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Spatial Frequency Characterization and Optimization of SSVEP Stimuli

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Introduction: Most traditional SSVEP systems utilize rectangular stimuli that flash by alternating between two solid colors (typically white and black) at different temporal frequencies. However, it is also common for SSVEP systems to use spatial checkerboard patterns as visual stimuli, for which the checkerboards are pattern-reversed for the flashes. Several SSVEP BCI studies have examined the difference between using solid vs. a checkerboard stimulus and have reported conflicting results as to which is superior [1,2]. These studies did not examine the effects of SSVEP stimuli with respect to spatial frequency (i.e. size of the individual checks). Although spatial frequency has been studied in the clinical field by analyzing the morphology of elicited pattern VEPs, the effect of the spatial frequency of checkerboard stimuli on SSVEP performance has not been studied in the context of BCIs where multiple stimuli are presented simultaneously.

Material, Methods and Results: Data were collected from 11 healthy subjects with 16 active electrodes over the parietal-occipital regions. Subjects participated in two online SSVEP experiments in which nine different spatial frequency stimulus conditions were tested (0, 0.15, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6, and 19.2 cycles/deg). In the first experiment, subjects controlled a traditional 4-class SSVEP BCI where each of the four stimuli was presented simultaneously on the top, bottom, left and right portions of the screen flashing with temporal frequencies of 6, 6.66, 7.5 and 8.57 Hz, respectively. During the start of the trail, subjects were cued to attend to a single stimulus, followed by a 6 second stimulation period, and ending with a 2 second feedback period where the predicted target from the BCI was shown. In the second experiment, subjects used the 4-class BCI for continuous control in a simple 2d path-navigation task. The goal was use the four-class BCI (move up, down, left or right) to traverse simple paths as rapidly as possible. To test the effect that spatial frequency has on the elicited SSVEP signal, both experiments were repeated with the nine different spatial frequency conditions in a random fashion. For all trials, the SSVEP signals were classified using standard canonical correlation analysis (CCA). Figure 1 shows the average accuracy and ITR across subjects for the nine different spatial frequency stimulus conditions as well as for varying time window lengths (i.e. observation length used for classification). The SSVEP BCI accuracy (left panel) shows a bimodal distribution with a primary peak at the 0 c/deg (solid stimulus) condition and a secondary peak at the 2.4 c/deg condition. The SSVEP ITR (right panel) shows that the 2.4 c/deg condition achieves the highest transfer-rate amongst all spatial frequency conditions tested.

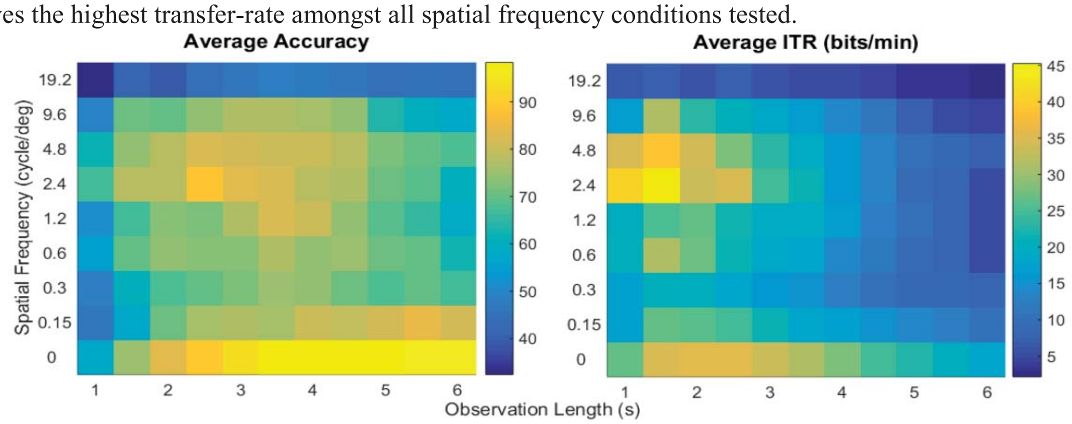

Figure 1. *Average SSVEP accuracy and ITR of the four-class SSVEP BCI from experiement 1. The accuracies and ITRs are shown for the nine differnent spatial-frequency conditions as well as for varying time-window lenghts used in the CCA based classification.*

Discussion: The 0 c/deg stimulus condition achieves the highest accuracy, which increases with increasing observation length. The 2.4 c/deg, is able to achieve a modest accuracy (~85%) in a very short time-window leading to an ITR that outperforms that of the 0 c/deg condition. Interestingly, the accuracy of the 2.4 c/deg condition (along with most of the other checkerboard conditions) decreases with observation length, supporting a potential mechanism of spatial frequency adaptation in the retina using checkerboard stimuli.

Significance: This is the first study to test the effect of different spatial frequency conditions on SSVEP BCI performance. This information can be used to determine the spatial frequency of checkerboard stimuli to optimize BCI performance, with potential improvement over solid flashing stimuli.

References:

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