High frequency stimulations for Steady-States Visual Evoked Potentials (SSVEP)

Simon Ladouce
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)

Ludovic Darmet
ISAE-Supaero

Juan Jesús Torre Tresols
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)

Sébastien Velut
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)

High frequency stimulations for Steady-States Visual Evoked Potentials (SSVEP)

Simon Ladouce[1], Ludovic Darmet[1], Juan J. J. Tresols[1], Giuseppe Ferraro[1], Sébastien Velut[1], and Frederic Dehais[1,2]

[1]ISAE-SUPAERO, Human Factors and Neuroergonomics, Toulouse, 31000, France

[2]Drexel University, School of Biomedical Engineering, Philadelphia, PA, United State

Introduction and motivation

The Steady-States Evoked Potentials (SSVEP) characterize neural responses to the presentation of periodic visual stimuli, with specific frequency. The sustained rhythmic entrainment of visual cortex neuronal populations to the frequency of the stimuli can be recorded with surface electroencephalography (EEG). Brain Computer Interface (BCI) applications have capitalized on the robustness of the SSVEP effect to achieve unequalled classification performances (e.g., Information Transfer Rate over 300 bits/mins for a 40-class keyboard application) which has further established the SSVEP as a ubiquitous approach for reactive BCIs. Although SSVEP-based paradigms have been proven to be an efficient approach, several concerns regarding the user experience have been raised. More pointedly, the presentation of visual information with flickering rate between 6 to 30Hz has been shown to cause eye strain and may trigger photosensitive epileptic seizures. One potential remedy to improve user experience is to display high frequency stimulus. SSVEP frequencies are typically selected in the 8-20Hz range and some specific studies tried using frequencies up to 30Hz with high luminance intensity LEDs (Kuś et al., 2013). To the best of our knowledge, exploiting frequencies above 30Hz has not been documented yet in the context of BCI, using monitor display. The highest stimulation frequency is limited to half of the monitor refresh rate (Nyquist rate). Typical monitors could only display 60 frames per second limiting the presentation of stimuli to a maximum of 30Hz. The latest generations of computer monitors are characterized by their high refresh rates (i.e., up to 240 frames per seconds) that allow the presentation of higher frequency visual stimuli (up to 120Hz) opening up the use of high frequency stimuli for SSVEP-based BCI applications with better user experience.

Research question

Due to the aforementioned hardware limitations, the Signal-to-Noise Ratio (SNR) or classification performances of SSVEP-based BCI with stimuli frequencies above 30Hz have not been formally characterized. It is however widely documented that the EEG power spectrum follows a decreasing 1/f law. Although lower SSVEP signal is expected at higher frequencies, variability related to endogenous brain activity (typically recorded at low frequencies) should be less salient. An open question is therefore whether SSVEP responses at higher frequencies have a sufficient SNR to achieve high classification performance.

Methods and experimental setting

The present study aims to evaluate user experience and characterize SSVEP response elicited across a wide frequency range. To this end, subjective assessment of visual stimuli, SNR of SSVEP responses and classification performances is compared across 24 frequencies ranging from 8 to 60Hz (with a step increase of 2). Neighbouring frequencies to the line noise are excluded (48, 50 and 52Hz). Each frequency is presented alone to avoid confounding factors. We noticed that the elicited response, for example, at 30Hz is different if it is presented simultaneously next to a 8Hz or 60Hz frequency flicker. We used a standard 10-20 system 32 channel EEG from BrainProducts with a sampling frequency of 500Hz. Signals are band-pass filtered between 1-250Hz. Twelve healthy adults (4 women, mean age: 26 years, range: 21-39 years) with normal or corrected-to-normal vision participated in this study. SNR studies are performed using the Rhythmic Entrainment Source Separation (RESS) methodology (Cohen & Gulbinaite, 2017). We use the state of the art Task Related Component Analysis (Nakanishi et al., 2018) to assess classification performance. A manual selection of electrodes [O1, O2, Oz, P3, P4, Pz, P7, P8] and downsampling to 250Hz is performed for the TRCA algorithm.

Results and findings

Preliminary results reveal that the optimal trade-off between SNR/classification performance and user experience is found within the 30-38Hz range. Reported classification accuracy per frequency in Figure 1 suggests that frequency above 42Hz could not be used for a reliable SSVEP-based BCI, as accuracy is below 50% (chance level is 8%). Based on Figure 2, it implies that the maximum subjective comfort score achievable for this pool of subjects is around 7/10. For the 30-38Hz range, participants report a comfort score of approximately 5/10 (see Figure 2) and a classification accuracy of 71.8% (see Figure 1) with 1s epochs. Average accuracy only decreases by -17.4% (from 89.2% to 71.8%) compared to stimuli from the 10-18Hz range. This lower range of frequencies achieves a comfort score of approximately 3/10, really poor in terms of user experience. Thus when using higher frequency, the improvement in terms of comfort for the user is considerable while the classification performances remain acceptable. Beside that and without taking into account user experience, the sweet spot for classification performances and SNR seems to be around 16-18Hz. It is not surprising as more endogenous activity is expected in the lower range of 8-14Hz. Though in Nakanishi et al. TRCA paper they select frequencies between 8 and 16Hz. Our study seems to indicate that their performances could be improved using slightly higher frequencies. The inter-subjects variability is really high with stimuli above 38Hz. For instance for the 40Hz class, and resp. 42Hz, reported classification performances with 1s epochs range from 20% to 100% with standard deviation of 26, resp. 8% and 93% with standard deviation of 27. To compare, standard deviation of the accuracy is only 6 for 16Hz and 1s epochs. The higher ranges provide the higher user comfort but require the setting of an individual threshold for frequency range to counterbalance the inter-subjects variability.

Conclusion and future work

This study reveals that higher frequencies (above 30Hz) than usually selected for SSVEP-based BCI could be considered to improve user comfort while keeping a competitive SNR and classification performances. The preliminary results also indicate that frequencies above 42Hz are not reliable, in general as inter-subject variability is significant in this high range, for SSVEP-based BCI.

In our previous work (Ladouce et al., in press), we have shown that reducing amplitude of stimulation also improves user experience of SSVEP-BCI. Reduction of amplitude, with new trade-offs, could be brought together with the use of high frequency. To allow the comparaisons in a realistic scenario, further investigations with simultaneous flickering stimulus will be conducted in our future work.

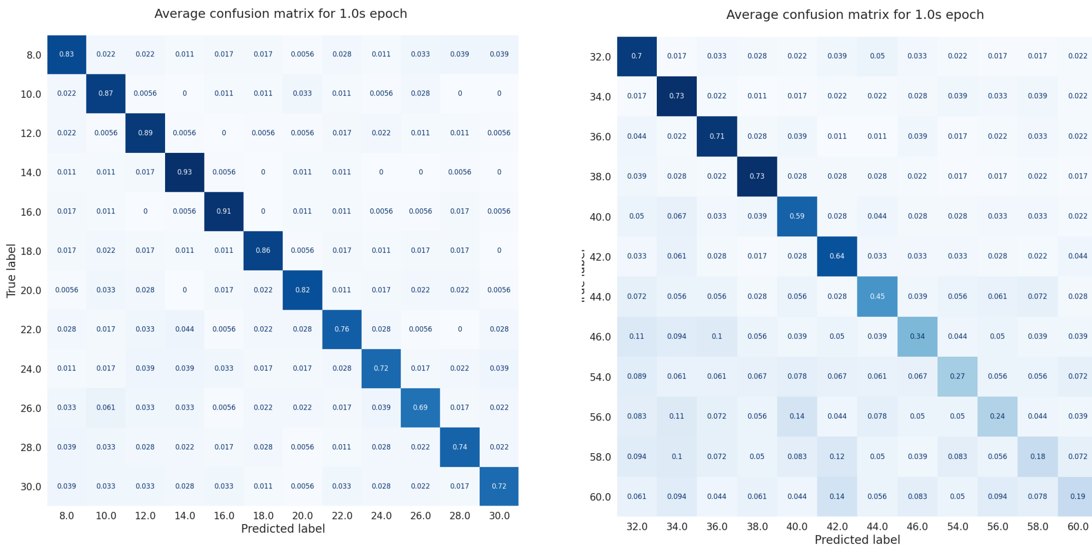

Figure 1. Confusion matrices with classification accuracy using TRCA classifier and 1s epoch. Classification accuracy is computed using 5-folds cross validation over 15 trials. We observe some reliable performances until around 40Hz when it starts to decrease. With higher frequencies (plot on the right) the SSVEP frequencies are closer to Nyquist frequency (data are downsampled to 250Hz) thus less band can be used in the filterbank of the TRCA method, which downgrades performance.

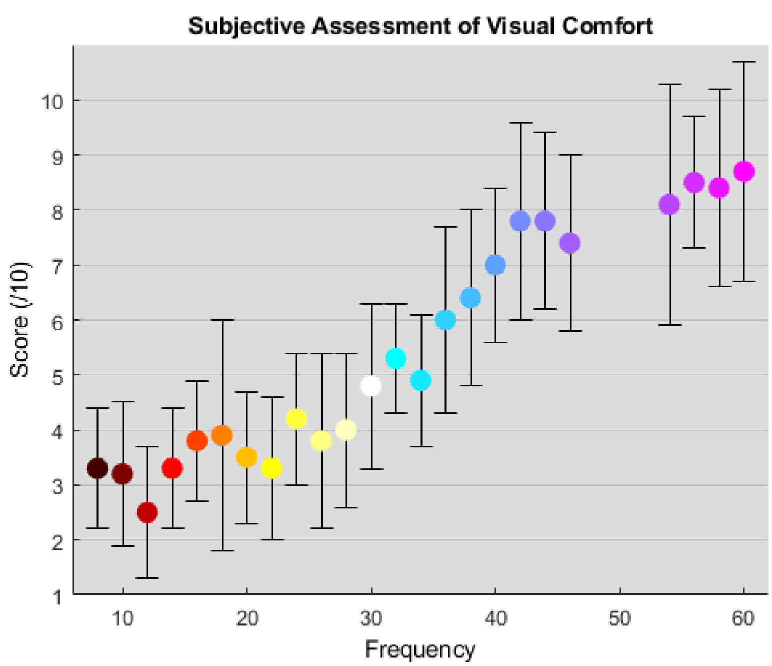

Figure 2. Grand average (N=12) subjective visual comfort assessment of RVS for each experimental frequency [8-46; 54-60]. The results indicate that visual comfort increases as a function of stimulus frequency. It can be noted that this increase in user visual comfort onsets at 30Hz.

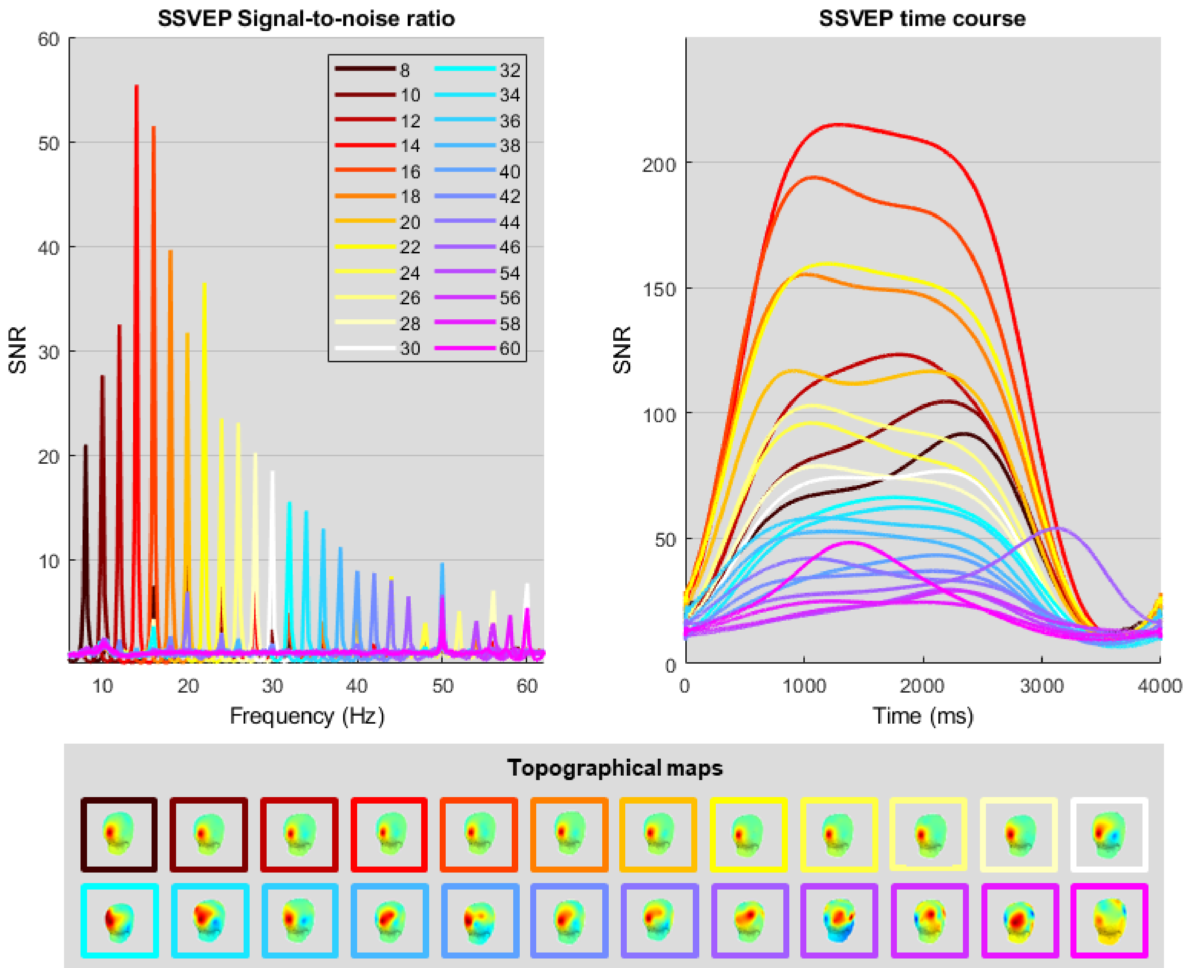

Figure 3. Top left: Grand average (N=12) Signal-to-Noise Ratio (SNR) of Steady-States Visually Evoked Potentials (SSVEP) responses elicited by each experimental frequency [8-46; 54-60]. Top right: Grand average time course of SSVEP responses. Bottom: Topographical maps representing the spatial distribution of the SSVEP responses. The SSVEP response SNR is maximal within the 16-22Hz range. Following the 14Hz peak, SNR at higher frequencies follows a regular 1/f spectral distribution trend. The prototypical occipital distribution of the SSVEP response is observed up to 44Hz. SSVEP responses elicited by frequencies over 44Hz exhibit lower SNR, unstable time course and high variance of their spatial distribution.

References:

R. Kuś, A. Duszyk,P. Milanowski, M. Łabęcki, M. Bierzyńska et al. (2013) On the Quantification of SSVEP Frequency Responses in Human EEG in Realistic BCI Conditions. PLOS ONE 8(10)

M. Nakanishi, Y. Wang, X. Chen, Y. -T. Wang, X. Gao and T. -P. Jung, "Enhancing Detection of SSVEPs for a High-Speed Brain Speller Using Task-Related Component Analysis," in IEEE Transactions on Biomedical Engineering, vol. 65, no. 1, pp. 104-112, Jan. 2018, doi: 10.1109/TBME.2017.2694818.

M. X. Cohen and R. Gulbinaite, “Rhythmic entrainment source separation: Optimizing analyses of neural responses to rhythmic sensory stimulation” in NeuroImage, vol. 147, pp. 43-56, 2017,doi: 10.1016/j.neuroimage.2016.11.036.

Y . Wang and T. -P. Jung (2010). Visual stimulus design for high-rate SSVEP BCI. *Electronics letters*, *46*(15), 1057-1058.

S. Ladouce, J.J. Tresols,L. Darmet, G. Ferraro and F. Dehais (In press). A transparent SSVEP-BCI using low amplitude modulations. IEEE Transactions on Systems, Man, and Cybernetics.