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Nonlinear interactions in the visual system: a steady-state VEP study

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Abstract. To study the interaction between different receptive fields in human visual processing, the present study investigated the steady-state evoked potentials (ss-VEPs) by two light emitting diodes (LEDs) lit at the different temporal frequencies, which were presented separately to each hemivisual field of the subjects. Two LEDs set in front of the subject were energized at different temporal frequencies of combinations of 7, 9, 11, and 13 Hz. The subject was asked to look at a fixation point at the midpoint. Nineteen EEGs were recorded and the data were averaged 80–100 times triggered at the peak of a light intensity for each quartile range of phase lag. The phase dependency was studied by comparing steady-state visual evoked potentials (ss-VEPs) and also by using higher-order spectra (HOS). The interactions between background EEGs and ss-VEPs were also investigated. The power spectra of ss-VEPs exhibited peaks at the frequency other than those of stimuli. HOS analysis showed that nonlinear phase coupling between the peak frequencies of ss-VEPs were partially detected. Frequencies of the visual stimuli were suspected to reflect onto the bilateral visual area. The changes in the ss-VEPs triggered by the peak of stimuli were affected by the phase lag between bilateral stimuli. Our results are suggestive of some nonlinear interactions in the visual processing over the different areas. © 2004 Published by Elsevier B.V.

Keywords: Steady-state evoked potential; Visual system; Interaction; Spectral analysis; Bispectrum; Phase coupling

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1. Introduction

The brain is composed of multiple local modules interacting with one another to process and integrate multiple sensory input from the environment. To investigate this integrative multimodule system, researchers have focused on the paradigm where stimuli oscillating at different frequencies are presented to different areas in the visual field [1]. If the brain were a linear system, visual signals with frequency f1 and f2 would give a response (EEG) with frequency composed of only f1 and f2. But as is well known, what we actually see are f2−f1, f1+f2, or 2f1−f2, etc., besides f1 and f2. This nonlinear property is supposed to characterise the integrative function of processing in the human visual system [2].

Our present research tried to study the steady-state evoked potential (ss-VEPs) as one of the outcomes of this complex visual processing. While ss-VEPs have been studied by means of linear frequency analysis, which is essentially ignorant of phase coupling or modulation of frequency, we choose to analyse them using phase-oriented protocol and higher-order spectra (HOS) analysis.

2. Subjects and methods

Subjects were healthy volunteers with age ranging from 41 to 53. Two light emitting diode (LEDs) were placed 2 m apart in front of the subject, 10 cm separated from each other. The LEDs were energized by a sinusoidal voltage wave at different temporal frequencies, such as 7, 9, 11, and 13 Hz (Fig. 1A). The subject was asked to sit relaxed and look at a fixation point at the midpoint.

EEGs were recorded from 19 electrodes placed on the scalp according to the 10–20 system with the balance noncephalic reference. Filters were set between 0.05 and 300 Hz, and signals were digitalized at 1 K samples per second using 14-bit A/D converter.

All samples were classified to four groups by the quartiles of phase lag, which is measured from each peak of the light intensity of one LED with larger frequency to the

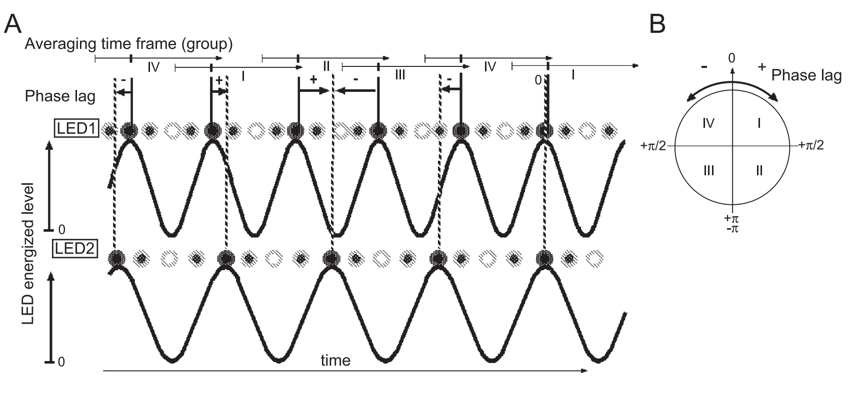

Fig. 1. (A) Two LEDs are energized in sinusoidal wave with frequency f1 and f2, respectively. Phase lag is measured from each peak of one LED (with larger frequency) to the nearest peak of the other. (B) Each time frame is classified in four groups according to its quartile range of the phase lag and averaged over each group to obtain ss-VEPs.