

# Steady State Visually Evoked Potentials and Their Analysis with Graphical and Acoustic Transformation

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**Abstract.** In this paper we present the experimental set-up that was constructed to study Steady State Visually Evoked Potentials (SSVEP). It is based on the DSM-51 unit that works as a hard real-time controller, connected with goggles containing blinking tricolor (RGB) LED diodes. The EEG system used in our experiments was Mindset-1000 with 16 channels, 16 bit Analog to Digital Converter (ADC) manufactured by Nolan Computer Systems. The EEG signal extracted from the Mindset-1000 EEG device was recorded synchronously with the stimulating signal from the DSM-51 controller.

**Keywords:** SSVEP · EEG · BCI

## 1 Introduction

Last decades have shed new light on understanding brain functionalities and also have given new technologies for looking into the brain and establishing its communication with its external environment [1–3].

Visually Evoked Potentials (VEP) have been known since 1900, when Adolf Beck studied the electrical phenomena taking place on the retina of musky octopus (*Eledone moschata*) as a result of light stimulation [4, 5].

If the stimulatory signal is of monotonous and repetitive nature, we can talk about Steady State Visually Evoked Potentials.

The SSVEP mechanism is explained as the transformation of light impulses stimulating the retina into an electrical activity in the brain's visual cortex.

The influence of light stimulation can be observed in cortical activity, however, there is still no universal function representing this process.

Good understanding of SSVEP may be very helpful for engineers designing and developing new-generation Brain Computer Interfaces (BCI) [6].

Through the research presented below we attempted to analyze how the EEG signal in the primary visual cortex (PVC) is influenced by the modulation frequency and color of the light stimulating human retina.

## 2 Materials and Methods

### 2.1 Participants

The study engaged a group of 37 volunteers, including 6 women and 31 men, aged between 19 and 49, median = 21, mean = 23.3, standard deviation = 8.49.

The characteristic of the cohort results from the fact that the majority of the group were students and faculty of the Institute of Computer Science of Maria Curie-Skłodowska University.

Before the start of the study, the nature and procedure of the experiment had been explained to the participants, and they provided a written consent for participation in it.

### 2.2 EEG Recordings

During the experiment all participants were placed in a quiet room. The EEG signal was recorded from Cz, O1 and O2 electrodes (in accordance with 10–20 system) with 256 Hz sampling frequency. The Cz electrode was treated as the reference one. The signals were amplified by the 16-channel Mindset MS-1000 system. The retina was stimulated by self-developed goggles with sinusoidally blinking tricolor (RGB) LED diodes controlled by the DSM-51 system. The DSM-51 module was working in hard real-time mode, generating the output signal with 1024 Hz sampling frequency.

Precise synchronization of the simulation signal and the EEG recording was provided by an additional junction connecting the DSM-51 system with the EEG amplifier through a selected channel. For a detailed description of the system used in the experiment see [7].

### 2.3 Design

Participants put a pair of goggles on their heads. Apart from the sinusoidally blinking diodes, the goggles provided very good isolation from external light influence.

Each subject participated in two scenarios of the experiment.

In the first scenario, for each of the 28 possible blinking light frequencies (changed by 1 Hz from 3 Hz to 30 Hz) 1 of the 37 possible colors stimulated the retina, each for the period of 1 s. There was 1 s of no stimulation (dark goggles) before a frequency change.

In the second scenario, for each of the 37 possible colors (changed from #FFFFFF to #0000FF (HTML-RGB notation, see Table 1 for details)) 28 frequencies stimulated the retina, each for the period of 1 s. There was 1 s with no stimulation (dark goggles) before a color change. Table 1 shows the set of colors used in the experiment.

The pseudo-codes listings (see Listings 1.1 and 1.2) describe the way in which the retina was stimulated in both scenarios.

**Table 1.** Stimulation colors

FFFFFF		
FFFF7F	FFFF3F	FFFF00
FF7F7F	FF7F3F	FF7F00
FF3F7F	FF3F3F	FF3F00
FF007F	FF003F	FF0000
7FFFFFFF	3FFFFFFF	00FFFF
7FFF7F	3FFF7F	00FF7F
7FFF3F	3FFF3F	00FF3F
7FFF00	3FFF00	00FF00
FF7FFF	FF3FFF	FF00FF
7F7FFF	7F3FFF	7F00FF
3F7FFF	3F3FFF	3F00FF
007FFF	003FFF	0000FF

```

# scenario 1
for each Frequency from 3 to 30 step 1
  for each Color from Table 1
    stimulate retina with Frequency and Color for 1 second
  darken goggles for 1 second
darken goggles for 28 seconds

```

**Listing 1.1.** The pseudo-code of the scenario 1

```

# scenario 2
for each Color from Table 1
  for each Frequency from 3 to 30 step 1
    stimulate retina with Frequency and Color for 1 second
  darken goggles for 1 second
darken goggles for 37 second

```

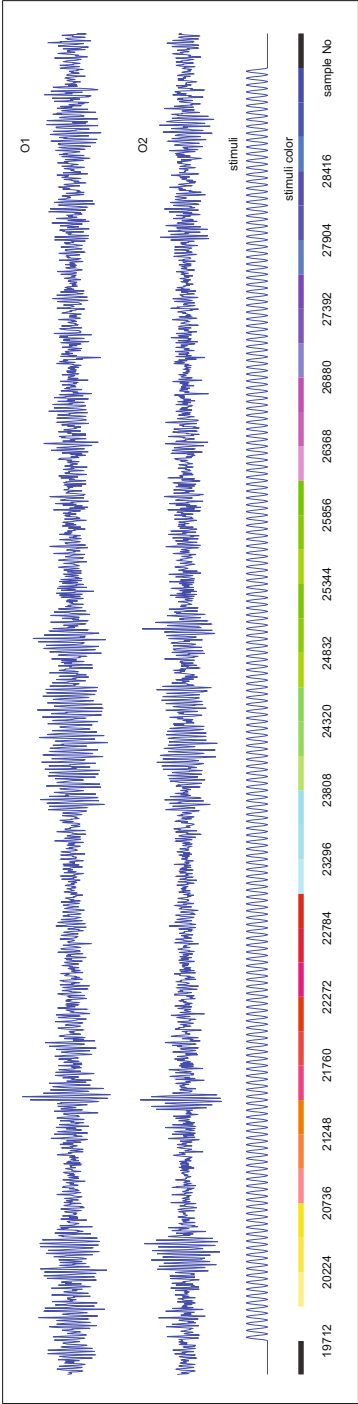
**Listing 1.2.** The pseudo-code of the scenario 2

The EEG activity was recorded from O1 and O2 electrodes. Synchronously to EEG activity, the LED modulating signal was recorded. At the end of the first scenario there were 38s of no stimulation (darkness). Similarly, at the end of the second scenario there were 29s of no stimulation. It is easy to calculate that each scenario took  $(28 + 1) \cdot (37 + 1) = 1102$  s, that is 18 min and 22 s.

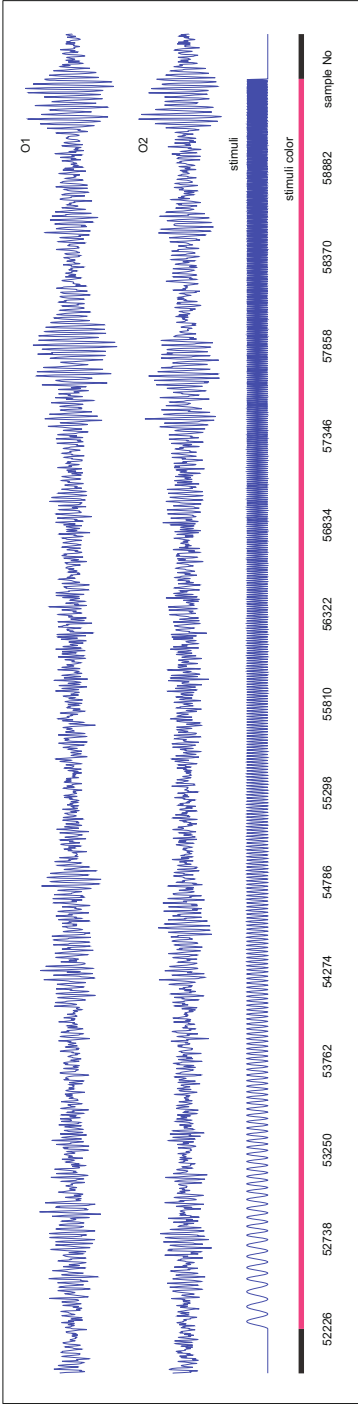
### 3 Results

#### 3.1 Initial Data Processing

The data collected during the experiment were digitally filtered in order to eliminate the frequencies exceeding our range of interest. Two sinc-types filters shaped by Blackman's window were applied. They were: a 40 Hz low-pass filter with 95



**Fig. 1.** EEG signal from O1 and O2 electrodes, stimuli signal and colors for 39 s of scenario 1



**Fig. 2.** EEG signal from O1 and O2 electrodes, stimuli signal and color for 30 s of scenario 2

samples length, mainly eliminating the 50 Hz power supply noise, and a 1.5 Hz high-pass filter with 511 samples length, eliminating slow motion artifacts.

Next, a part of 1104 s was cut out from the filtered file (two one-second periods of darkness before and after experiment were added).

Thanks to the fact that the stimulating signal from the DSM-51 was synchronously recorded with EEG activity, it was easy to define which color at which frequency was stimulating the retina at a given time. Figures 1 and 2 present the EEG and stimulating signals, as well as color sequences for fragments of both scenarios.

### 3.2 Data Analysis

In order to find the correlation between the stimulating signal and the electrical activity of PVC the Fourier transformation was applied to the data collected during experiments.

37 participants took part in the two scenarios. For 25 of them poor SSVEP susceptibility was observed, poor signal/noise ratio was achieved, or the recording was useless for analysis because of other causes.

In the case of the remaining 12 subjects, the influence of stimulation was strong enough. For the purpose of this article three interesting cases have been chosen.

Figure 3(a–c) presents 116 s of study conducted according to scenario 2 for 4 colors, derived from 3 different subjects. One can see four characteristic rising lines, which proves that stimulation has a significant effect on the EEG signal.

Figure 3d shows the Fourier transform of the stimuli signal. This facilitates the search of SSVEP in Fig. 3(a–c). The X axis is the time axis of a range of 0 to 116 s. In order to facilitate the interpretation of the figure, the colors of light used for stimulation are shown.

Figure 4(a–c) shows 1102 s of the Fourier transform of the study conducted according to scenario 2. This shows the study for all 37 colors, for the same three subjects.

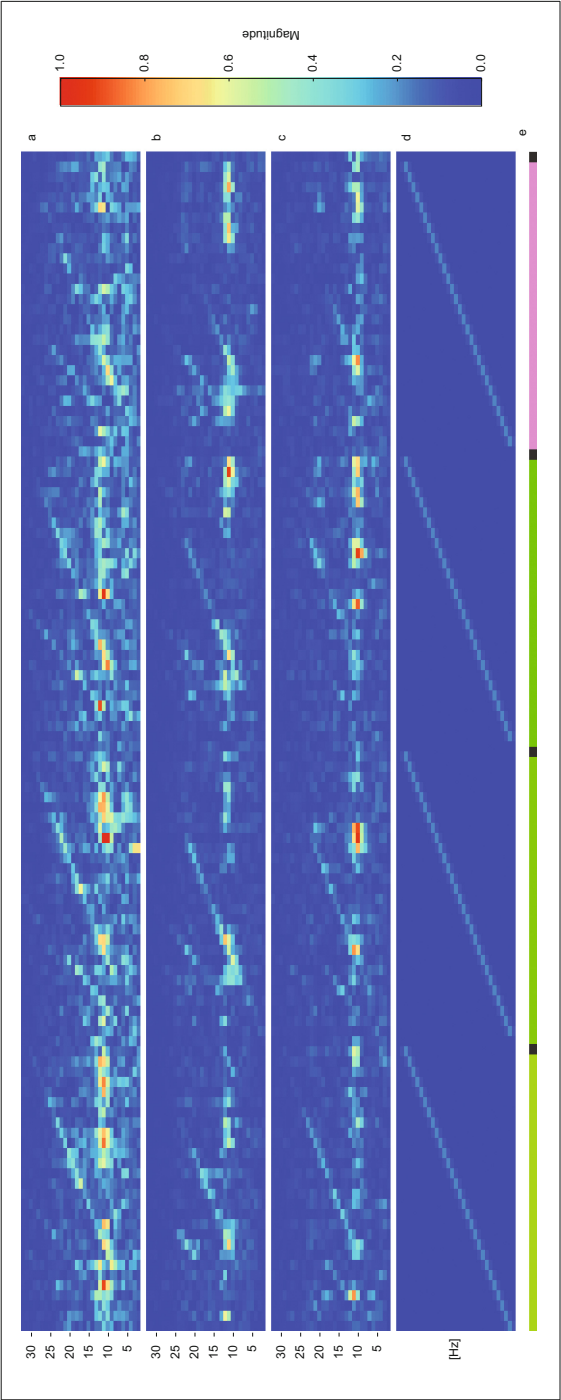
Figure 4d shows the Fourier transform of the stimuli signal. This facilitates the search of SSVEP in Fig. 4(a–c). The X axis is the time axis of a range of 0 to 1102 s. In order to facilitate the interpretation of the figure, the colors of light used for stimulation are shown.

Figure 5(a–c) shows the Fourier transform for the full 1102 s of the study according to scenario 1, again for the same 3 subjects. One can see one slowly rising line, originating from the stimulation frequency change from 3 to 30 Hz.

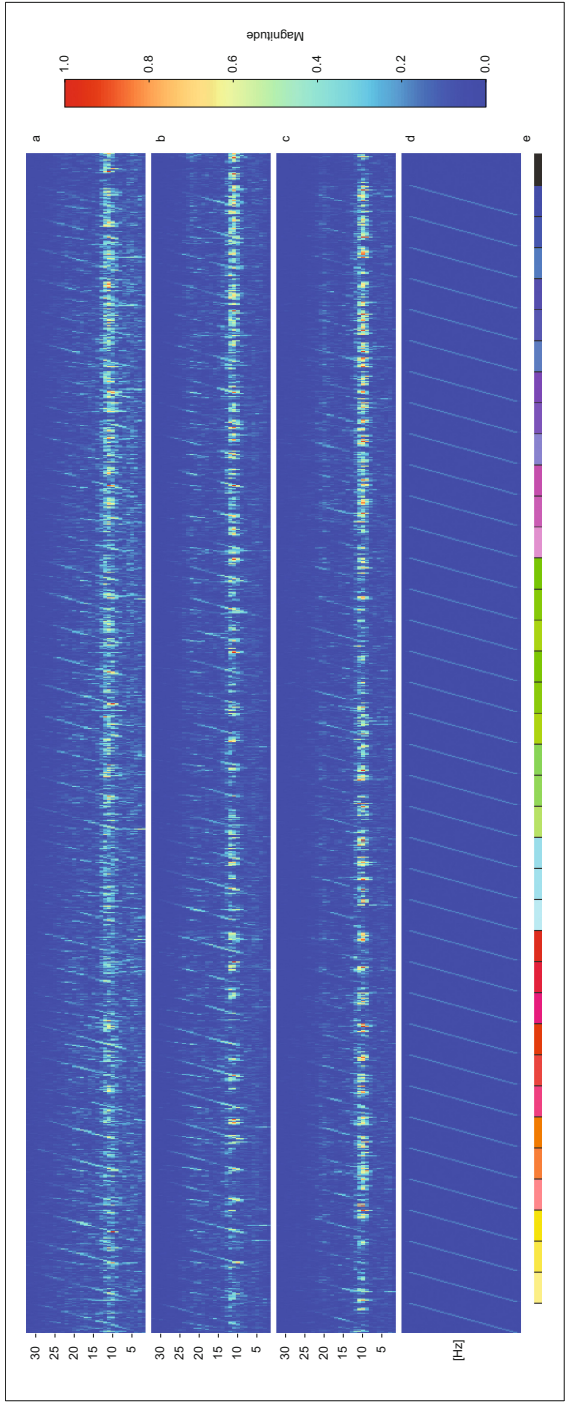
Figure 5d shows the Fourier transform of the stimuli signal. This facilitates the search of SSVEP in Fig. 5(a–c). The X axis is the time axis with a range of 0 to 1102 s, but in order to facilitate the interpretation of the figure it is described by stimulation frequency.

In Figs. 5(a–c), for the frequency of stimulation from 7 to 13 Hz, the second harmonic (14–26 Hz) can be observed in the spectrum of the EEG signal.

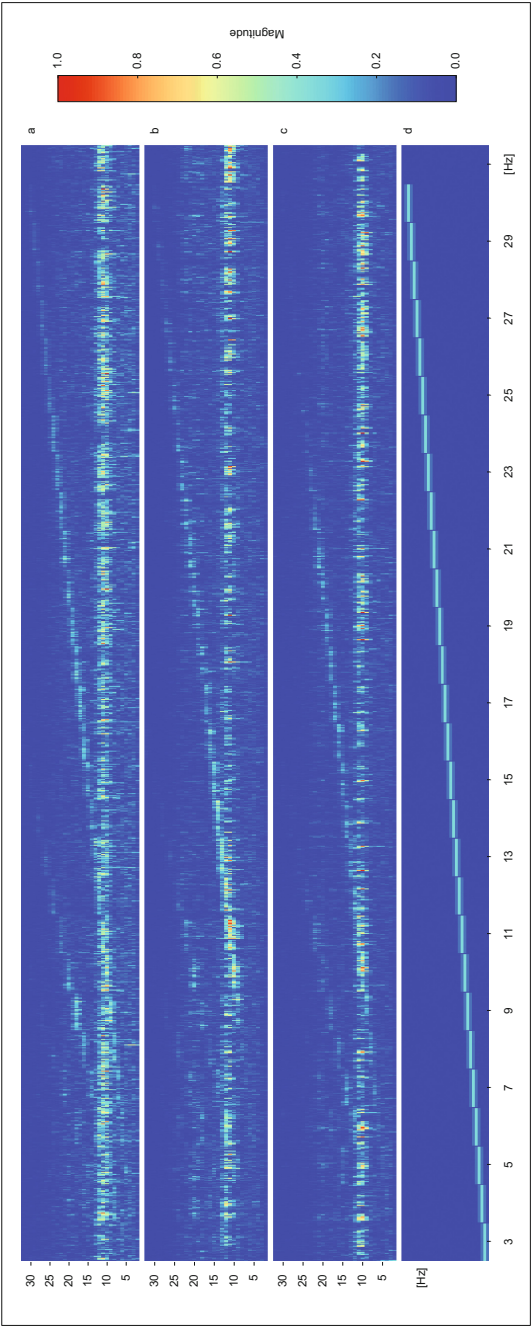
For the stimulation of 5, 6, 7 Hz, we can also observe the third harmonic (15, 18, 21 Hz). Both of these facts are a bit surprising because we deliberately used



**Fig. 3.** The Fourier transformation-based visualization of scenario 2 of 3 subjects (sections a–c) for a 116 s run for 4 colors (section e). Section d shows the Fourier transform of the stimuli signal



**Fig. 4.** The Fourier transformation-based visualization of scenario 2 of 3 subjects (sections a-c) for the 1102 s of the full run. Section d shows the Fourier transform of the stimuli signal. Section e shows stimuli color



**Fig. 5.** The Fourier transformation-based visualization of scenario 1 of 3 subjects (sections a–c) for the 1102 s of the full run. Section d shows the Fourier transform of the stimuli signal



a sinusoidal signal for stimulation. The occurrence of harmonics can, however, be used to improve the reliability of the identification of stimulatory frequency, as described in [8].

In addition, the initially pre-processed data (see Sect. 3.1) was transferred to the acoustic frequency range using self-developed wave encoder.

The resulting sound files can be found at <https://youtu.be/Gcqnq4B1lHs> (<http://tinyurl.com/SSVEPfc>) and <https://youtu.be/dhFsaMJepP0> (<http://tinyurl.com/SSVEPcf>).

While listening to the samples one can easily hear the components caused by the stimulation of the retina.

## 4 Conclusions and Future Remarks

With the use of relatively simple hardware and methodology we have shown that there is a noticeable correlation of the retina stimulation and EEG activity recorded from the occipital lobe of the cortex. Such an approach to SSVEP is inexpensive, effective enough and relatively easy to extend and to adapt in BCI application. If one can “hear” the correlation and see it thanks to the Fourier transformation, then we can postulate the existence of methods and algorithms for quantitative measurement and interpretation of SSVEP. This may lead to useful applications, for example in the BCIs mentioned above.

One should note that we will have a possibility to apply a double approach to our investigations as we have experience in modelling of large biological neural networks [9–12]. In future research, we are going to simulate some electroencephalographical activity in order to get a better understanding of higher cortical functions of the human brain [13, 14].

It is also worth to be mentioned that brain-computer interfaces based on SSVEP phenomenon can be applied as additional solutions for the people with disabilities [15–17].

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