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MINDFULNESS BASED STRESS REDUCTION IMPROVES TACTILE SELECTIVE ATTENTION BCI ACCURACY

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ABSTRACT:
Brain-computer interfaces (BCI) control is a mentally tasking activity that requires the user's concentrated attentional efforts. We hypothesized that mindfulness-based exercises, such as a 20-minutes Mindfulness-Based Stress Reduction training session (MBSR), can help to improve BCI performance. This pilot experiment demonstrated a BCI accuracy improvement after four subjects engaged in a 20-minute MBSR intervention session. The average BCI performance of the four subjects before the session was 67.42% and after the session was 78.94%, resulting in a performance increase of 11.52%. Three of the four subjects were considered BCI-illiterate (<70% accuracy) in the pre-MBSR session, and all three subject's accuracies were improved to >70% in the post-MBSR session. Moreover, an enhanced event related desynchronization in the alpha frequency band was found in post-MBSR intervention. These results demonstrate promising potential for using mindfulness-based exercises to improve BCI accuracy.

INTRODUCTION

Brain-computer interface (BCI) uses brain activity alone to control external devices or to communicate with the external world [1]. It provides a non-muscular channel of communication for severely disabled individuals who are totally paralyzed or 'locked in' by neurological disorders, such as amyotrophic lateral sclerosis, stroke, or spinal cord injury [1]. An electroencephalogram (EEG) based BCI measures brain activity through non-invasive electrodes at the scalp surface. One of the biggest challenges in BCI is for users to produce consistent and reliable EEG patterns, which can be significantly affected by the user's mental state [2]. Stress, anxiety, fatigue, frustration, and loss of concentration may cause an unstable mental state which may in turn cause inconsistent EEG patterns to be produced. Even distraction during the experiment such as feedback presented by the BCI (i.e. in game control) can modify the user's global mental state and hence their EEG, introducing noise to the system [3].

Researchers have been attempting to apply different signal processing techniques to improve its signal-to-noise input signal to increase the accuracy and classification of EEG-based BCI. Some studies trained the users through extensive neuro-/biofeedback training [4], [5]. Nevertheless, the inconsistencies in EEG due to mental state changes still remains to be a great challenge in EEG-based BCIs, whereas 15~30% of the users cannot usefully control a BCI, which is termed the 'BCI-illiteracy phenomenon' [6].

It is suggested that psychological parameters such as high attention span, sustained focus and concentration could yield better BCI performance, as BCI-control requires a substantial amount of focused attention [7]. In event-related desynchronization (ERD) based BCI, attention plays a significant role, with high attention correlating with to a significantly higher ERD value compared to lower attention [8]. Mindfulness based interventions have also been shown to lead to an increased level of attention, self-reported mindfulness and improvements in psychological functioning [9]. By providing participants who do not succeed in BCI control with such intervention to increase their oscillatory activation (ERD), it may lead to more accurate and consistent BCI performance and hence overcome the problematic 'BCI-illiteracy phenomenon' [7]. Previous research on meditation-based intervention and BCI accuracy demonstrated a 12-week meditation intervention program to significantly increase a group of 23 participants' baseline accuracy from 58% to 64% [2]. This finding motivated us to investigate whether a shorter session of mindfulness-based intervention can lead to a similar effect of increasing BCI accuracy.

The mindfulness-based intervention we will be investigating is a 20 minute standard Mindfulness-Based Stress Reduction (MBSR), which have shown to be able to increase mindfulness and well-being, while decreasing stress and improving psychological wellbeing [10], [11]. It has been proposed that the mechanisms responsible for positive changes following MBSR involve attentional improvements, the cultivation of a nonjudgmental attitude, and an intention to be present in the present task. This current study aims to examine the effect of mindfulness-based training on the ability to control a tactile BCI using selective sensation (SS) [12], [13], and to improve the performance accuracy for poorly performing BCI subjects.

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MATERALS AND METHODS

Subjects

A total of four healthy subjects participated in this experiment (all male, all right handed, age 20~25, mean age 22.75 ± 2.22 yr). All subjects had no prior experience with EEG. The study was approved by the Ethics Committee of the University of Waterloo, in Waterloo Canada. All subjects signed an informed consent form prior to participation.

Experiment Paradigm

In order to discriminate the subject's active attention to the sensations on respective hands, a vibration stimulation is provided to the subject's respective wrist to help direct their attention. This task of paying attention to either the left or the right hand is termed tactile selective sensation (SS); SS-L for left hand and SS-R for right hand.

Fig. 1 illustrates the experiment paradigm. The subject was seated on a comfortable armchair 1 meter in front of the display screen, with their forearms and hands resting on the armrest. They are instructed to limit all physical movements (i.e. facial, arm) and limit eye blinks to a minimum. During the experiment, a randomized series of one of two visual cues that correspond to the above SS task were displayed on the screen; a left-pointing red bar indicates the SS-L task and a right-pointing red bar indicates the SS-R task. After 3 runs of 40 trials (120 trials total), the subject is asked to complete a 20-minute guided sitting MBSR session. After the MBSR session, the subject repeats 3 runs of 40 trials of SS (another 120 trials total).

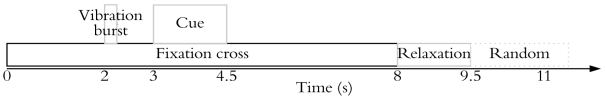

Figure 1. An illustration of the experiment protocol.

MBSR Training Session

During the 20-min MBSR training session, participants were guided through a 'body-scan' by the voice recording of a trained instructor. The participants were asked to sit quietly while focusing on the flow of their breath, with their eyes closed, and to adopt a nonjudgmental mentality while becoming aware of their thoughts, senses, and feelings. They were taught to calm down their mind by remaining focused on their breath, in performing the 'body scan'. This brings awareness to the physical sensations throughout the whole body while nonjudgmentally allowing discursive thoughts to simply pass [2]. The link to this 20-min guided sitting meditation MBSR mp3 audio file can be found here[1].

EEG recording and Sensory Stimulation

A 32-channel wireless g.Nautilus EEG system from g.tech Australia was used to record EEG signals. The electrodes were placed according to the extended 10/20 system, with the reference and ground placed on the right earlobe and forehead, respectively. A hardware notch filter of 60Hz was applied to the raw signals, which were digitally stamped at 250Hz. All EEG data were recorded, stored, and processed offline.

Mechanical stimulation was applied to the wrists. Linear resonant actuators (10 mm, C10-100, Precision Microdrives Ltd., typical normalized amplitude 1.4 G) were used for producing vibrotactile stimulation. The stimulation device produced a 23-Hz sine wave for the left wrist, and 27-Hz sine wave for the right wrist. Both stimuli were modulated with a 175-Hz sine carrier wave.

Algorithms and performance evaluation

The EEG data was manually corrected for artifacts using EEGLAB toolbox [14]. The trials that were affected by artifacts such as swallowing and physical movement (either in baseline or task line interval), were excluded in the analysis.

A fourth-order Butterworth filter of [8 26] Hz was applied to the raw EEG signals before the CSP spatial filtering. A 10×10 fold cross-validation was utilized to evaluate the BCI performance.

RESULTS AND DISCUSSION

Tactile BCI performance improved with MBSR

The BCI performance before and after the MBSR intervention is shown in Fig. 2, with a mean performance accuracy of 67.42% before MBSR and 78.94% after – an average improvement of 11.52%. This method demonstrated a clear benefit for poor-performing subjects (subject 1, 2, and 3 had <70% accuracy before MBSR). For example, subject 1 had a dramatic improvement from 55.50% before the 20-minute MBSR session to 77.5% after the session, a 22% improvement.

This increase in BCI accuracy is consistent with another BCI study on the effect of a 12-week meditation training

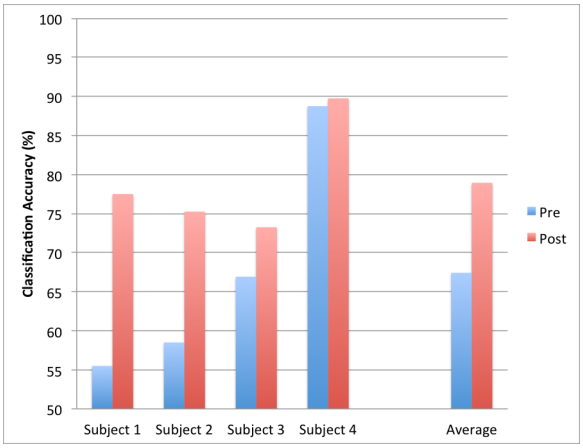

Figure 2. BCI performance before and after the MBSR training. The blue bar indicates BCI performance prior to the MBSR session; and the red bar indicates BCI performance after the MBSR session.

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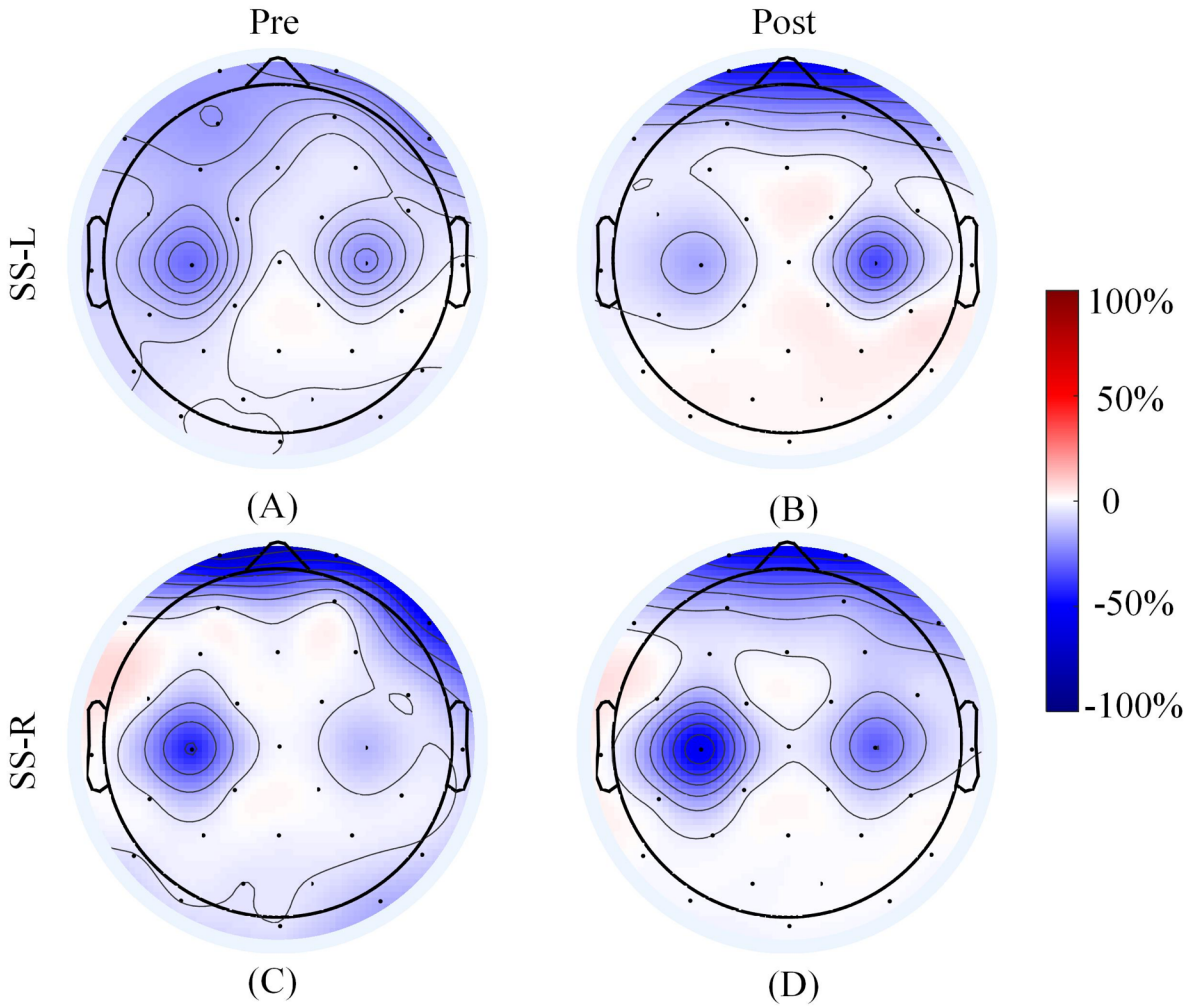

Figure 3. Cortical activation distribution across the scalp (ERD within the [8 13] Hz alpha frequency band). (A) ERD topolot of the SS-L task in Pre-MBSR session. (B) ERD topolot of the SS-L task in Post-MBSR session. (C) ERD topolot of the SS-R task in Pre-MBSR session. (D) ERD topolot of the SS-R task in Post-MBSR session. The colour bar indicates the ERD/ERS value.

program that resulted in an accuracy increase from 58% to 64% – a significant increase of 6% in a group of 23 subjects [2]. This study utilized motor imagery for BCI control [2].

The ERD cortical distribution before and after the MBSR intervention with respect to different SS tasks can be seen from a representative subject (subject 1 in Fig. 3 demonstrate an increased ERD activation between 8 to 13 Hz of the frequency band. This could be one of the factors underlying the increase in classification discrimination.

The effect of learning should also be taken into consideration, as the subjects will become increasingly familiar with the BCI system controls with practice and this may lead to an increase in BCI accuracy. Therefore, a control group should be implemented with future research.

CONCLUSION

Focused tactile selective attention was required in tactile BCIs, in which the subjects were instructed to focus their attention either to the vibration stimulation on either the left or right hand. The 20 minute MBSR based training session may have improved attention which in turn improved the subject's BCI performance.

In this study, we demonstrated that a 20 minute MBSR guided sitting meditation program can help improve BCI performance, accompanied by an enhanced ERD activation. Further research needs to be done on to understand the underlying physiological mechanism for the changes observed and to incorporate MBSR into a training paradigm to maximize the effect of MBSR in improving BCI performance and user compliance.

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