A MOBILE EEG SYSTEM FOR PRACTICAL APPLICATIONS

Xiaohuan Chen, Enzo Yee, Ryan Yang, Rosi Saab, Xiaorong Gao

Introduction

Over the past few years, brain-computer interface (BCI) systems have become more powerful and robust under laboratory conditions, benefitting from advancements in signal processing and paradigm design etc. However, moving BCI systems into real-life applications is still one of the major challenges in the field. Although EEG systems are much more convenient than other brain activity monitoring technologies, they still weigh several kilograms and require wires to transfer the EEG signals. Therefore, conventional EEG systems are cumbersome for applications outside the laboratory. A small and wireless mobile EEG system has practical advantages as it provides advantages such as flexibility, portability, and tolerance to gross movements, but it may compromise the EEG signal quality.

In this study, we present a new 64-channel mobile EEG system (Neuware, Neuracle Inc.), and compare it to a state-of-the-art wired laboratory EEG system and evaluate the EEG signal quality. Previous studies were only performed on seated participants in laboratory environments, and only a very limited number of conditions were tested. In this study, we instead implemented experiments in standing and running conditions. To preliminarily evaluate the signal quality recorded by both EEG systems, we first compared the alpha wave (8-13 Hz) frequency band using a spectral analysis approach, due to the fact that, while a EEG user may not be able to maintain particularly strong alpha rhythms even in his/her own resting state, the stronger alpha waves are one of the most popular BCI paradigms [4-5]. Here, SSVEP is a periodic response elicited by specific visual stimuli. In our approach, we further validated the mobile EEG system using a SSVEP-based BCI paradigm. Finally, to evaluate the EEG signal quality, the online and offline classification accuracies were compared.

Methods and Materials

Participants: Six able-bodied volunteers (five males, one female) between the ages of 20 and 30 (mean 26.33 years) participated in this study. All participants had normal or corrected-to-normal vision, and normal cognitive functions. All participants provided written informed consent.

Data collection: In the experiments, we compared the new mobile EEG (Neuware, Neuracle Inc.) to a well-established, wired laboratory EEG amplifier (Syna), using a repeated measurement design (see Fig. 1). The mobile EEG amplifier weighed 77 g (size 8.5×5.5×1.5 cm3), was tightly attached to the cap, and had a higher signal-to-noise ratio. Contrast, the reference EEG wired amplifier weighed 138 g (size 21.0×18.7×5.5 cm3), and was connected with a cable to the recording PC. EEG signals were recorded via eight electrodes placed at PO7, PO3, PO1, PO4, PO6, O1, Oz, and O2, referenced to CFz and grounded to FPz. Impedances were kept below 10 kΩ prior to recording using conductive paste. The EEG signals were sampled at 256 Hz and filtered using a 50-Hz notch filter.

SSVEP-based BCI experiment: This study employed a 12-target SSVEP-based BCI system with a 3×4 matrix. Each cell in the stimulus flickered between white and black at 50-Hz frequency. The flickering frequencies were employed in the design of a periodic stimulus mechanism (i.e. 9.25-14.75 Hz with an interval of 0.5 Hz).

Experimental Procedures: The experiments were performed in a normal laboratory. Each participant took part in two sessions, wearing two different EEG systems, on two different halves within a one-week period. The experimental setup was identical between sessions, only the EEG system was switched. The sequence of the sessions was randomized to avoid order effects. Additional details of the experimental arrangement are illustrated in Fig. 2.

Target detection: In this study, we employed filter bank canonical correlation analysis (FBCCA) for target detection [5]. The bandwidth of the stimulation frequencies was 5.15 Hz. A frequency range of 8-8.8 Hz was selected for the filter banks. In the implementation of bandpass filter, an additional bandwidth of 0.2 Hz was added to both sides of the passband for each sub-band.

Results

Copy-spelling performance: Although the stimulus period of each trial was 3 s, the online spelling results were detected based on 2 s EEG signals as it is the mostly widely used approach to reduce inter-trial variability [6-7]. The online recognition accuracy was measured using the two EEG-based BCI systems. Table 1 lists the online accuracies of both EEG systems under all conditions of standing and walking. The performances of both EEG systems were quite similar, both surpassing 95%. Interestingly, in the running condition, the average accuracy of the new mobile EEG system (73.14%) was significantly higher than the one of the referenced EEG system (56.95%). Moreover, we also compared the classification accuracies between the two EEG systems using the offline analysis approach (see in Fig. 3). As shown in Fig. 3, the accuracies of both EEG systems were similar when the results of the mobile EEG system were more robust than the weaker one. These results indicated that the mobile EEG system may be more robust to high-frequency non-task related components.

Spectral analysis: To further evaluate the signal quality, we compared the frequency spectrum in eyes open and closed conditions, by averaging the 2-40 Hz spectra of all selected channels over the 6 participants (seen in Fig. 4). We found that both EEG systems yielded similar alpha amplitudes in all the conditions. Moreover, the spectral power above 20 Hz was consistently higher in the reference EEG system. We further analyzed the frequency spectra of all conditions during SSVEP tasks (seen in Fig. 5). The frequency spectra show that the second and third harmonics of SSVEP were referenced in all conditions. The spectra of SSVEP were obviously stronger than the mobile EEG system. These results indicated that the mobile EEG system may be more robust to high-frequency non-task related components.

Conclusions and Discussions

In this paper, we compared the EEG signal quality recorded by a new mobile EEG system that is a state-of-the-art wired laboratory EEG system. Specifically, alpha waves and SSVEP signals were recorded during standing, walking, and running conditions. In both standing and walking conditions, similar results were obtained with the two reference EEG systems. In the SSVEP testing and reference EEG systems, in terms of spectral amplitudes of alpha wave and classification accuracies of SSVEP-based BCI system. However, better performance was achieved by the mobile EEG system compared with the reference wired EEG system in all conditions. As is known, wired EEG systems limit the natural behavior of users during signal acquisition and thereby lead to highly constrained recording conditions. A mobile EEG system on the other hand is quick to set up, provides better wearing comfort, and is more robust against gross movement. Therefore, we believe that the mobile EEG system could be employed in a wider range of environments, especially for out-door motion scenes, which could facilitate the transfer of BCI applications from the laboratory to real-life environments.

To understand and explain why the new mobile EEG system can provide high-quality EEG acquisition and perform wired EEG systems in running conditions, we hypothesize that the following four factors contributed to the performance improvement: (1) signal transmission is based on a precise wireless protocol, which achieves reliable and accurate performance on event synchronization; (2) the amplifier adopts wide dynamic range and DC-coupled technologies, to prevent saturation of the amplifier induced by electrode offset voltage and artifacts; (3) the amplifier is lightweight and head-mounted, which ensures all relevant parts remain together when individuals perform any gross movements; (4) long and isolated cables are avoided, which reduces the strong electromagnetic interferences induced by the movements of individual's cables.

References


