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Imperceptible Polychromatic Visual Stimuli for Brain-Display Interfaces

Fang-Cheng Lin[1*], Yu-Yi Chien[2], John K. Zao[3], Ching-Chi Chou[1], Yi-Pai Huang[1], Yijun Wang[4], Tzyy-Ping Jung[4], and Han-Ping D. Shieh[1]

[1] Department of Photonics & Display Institute, [2]Institute of Electro-Optical Engineering, [3]Department of Computer Science & Institute of Biomedical Engineering, National Chiao Tung University, 30010 Hsinchu, Taiwan
[4] Swartz Center for Computational Neuroscience, University of California, San Diego, La Jolla, 92093 CA, USA
*E-mail: fclin.eo93g@nctu.edu.tw

1. Introduction

Steady-state visual evoked potentials (SSVEPs) are responses to repetitive stimuli modulated at a constant temporal frequency on the central retina [1]. Using SSVEPs, Brain-computer interface (BCI) is an interactive system with high potentials. And brain-display interactive (BDI) systems can be regarded as a special type of exogenous BCIs, in which images appear on the displays are used as stimuli to evoke electroencephalographic (EEG) responses from viewers' visual cortices. For the practical purpose of inducing strong responses, most SSVEP-BCIs employ visual stimuli in the low-frequency band, which causes visual fatigue, migraine headaches and occasionally seizures.

This study demonstrates the effectiveness of inducing SSVEP using polychromatic LEDs flashing above the critical flicker frequency (CFF) for chromatic flicker to induce highly-detectable SSVEP responses and to hide these stimuli within the displayed images.

2. Methods

Regarding the luminance, duty cycles and relative phases of the component color lights, we made the choices so as to verify a hypothesis and experimental conditions are presented in Table I:

A complete alternation of two color lights (such as red/green or red/blue lights) with identical luminance, 50% duty cycles and 180° phase offsets should cause the least flickering sensation while inducing the SSVEP responses with significant SNRs.

Table I Experimental parameters

Color Light	Frequency (Hz)	Luminance (nits)	Duty Cycle (%)	Relative Phase (°)
Red/ Green	{32, 40}	{R76.5+G76.5, R51 +G102}	50	180
Red/ Blue	{32, 40}	R76.5+B76.5	50	180

3. Results

SSVEP Responses

The SNR distribution of each subject is illustrated in the box plots shown in Figure I. These visual stimuli were judged by subjects with the flicker perception of perceptible but not annoying [2].

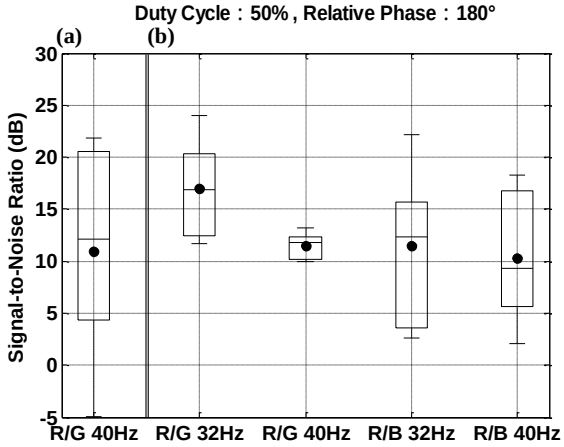

Figure I　Box plots of SSVEP SNR (dB) at Oz channel in response to R/G or R/B composite lights flickering at 32/40Hz with (a) different luminance and (b) identical luminance.

In these five imperceptibly flickering visual stimuli, the R/G lights with identical luminance, 32Hz flicker frequency, 50% duty cycle and 180° relative phase evoked the highest SNR SSVEP responses. Generally, the individual difference of R/G lights was smaller than R/B lights, and the SNRs of R/G lights were stronger than R/B lights, especially at 32Hz flicker frequency which agreed with the preponderance of L/M cones [3].

4. Conclusion

The composite R/G/B color lights induced SSVEPs with high SNRs but causing little or no flickering sensation for their viewers. These high-frequency polychromatic visual stimuli would likely find their potential use in the next generation BCI systems, especially on brain-display interactive systems.

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