Comfort voice instructions for MI-BCI rehabilitation

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Abstract

The quality of the voice instructions may influence the process as well as the outcomes of a Motor Imagery - Brain-Computer Interface (MI-BCI) based rehabilitation procedure. In this paper, three types of voice instructions, which utilize different types of background noise, were introduced to the MI-BCI rehabilitation and compared against the original synthesized voice instruction regarding the comfort experience of the user. An experiment was designed where 22 participants were invited. The Local Pressure Distribution (LPD) body map, the NASA Task Load Index (NASA-TLX) and the Positive And Negative Affect Schedule (PANAS) were utilized as subjective measures of the comfort experience of the subjects. Meanwhile, the Heart Rate Variation (HRV) and the skin conductance of the subjects were also recorded throughout the rehabilitation process as objective measures. Experiment results indicated that there were significant differences regarding the comfort experience among using different types of background noises in the voice instructions, where using the rain sound as the background noise provided a higher level of comfort based on the outcomes of the subjective and objective measures. Therefore, it can be recommended to the MI-BCI intervention.

Keywords:

MI-BCI, comfort, voice, background noise, rehabilitation

1. Introduction

An estimated 75% of people who have had a stroke will survive for at least a year [1]. Among the survivors, about one-third of them will have moderate to severe disabilities in the movement, the speech, the concentration, and/or the cognition [2]. These affects the activities of daily living (ADL) of the patients. With effective rehabilitation, most of these patients could (partially) regain their motor control and perform their ADL [3], which may significantly improve their Quality of Life (QoL) and reduce the burden of caregivers as well as the societal cost.

Among different rehabilitation methods, the brain-computer interface (BCI) based rehabilitation attracted attentions of many researchers in the past decade [4], mainly due to its effectiveness in precisely interpreting human brain signals. Via a BCI, physicians/researchers were able to acquire brain signals, analyze them, and translate the results to effective interventions [5]. For instance, based on the collected electroencephalography (EEG) signals, researchers is able to extract the event-related (de)synchronization (ERD/S) features [6] and associate them with motor execution (ME), motor imagery (MI), and/or motor observation (MO) functions. Here the ERD is a relative power decrease during ME/MI/MO, whereas the ERS is a relative power increase after the termination of ME/MI/MO [7]. Based on these two features, the ME/MI/MO of the patients can be detected in real-time. Interventions, e.g., assistive movements by the exoskeleton, can be deployed consequentially in order to help patients in the neurorehabilitation. Currently, BCIs were adopted in many rehabilitation/assistive devices, such as the exoskeleton[8], the powered-wheelchair [9] , and the P300-based speller [10].

Most of research on the BCI based re-habilitation focused on theoretical and technical aspects of the BCI, including the effects of vocabulary, data acquisition and signal processing [11][12], conceptual applications/novel prototypes [13][14], etc. While these topics are necessary to ensure the functions and the reliability of the BCI technology, few attention was paid on the ergonomics of using the BCI and the comfort experience of the user [15]. This is especially important that with the growing uses of the BCI equipment in research and applications, the number of users is continuously increasing. For instance, in a MI-BCI rehabilitation procedure [16], it was found that subjects often lost concentration, were frustrated or even dropped out of the sessions. Although the reason behind might be complicated, users did point out that in the process of using MI to trigger endogenous tasks, the sound of the synthesized voice instructions was one of the key reasons of the lower level of comfort.

Meanwhile, in different application fields, researchers [17] identified that listening to white noise may improve different aspects of the cognitive performance of healthy subjects. Evidence also indicated that using white noise can improve the task performance of subjects with attention deficits and/or Attention Deficit Hyperactivity Disorder (ADHD) [18]. However, most of these studies focused on physiological aspects of the subjects, the comfort experience of the subjects and the related physical, cognitive and emotional effects of using voice instructions with different background noise, especially in the MI-BCI intervention, was not discussed.

Aiming at improving the comfort experience of the users during the MI-BCI based rehabilitation, this paper explores the effects of using voice instructions with different background noise, i.e., the white noise, the rain sound, the sinusoidal pure tone and no background noise, in the rehabilitation process. The major scientific contributions of this paper are that: 1) we identified that using rain sound as the background noise of voice instructions improved the comfort level of the users, therefore it can be recommended to the MI-BCI intervention and 2) through objective and subjective measures, we discovered that besides physical and cognitive aspects, emotion also played an important part of the comfort experience of participants.

2. Materials & Methods

2.1 Participants

The experiment was conducted in the EEG laboratory, School of Academy of Medical Engineering and Translational Medicine, Tianjin University, China. Prior to the experiment, the content and the protocol of the experiment were approved by the Medical Ethics Committee of Tianjin People's Hospital in accordance with the Helsinki Declaration. Twenty-two healthy subjects (14 males and 8 females, mean age 24.4±3.35) participated in the experiments with remuneration. Informed consent was obtained from each participant before the experiment.

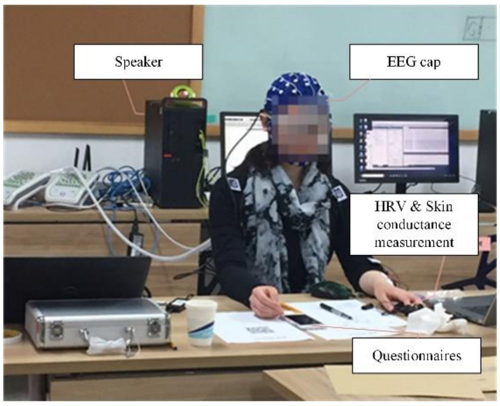

Fig.1. The setup of the experiment, photo was taken by the camera in front of the user

2.2 Materials

An EEG cap with 64 active electrodes (Brand: NeuroSky) was prepared for simulating the clinical setup. A Heart Rate variability (HRV) and skin conductance recorder (Brand: Ergolab) were prepared for measuring the HRV and the skin conductance of each participant, respectively. For recording the scenario, a camera was setup in front of the user. Four types of voice instructions were prepared as: 1) using synthesized voice instructions only, 2) using standard white noise as the background of the synthesized voice instructions, 3) using rain sound as the background of the synthesized voice instructions, and 4) using sinusoidal pure tone as the background of the synthesized voice instructions. In all types of voice instructions, the amplitude of the synthesized voice instructions was adjusted to 70 db where the background (if any) was adjusted to 50 db. Those instructions were played by a speaker which was installed 1.5 meters behind the user.

A set of questionnaires was prepared for measuring the subjective opinions regarding different setups. They include: the Comfort/Discomfort questionnaires (2 questions) [19], the Localised Postural Discomfort (LPD) body map (20 questions) [20][21], the NASA Task Load Index (NASA-TLX, 6 questions) [22][23], the Positive And Negative Affect Schedule (PANAS, 20 questions) [24]. Among those questionnaires, users were able to fill in the NASA-TLX, PANAS, Comfort/Discomfort Scales, and the self-designed questionnaire (in total 28 questions) using a mobile device. The LPD (20 questions) was prepared on paper due to its graphical nature. Figure 1 presents the setup of the experiment.

2.3 Protocols

Before the experiment, each participant received a short instruction about: 1) the purpose of the experiment; 2) the specific MI activities (right-hand grip and relaxation), 3) materials will be used in the experiment and 4) the protocol of the experiment. Then the participant was invited to sit at the designated position. The EEG cap was worn with the help of the researcher(s) to simulate the actual procedure. At the same time, Ergolab physiological measurement equipment was attached to the left hand of the researcher for recording the HRV and the skin conductance of the subject.

During the experiment, the voice instructions were given by a speaker, and its position was fixed regarding the subject. Following the instructions, participants were required to complete four sets of rehabilitation training sessions, each 10 minutes. During each session, a specific type of voice instructions was used to guide the subject to perform MI. The sequence of using different types of voice instructions was randomized regarding each participant. At the end of each session, the questionnaires were filled to evaluate the perceived comfort/discomfort, workload and emotion effect. The complete experiment lasted about 50 minutes for each subject.

2.4 Data analysis

Prior to the data analysis, all collected subjective data was preprocessed regarding each subject where the minmax scaler was used to normalize all data to the span from 0 to 1, e.g., for the question “comfort level”, 0 is the minimal level of comfort and 1 is the maximal. The student t-test was used to identify the difference between two sets of data. Besides, the swarm plot was introduced as an add-on of the box plot for a better visualization of the distribution of the data.

3. Experiment results

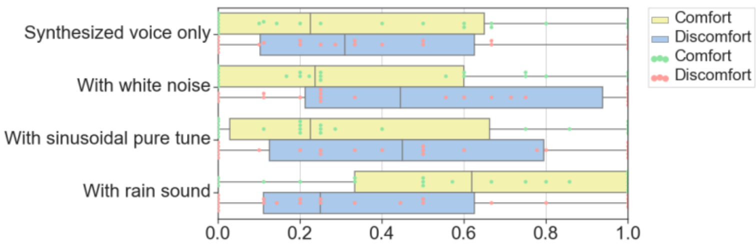

Fig.2: Comfort/discomfort regarding the four types of voice instructions (horizonal axis: the levels of comfort/discomfort, 1 = high comfort/discomfort regarding the two measures, respectively)

3.1 The results of comfort/discomfort questionnaire

The normalized results of the comfort/discomfort questionnaire regarding four types of voice instructions are presented in Fig.2, which is a combination of a box plot and a swarm plot. In the figure, yellow stands for the value of the level of comfort and blue stands for discomfort. It can be observed that *with rain sound as background* (mean =0.59, STD = 0.37) performs significant better (p=0.012) than using *synthesized voice only* (mean=0.37, STD=0.37) regarding comfort. In other two options, the means of both had slightly difference than *synthesized voice only* (*with white noise as background*: mean = 0.35, STD = 0.35; *with white noise as background*: mean =0.36, STD = 0.38), however, not statistically significant. Regarding discomfort, the mean and the standard deviation of the four setups are: 0.39±0.36 (synthesized voice only), 0.50±0.38 (with white noise), 0.46±0.38 (with white noise) and 0.38±0.37 (with rain sound). Though *with rain sound* performed slightly better (scores lower), it was not statistically significant.

3.2 The results of the LPD body map & NASA questionnaire

Figure 3 and 4 presents the results of the LPD body map and the NASA TLX, respectively. It can be found that participants rated similar results regarding the four types of voice instructions, which indicated the physically and cognitively, there was no significant difference among the uses of four types of voices instructions.

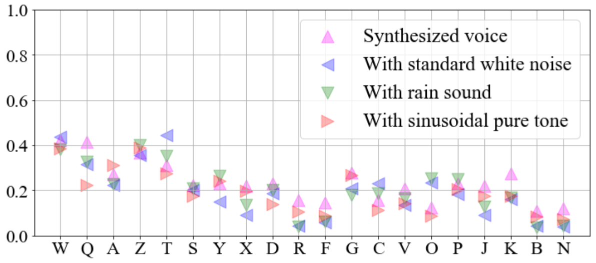

Fig.3. The scores of LPD regarding the uses of four types of voice instructions (vertical axis: discomfort, 0 = minimal level, 1 = maximal level, horizonal axis definitions can be found in [20], except W = head)

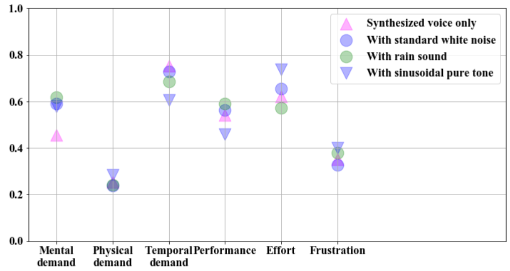

Fig.4. The scores of NASA_TLX regarding the uses of four types of voice instructions (vertical axis: the normalized scores, 1 = maximal and 0 = minimal)

3.3 The results of the PANAS questionnaire

Table 1 lists the results of the PANAS questionnaire. Analysis of results indicates that *with rain sound* stimulated the users' positive emotions, followed by *with sinusoidal pure tone*, *with standard white noise*, and the *synthesized voice only* was ranked last. On the other hand, the negative sentiment caused by *with sinusoidal pure tone* was higher, followed by *with rain sound*, *with standard white noise* and *synthesized voice only*.

Table 1: The results of the PANAS questionnaire

	Positive emotion	*STD*	*Negative emotion*	*STD*
Synthesized voice only	15.5	5.3	16.2	6.9
With standard white noise	15.9	4.1	16.6	8.0
With rain sound	16.3	4.9	17.1	8.6
With sinusoidal pure tone	15.9	4.9	21.1	11.0

3.5 Effects on the HRV index and skin conductivity

Four different voice instructions had different effects on the subjects' HRV data (as in Table 2), which can be observed by the differences in the SDNN (Standard Deviation of the Normal, Normal (R-R) intervals), RMSSD (Root mean square of the successive differences), and PNN50 (Proportion of NN50 divided by the total number of normal to normal (R-R) intervals), respectively. The results show that regarding SDNN and RMSSD, *with rain sound* scored higher than the rest three. *With standard white noise* scored highest on PNN50, but it was not statistically significant. *With sinusoidal pure tone* was lowest on SDNN and RMSSD, but slightly better regarding PNN50. Regarding the skin conductance, *with rain sound* performed the best with the lowest skin conductance, followed by *with standard white noise*, *with sinusoidal pure tone* and *synthesized voice only*.

Table 2: The mean HRV of using four different types of voice instructions

	SDNN (ms)	*RMSSD (ms)*	*PNN50(%)*
Synthesized voice only	133.80	167.04	26.67
With standard white noise	156.96	188.43	29.62
With rain sound	167.63	192.03	29.15
With sinusoidal pure tone	133.70	150.86	29.4

Table 3: The skin conductance of using four different types of voice instructions

	Mean (µS)	*Max (µS)*	*Min (µS)*
Synthesized voice only	1.93	2.67	1.55
With standard white noise	1.82	2.45	1.47
With rain sound	1.58	2.40	1.18
With sinusoidal pure tone	1.70	2.44	1.36

4. Discussions

4.1 Comfort/discomfort experience

Vink and Hallbeck [19] defined comfort as "*a pleasant state or relaxed feeling of a human being in reaction to its environment*" and discomfort as "*an unpleasant state of the human body in reaction to its physical environment*". They also indicated that comfort consists of more factors than discomfort, which is mainly caused by physical interactions. The discovery in this paper is in accordance with this conclusion. With nearly the same level of discomfort regarding different parts of the body (results of LPD body map), *using the rain sound as the background noise of voice instructions* had significant positive results regarding the comfort experience of the user, which is also reflected in the subjective measure (PANAS) and objective measures, e.g., the HRV and the skin conductance.

4.2 HRV & comfort

Previous studies had indicated that the HRV could be an objective measure for assessing emotional responses [25][26][27] as the HRV index has significant correlations with happiness and sadness [28]. Experiment results suggested that *using the rain sound as the background noise of voice instructions* appeased the users and triggered their positive emotions during the experiment. On the other side, *Using the sinusoidal pure tone as the background noise of voice instructions* brought sadness, impatience and other negative emotions to the subject, therefore it was the least preferred choice.

4.3 Skin conductance & comfort

The skin has electrical properties and it is able quickly change in the level of seconds. Meanwhile, studies have shown that those changes, e.g., the changes of the skin conductance, are closely related to psychological processes. Research had indicated that the fluctuations of the skin conductance have strong relations to the stress level of the subject [29]. Based on the measurement results of the skin conductance in the experiment, it can be seen that among the four types of voice instructions, *using the standard white noise as the background noise of voice instructions* led to the lowest mean skin conductance, which can be interpreted as that the subjects were more relaxed. And for *synthesized voice only*, subjects were relatively more nervous.

4.4 Limitations

Wearing an EEG cap with 64 active electrodes in this experiment was only used as a simulation. The sizes of the cap were limited, and each participant may have different comfort experience regarding the selected size. The HRV and skin conduction measurement devices were attached to the left hand of the subject, which may also influence the level of comfort of the subjects in the experiment. Due to time constraints, we only selected the standard white noise, the rain sound and the sinusoidal pure tone as the background noise. Using other natural noise, e.g., pink noise [30], as the background can be explored as well.

5. Conclusions

A comfortable rehabilitation experience may help the patients overcome of the long and tedious procedure to achieve a better clinical outcome. In this paper, using four types of voice instructions, named *Synthesized voice only*, *Synthesized voice with standard white noise as the background noise*, *Synthesized voice with rain sound as the background noise*, *Synthesized voice with sinusoidal pure tone as the background noise*, we simulated the MI-BCI based rehabilitation procedure and measured the overall comfort/discomfort experience, the discomfort of each part of the body, the cognitive workloads, the emotion, the HRV and the skin conductance of each participant. Subjective and objective measures indicated that in this context, there were significant difference regarding the comfort experience of the participants, which was mainly caused by the emotion. This discovery highlights the importance of the emotion aspect in the comfort experience and based on experiment results, the voice instruction which utilizes *Synthesized voice with rain sound as the background* is recommended to the MI-BCI procedure, as it is able to appease the users and trigger their positive emotions during the procedure.

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