after a certain degree of the angle disparities of two depths (Didyk et al., 2011).

Up till now, most of literatures mainly focus on the mechanism of the three-dimensional vision perception in the human brain. Although some studies have proved the disparities of ERP components evoked by different depths (Regan and Spekreijse, 1970; Dave et al., 2004), it is still unknown whether there is a correlation between vision depths and ERP components.

Based on the above mentioned, in this paper, we aim to reveal the correlation between three-dimensional vision depths and ERP components under strict experimental conditions. First, in order to select the suitable subjects we conducted a pretest to inspect subjects' three-dimensional vision; secondly, through binocular integration, a three-dimensional vision coordinate system was built. Under the unified coordinate system, we constructed three-dimensional visual images with different depths as stimuli using the ''translation transformation'' method, so as to eliminate the impact of the shift of the visual coordinate system; thirdly, it should be made sure that the target stimuli which led to the three-dimensional visual parallax appeared in the comfort zone of binocular integration, and the disparities of different depths were enough to be distinguished; Finally, simple and common geometric images were used as target stimuli, and a timber board was used to physically partition the left eye and right eye of subjects, so as to inhibit monocular cues.

EXPERIMENTAL PROCEDURES

Participants

30 volunteers from the Tsinghua University were recruited for this experiment. In the phase of the pretest, 11 of them were eliminated for their lack of keen three-dimensional depth perception or for the existence of a unilateral obvious advantage of their left or right eyes. The remaining 19 volunteers (10 men, aged 18–24 years, mean age = 20.4 years, SD = 1.8) took part in the experiment. All of these participants were not color-blind and had no history of neurological disorders. The standard visual disparities between their left eye and right eye were below 0.1. They were all confirmed to have keen three-dimensional depth vision in accordance with the experimental requirement.

Before the ERP experiment, all subjects were informed that our experiment was conducted under the guidance of the Declaration of Helsinki and approved by the Tsinghua University Institutional Review Board, and signed the Researcher's Consent Form voluntarily. Each of them was paid 35 Yuan (RMB) per hour for his/her participation.

Materials

First, the vision coordinate system was constructed. A picture with 10.6 cm length and 8.4 cm width was used, and its background was black. The picture was vertically divided into equal halves by a thin white line, which was used to demarcate the location of the vertical partition plate. In the middle of the region on each side of the white line, there was a 3.5 cm $*$ 2.6 cm rectangular zone. In the same place of the four angles of the two rectangular zones, there was a sign ''$\times$'' to demarcate the location for binocular integration, and the rectangular zones on left and right sides of the white line were not only symmetrical in terms of the white line but also in accordance with the characteristics of ''translation transformation'' (Ge et al., 2005).

Next, the target stimuli were constructed. The stimuli were gray-white geometrical figures within the two rectangular zones so as to reduce the discomfort participants might feel due to the color disparity between the foreground color and the background color. The shapes of these geometrical figures were as follows: triangle, rectangle, square, circle, oval, regular hexagon, trapezoid, diamond and parallelogram. According to the locations of the central points of these geometrical figures in the rectangular zones, the experimental materials could be classified into five conditions (see Table 1). Meanwhile, it must be guaranteed that all the three-dimensional visual stimuli should be located within the comfort zone of binocular integration (Barlow et al., 1967; Lambooij et al., 2007; Didyk et al., 2011).

We therefore constructed 45 three-dimensional visual stimuli (nine types of geometrical figures $*$ five kinds of offsets) (see Fig. 1).

Procedure

Our experiment consisted of two parts: the pretest and the experiment.

The goal of the pretest is to inspect whether the participants possessed the acute three-dimensional vision required by our experiment. We first examined their vision according to the standard vision acuity chart. Those with their vision acuity or corrected vision acuity below 1.0, or with vision disparity between two eyes more than 0.1, were eliminated. In the following depth recognition test, those whose accuracy of recognizing depth was below 70% were considered as unqualified and were not allowed to take part in the experiment. 30 volunteers participated in the pretest and 11 of them were eliminated. Finally, 19 subjects took part in the experiment.

The experiment consisted of eight blocks and each block included two parts: the study phase and the test phase.

In the study phase, the participants were asked to learn five different three-dimensional visual depths. Visual stimulus pictures with five different depths were presented to the participants one by one. When the participants perceived the three-dimensional depths, they should press the ''Enter'' key, and then a picture with five banners was shown, where the bright one represented the answer corresponding to the three-dimensional visual depth of the stimulus (see Fig. 2).

Table 1. The visual stimulus materials under the five conditions

	The position offset of the central point of the left geometrical figure to the central point of left rectangular area (+: to right; −: to left; unit: pixel)	The position offset of the central point of the right geometrical figure to the central point of right rectangular area (+: to right; −: to left; unit: pixel)
Condition 1	+16	−16
Condition 2	+8	−8
Condition 3	0	0
Condition 4	−8	+8
Condition 5	−24	+24