Human Steady-State Visual Evoked Potentials Induced by High-Frequency Polychromatic Flickering Stimuli

John K. Zao†, Yijun Wang, Fang-Cheng Lin, Ching-Chi Chou, Heng-Yuan Kuo, Yu-Yi Chien, Kuan-Chung Tu, Yi-Pai Huang and Tzyy-Ping Jung

LIGHT EMITTING DIODES (LEDS) become increasingly popular as energy efficient light sources. Their bright and sharp light pulses also hold the promise to be effective stimuli of visual evoked potentials. By mixing flickering red/green/blue (RGB) lights of different intensity like what the LCD panels with LED backlights have been doing, one can embed invisible VEP stimuli into color displays and use those stimuli for various brain-computer interface (BCI) applications. This study demonstrates the effectiveness of inducing steady-state visual evoked potential (SSVEPs) using polychromatic LED lights flickering above the *critical flicker fusion* and *color fusion frequencies* of human vision.

Jiang et al. showed that polychromatic lights flickering above human color/flicker fusion frequencies can activate distinct visual cortical areas observable using fMRI [1]. This study performed a parallel experiment to compare the SSVEP responses induced by the same combination of red and green lights. Leveraging on high temporal resolution of EEG signals, this study compared the SSVEP responses towards red/green stimuli with different duty cycles (20%, 50%) and relative phases (0°, 90°, 180°). The same equipment and darkened shielded room for our other experiments [2] were used, but two LED stroboscopes were employed to produce red and green light pulses at identical frequencies but different intensity of 51cd/m^2 and 102cd/m^2 respectively. Nine healthy subjects (7 male and 2 female) participated in this experiment. Their 64-channel EEG signals were analyzed using fast Fourier transform (FFT) and canonical correlation analysis (CCA) techniques. Subjects also reported their flickering perception in a 1–5 progressive scale. Figure 1 displays the boxplots of (a) the signal-to-noise ratios of SSVEP recorded at Oz, (b) the ratios between the CCA coefficients at the flickering frequencies and the average of those at the non-harmonic frequencies, (c) the flicker perception scores of the best performing stimuli against those of the reference stimuli.

Experimental results showed that: (1) dual-color SSVEPs yield significant SNRs at the fundamental flickering frequencies and the SNRs vary with respect to the relative phases between the color components; (2) dual-color SSVEPs produce high SNRs in 30Hz – 40Hz just like those induced by white stimulus [2][3]; (3) certain combination of duty cycles and phases yield highest SNRs at specific flickering frequencies; (4) dual-color stimuli with different duty cycles and phases may induce compatible or less irritating flickering perception as the square waveforms. These observations imply that (1) color components of a polychromatic stimulus can induce distinct SSVEPs, which are then combined in the EEG; (2) polychromatic flickering lights in the 30Hz – 40Hz range with tunable duty cycles and phases can be used as effective SSVEP stimuli.

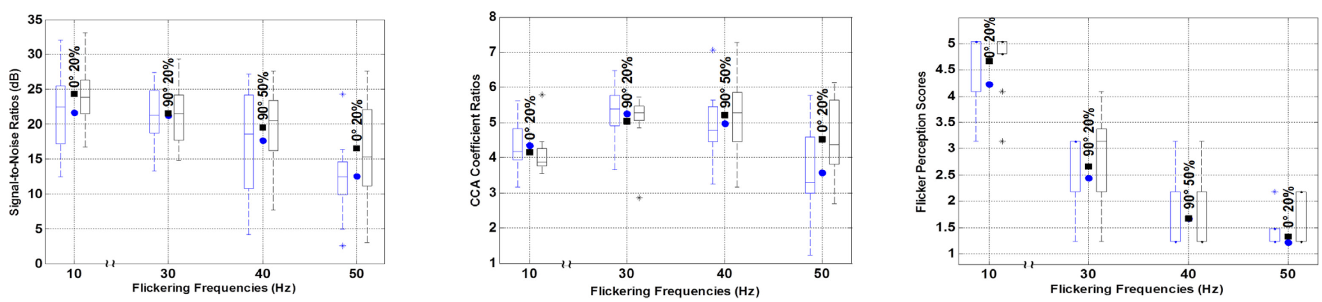

Figure 1. Boxplots compare the SSVEP responses towards red/green stimuli flickering at different frequencies, relative phases and duty cycles. Results of the best performing stimuli are plotted against those of the reference stimuli with 50% duty cycle and 0° phase offset: (a) shows their SNR values; (b) shows the ratios between the CCA coefficients at the flickering frequencies and the average of those at the non-harmonic frequencies; (c) shows subjects' flicker perception scores. Blue dots and black solid squares represent the mean responses induced by the reference and the best performing stimuli, respectively.

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John K. Zao jkzao@cs.nctu.edu.tw, the corresponding author†, is affiliated with the Computer Science Department and Biomedical Engineering Institute; Fang-Cheng Lin fclin.eo93g@nctu.edu.tw, Yi-Pai Huang boundshuang@mail.nctu.edu.tw, Yu-Yi Chien yuyichien2543.eo99g@g2.nctu.edu.tw, and Ching-Chi Chou chingchi.di00g@g2.nctu.edu.tw are with the Photonics Department and the Display Institute; Kuan-Chung Tu tukuanchung@gmail.com and Heng-Yuan Kuo hengyunkuo.iie00g@nctu.edu.tw are with the Biomedical Engineering Institute. All the above authors are affiliated with the National Chiao Tung University (NCTU) in Hsinchu, Taiwan, R.O.C. Yijun Wang wangyijun97@gmail.com and Tzyy-Ping Jung jungtp@gmail.com are affiliated with the Schwartz Center of Computational Neuroscience, University of California at San Diego (UCSD).

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