Feel the BCI Vibe – Vibrotactile BCI Feedback

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Abstract. Controlling a device via a brain-computer interface (BCI) requires the participant to look and to split the attention between the device and the BCI feedback, which is partly contradictory. Therefore, a stimulation system based on 6 coin-motors is developed, which provides a tactile illusion as BCI feedback. Several experiments are conducted to optimize the illusion parameters and to check the influence on the EEG. Furthermore, 6 healthy BCI subjects compared visual with tactile feedback in online MI recordings, and no performance degradation was found.

Keywords: brain-computer interface (BCI), electroencephalogram (EEG), tactile feedback, vibration, motor imagery (MI)

1. Introduction

End-users are starting to control application devices via brain-computer interfaces (BCI), but such a control requires them to look at both (the device and the BCI) and split their attention between both. Imagine controlling a wheelchair with the BCI: on the one hand you have to look where you want to drive your wheelchair, since you want to find the way and avoid obstacles, on the other hand you have to be aware of the BCI feedback, which shows your current brain status and gives information about how close you are to delivering commands with the BCI. Therefore, both visual feedback loops are important for a successful application control, but are competing for the same resource: our visual channel. This split attention is sometimes demanding for the participants [Leeb et al., 2013], especially since most BCI feedbacks are based on a visual feedback. So, is there a chance to reduce the load or to free the visual channel from one of the components? Auditory or somatosensory modalities have already been used in BCI research. Since, we are interested in controlling our applications in a self-paced way without any external cues, evoked activities like auditory BCIs or steady-state-somatosensory potentials are not in our focus. Therefore, we transferred the position of the normal visual BCI feedback bar, into a tactile feedback with stimulators on the neck of the participant. A similar approach was already presented in [Cincotti et al., 2007], but their magnetic actuators interfered slightly with the electroencephalogram (EEG). In this work we first present our new tactile stimulation hardware and optimize the illusion parameters. Furthermore, we analyze the influences of the tactile stimulation on the EEG and compare visual and tactile feedback during online BCI experiments.

2. Material and Methods

2.1. Tactile stimulator

Six coin motors (Precision Microdrives, UK) with a diameter of 10 mm and a typical vibrational amplitude range of 0.5 g to 1.8 g are utilized for delivering tactile BCI feedback. The motors are attached in a horizontal line on lower neck with a center point at the spine and about 2.5 cm of inter-motor-spacing (Fig. 1a). The spatio-temporal vibration pattern (pulse-width modulation) of the stimulator is controlled by the laptop through a single-board microcontroller (Arduino, Italy) to indicate the BCI performance of a subject in a 2-class BCI. A point-based protocol is applied, that converts the current BCI feedback to a spatio-temporal vibration pattern. Thereby an illusory tactile sensation point is placed at one point corresponding to the visual BCI performance. In addition, the amplitude of the vibration increases as the probability approaches to the extreme values.

2.3. Sensation of tactile illusion

The tactile illusion that places the virtual tactile sensation point in between the two real stimulation points [Alles, 1970] is employed to increase the spatial resolution (only 6 motors are attached). This illusion point varies the position depending on the amplitude ratio of the real stimuli. For example, when two motors vibrate with the equal amplitude, tactile illusion is located at the center, whereas when the amplitudes are unbalanced it moves closer towards the larger stimulation amplitude. Hence, if the amplitudes of two motors are properly varied over time, a smooth movement between the two motors appears. To determine the appropriate shape of this amplitude variation between two motors, a preliminary experiment is conducted. Three subjects were asked to rank (1=low–4=high) four stimuli that have different shapes of amplitude variation (linear and three logarithmic) based on the illusory movement characteristics: consistency of perceived strength, position of the illusion, and direction of the movement.

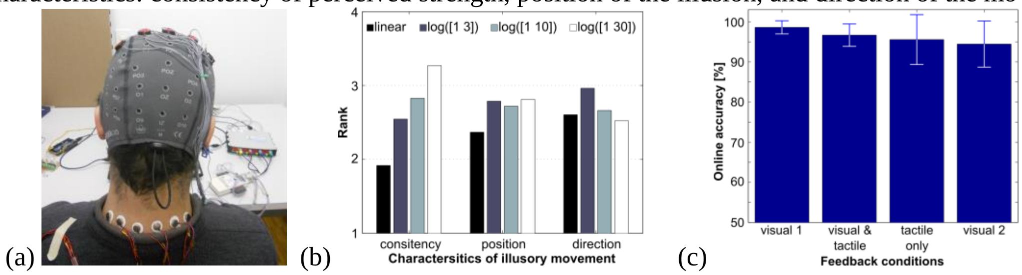

Figure 1. *(a) Subject wearing the EEG cap and placement of the vibrotactile stimulators on the neck. (b) Reported average ranks after normalization of different virtual movements between two motors. (c) Averaged online BCI accuracy during the 4 feedback conditions (only visual, visual and tactile, only tactile and again only visual).*

3. Results

3.1. Characterization for apparent tactile illusion

Fig. 1b shows the results of experiments to determine the shape of the amplitude variation. It shows that consistency increases as the shape becomes more logarithmic over time [Alles, 1970]. However, there is a certain preference to the shape of log([1 3]) in direction when the tactile illusion moves between two motors. For position, subjects preferred logarithmic shape, suggesting that it is better to use log([1 3]) for the point-based protocol.

3.2. Stimulation influence on the EEG

The EEG was recorded from 64 channels (active BioSemi amplifier, fs = 2048 Hz, filter: DC–417 Hz) while different tactile stimulation patterns (all motors / just left side / just right side / wave like / none) were tested 30 times each. Every trial consisted of 5 seconds stimulation and 15 seconds rest. The spectrum was calculated for 1-second epochs (5 per stimulation period and 5 per rest (second 6-11)) and averaged over the repetitions for each condition. No influence of the various stimulation patterns could be found in the EEG spectra while comparing stimulation to rest and over the conditions.

3.3. Online BCI experiments with vibrotactile feedback

Furthermore, to see the influence of the tactile stimulation on the online performance of a BCI (g.USBamp, 16 channels, fs = 512 Hz, filter: 0.5-100 Hz), six healthy trained BCI subjects compared the different feedback modalities: two runs with 15 left and 15 right hand motor imageries were performed for the following conditions: (1) normal visual feedback, (2) visual and tactile feedback, (3) only tactile feedback and (4) again only visual feedback. Fig. 1c shows that no statistical difference in the online performances could be identified, although the variance increased.

4. Discussion

In this work we presented the setup of a tactile stimulator, which can be used to provide smooth tactile BCI feedback on the neck without interfering with the EEG. Subjects are able to perceive this type of tactile feedback well and no online BCI performance degradation could be identified. The next step would be to test our system directly with an application, and to investigate the benefits from the reduced visual workload with more subjects.

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