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# Commanding a Robotic Wheelchair using High- or Low-Frequency SSVEP-BCI: A Comparative Study

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**Abstract**

This work presents a comparative study between low and high frequencies of visual stimulation used in a Brain-Computer Interface (BCI) based on Steady State Visual Evoked Potentials (SSVEP). This comparison has the goal of evaluating the visual tiredness produced by flickering visual stimuli in two distinct frequency ranges (low and high frequency). For this purpose, five volunteers with disabilities operated a wheelchair through a SSVEP-based BCI. In the experiments, each subject answered a questionnaire about performance and tiredness associated to the use of the BCI. Average ITR obtained for low- and high-frequency stimuli were 20.3 bits/min and 15.0 bits/min, respectively. Despite of a lower average ITR, it was found that high-frequency stimuli were more comfortable and could lead to a better performance in the accomplishment of the navigation tasks.

## 1 Introduction

Evoked potentials in electroencephalography (EEG) elicited by a train of stimuli are called Steady-State Visual Evoked Potentials (SSVEP). SSVEP can be used as a paradigm in BCI development [5]. Generally, SSVEP are stronger in low-frequency range (6 to 12 Hz) than in high-frequency range (more than 30 Hz) [6]. Therefore, the majority of SSVEP-BCI are based on low- and medium-frequency ranges [2]. However, high-frequency stimulation is less annoying and consequently produces a pronounced decrease of visual tiredness caused by flickering [6]. This statement is accepted in BCI bibliography, but there are insufficient studies focusing on it. This work presents a comparative study between two common stimulation systems used in SSVEP-based BCIs, trying to evaluate the visual tiredness of the user. More research has been conducted using computer screens than other stimulation source [7] and checkerboards is one of the basic choices. Hence, low-frequency stimulation was presented as checkerboards on a computer screen. However, high-frequency stimuli cannot be rendered on the screen, and because of this LEDs were used.

## 2 Materials

A BrainNet BNT-36 acquisition system was used to acquire EEG signals. Twelve EEG channels with the reference electrode at the left ear lobe and filtered between 0.1 and 100 Hz were digitized at 600 Hz. Using the extended international 10-20 system, the locations for the electrodes were $P_7$, $PO_7$, $P_5$, $PO_3$, $PO_Z$, $PO_4$, $P_6$, $PO_8$, $P_8$, $O_1$, $O_2$, and $O_Z$.

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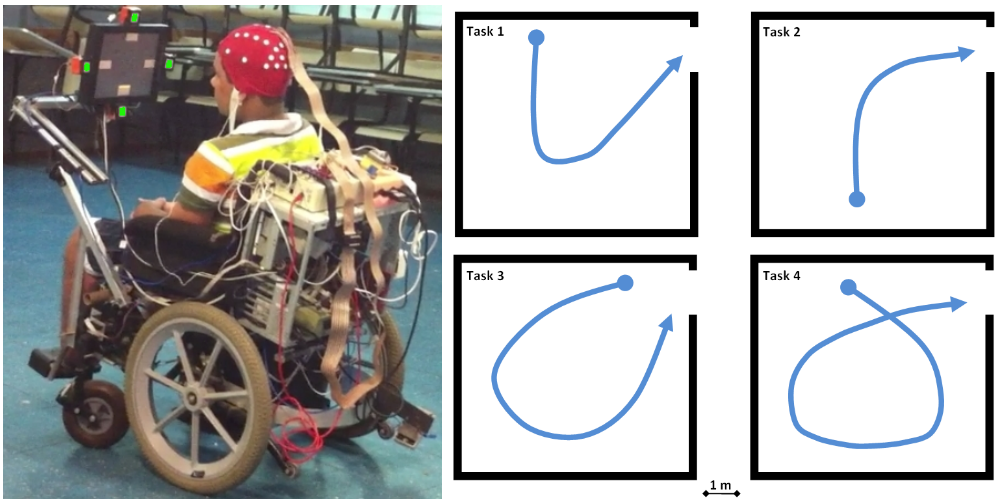
Two FPGA are used to produce stimuli in low- and high-frequencies. The stimuli in low-frequency range are shown in a 12" LCD display at a distance of 0.5 m from the user. They are composed of four black/white checkerboard stripes, flickering on the screen at 5.6 Hz (top), 6.4 Hz (right), 6.9 Hz (bottom) and 8.0 Hz (left), as illustrated in Figure 1 (a). On the other hand, stimuli in high frequency range are illuminated by high efficiency green LEDs flickering at 37 Hz (top), 38 Hz (right), 39 Hz (bottom) and 40 Hz (left) on the LCD sides, also shown in Figure 1 (a). Each checkerboard stripe or led corresponded to a movement of the wheelchair: forward, left, right and stop.




(a) Volunteer onboard the wheelchair under a low and high frequency stimulation, used at different times.

(b) The four navigation tasks.

Figure 1: Volunteer onboard a wheelchair and the four navigation tasks.

Five volunteers with different disabilities (quadriplegia, paraplegia and Duchenne dystrophy) participated on the experiments. They were informed about the experimental procedure and they (or their relatives) provided written consent to participate on. The experiments were carried out according to the rules of the Ethics Committee of UFES/Brazil (reg. number CEP-048/08).

## 3 Methods

Before operating the wheelchair, each volunteer performed a training session with the BCI. They were asked to follow the verbal cues to gaze at a stripe for 30 seconds. Visual feedback denoting the detected stripe was presented to the user. Then, the volunteers could operate the wheelchair. The four tasks are illustrated in Figure 1 (b). The room dimensions are 8.75m long by 7.07m wide. The goal of all tasks was to reach the area next to the door.

Finally, the volunteers answered a questionnaire with questions related to tiredness and comfort when using the BCI. This questionnaire allows evaluating the influence of tiredness and concentration on user performances qualitatively. The questions were:

(A) Are you tired?

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(B) Did the screen oscillations interfere with your concentration? (This question is related to screen oscillations due to wheelchair movements, particularly when it begins or ends a movement).

(C) Was the stimuli colour annoying?

These questions should be answered according to the ranking: 1 - None; 2 - A little; 3 - Medium; 4 - Quite.

The EEG signal processing method is fully described in [3]. Basically, the EEG is filtered and then, the Power Spectral Density (PSD) was determined. Later, a Spectral F-Test (SFT) is applied in the feature extraction step [1]. A classifier based on a decision tree was implemented with attributes that maximize the discrimination among classes. The training step is unnecessary for this classifier because its operation is straightforward. Moreover, baseline or reference signal are unnecessary and supervisor intervention is not required. Thus, since the user sits on the wheelchair and wears the EEG cap, he will be ready to use the BCI. This BCI worked asynchronously and detections were performed at each second, accordingly a command is sent to the wheelchair every second. On one hand, the BCI considered the first three harmonics in SSVEP detection for low frequencies. On the other hand, only the first harmonic was considered for high frequencies."

# 4 Results

Table presents the hit rate and the ITR obtained just before the wheelchair operation for low- and high-frequency stimuli. Table 1 presents the average detection accuracy (Acc) among the four classes and its respective average ITR, calculated according to [5]. The number of navigation tasks completed by each volunteer is presented as well.

Table 1: Results for low- and high-frequency stimulation.

| | Low Frequency | | | High Frequency | | |
|---|---|---|---|---|---|---|
| Vol | Acc ± SD | ITR | Completed Tasks | Acc | ITR | Completed Tasks |
| 1 | 46% ± 6.05 | 8.9 | 4 | 60% ± 13.12 | 23.7 | 4 |
| 2 | 44% ± 7.5 | 7.4 | 1 | 40% ± 10.24 | 4.7 | 3 |
| 3 | 78% ± 5.35 | 53.5 | 2 | 63% ± 15.04 | 27.8 | 4 |
| 4 | 62% ± 9.88 | 26.4 | 2 | 51% ± 13.12 | 13.4 | 3 |
| 5 | 41% ± 11.81 | 5.3 | 1 | 41% ± 9.6 | 5.3 | 2 |
| **Average** | **54%± 8.12** | **20.3** | **2** | **51% ±12.22** | **15.0** | **3** |

Classification results were evaluated using a non-parametric statistical analysis, according to sample size [4]. Hence, the Wilcoxon signed paired test was used. Differences in the hit-rates obtained from low- and high-frequency stimulation range were not statistically significant (p=0.465). At the end of the experiments, the volunteers answered the questionnaire, whose results are presented in Table 2. The median values for Question A was 'Medium' for low-frequency stimulation and 'A little' for high-frequency stimulation. This difference in tiredness was statistically significant according to Wilcoxon signed paired test (p=0.025). On the other hand, differences for the questions related to display movement and colour tiredness were not statistically significant (p=0.317 and p=0.461, respectively).

# 5 Discussions and Conclusions

Stimulation parameters are a very important issue for a SSVEP-based BCI implementation and can affect the system performance and the user comfort and safety. A statement issued in

Table 2: Questionnaire applied to the volunteers after the robotic wheelchair operation.

| Question | Frequency Range | Vol1 | Vol2 | Vol3 | Vol4 | Vol5 | Median |
|---|---|---|---|---|---|---|---|
| A | Low | Medium | Medium | A little | Medium | A little | Medium |
| | High | A little | A little | None | A little | None | A little |
| B | Low | None | Medium | Medium | None | A little | A little |
| | High | None | Medium | None | None | A little | None |
| C | Low | None | Quite | None | Quite | None | None |
| | High | A little | A little | A little | None | None | A little |

BCI bibliography is that high-frequency stimulation produces less visual tiredness than lower frequency stimulation [2], [6]. However, is high-frequency stimulation less annoying than lower frequency stimulation? The current research tries to answer partially this question by evaluating the two commonly used stimulation system in SSVEP-based BCI, checkerboards in low-frequency and LEDs in high-frequency. Note that the different stimulus patterns could affect the SSVEP signals.

In low frequency stimulation, only volunteer Vol1 could execute the four navigation tasks. Volunteers reported less tiredness for high-frequency LED stimulation than for low-frequency checkerboard stimulation (except Vol1), which was statistically significant ($p=0.025$). However, the other analyzed variables such as colour and display movement, do not seem to affect the volunteer performance, since those differences were non-significant ($p>0.05$).

Although average ITR values in low-frequency (20.3 bits/min) and in high-frequency (15 bits/min) were different, the volunteers could perform more tasks with high-frequency stimuli. Then, less tiring stimuli are visually more comfortable and could lead to a better performance.

Although the SSVEP are stronger in low-frequency range (and consequently their detection is easier), the developed BCI could detect the visual evoked potentials in high-frequency range with good performance. Results show that the LED stimuli in high-frequency range produce lower visual tiredness on the users, compared with low-frequency checkerboard. Note that the small sample size limits the conclusions exposed on this paper.

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