A MOBILE EEG SYSTEM FOR PRACTICAL APPLICATIONS

Xiaoshan Huang[1,2]*, *Erwei Yin*[3] *, *Yijun Wang*[4], *Rami Saab*[1], *Xiaorong Gao*[1]

[1]Department of Biomedical Engineering, Tsinghua University, Beijing 100084, China;
[2]Neuracle Technology Co. Ltd, Beijing, 100097, China;
[3]National Key Laboratory of Human Factors Engineering, China Astronaut Research and Training Center, Beijing 100094, China;
[4]State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

Introduction

Over the past few years, brain-computer interface (BCI) systems have became more powerful and robust under laboratory conditions, benefiting from advancements in signal processing and paradigm design etc [1]. However, migrating BCI systems into real-life applications is still one of the major challenges in the field [2]. Although conventional EEG systems are much more compact than other brain activity monitoring technologies, they still weigh several kilograms and require wires for signal transmission [3]. 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 (NeusenW, 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 focus on motion conditions. In this study, we instead implemented experiments in standing, walking and running conditions. To preliminarily evaluate the EEG 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 has their eyes closed, the alpha wave power is the strongest spontaneous EEG signals. Steady-state visually evoked potential (SSVEP)-based BCI spellers 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 had no cognitive deficits. All participants provided written informed consent.

Data collection: In the experiments, we compared the new mobile EEG (NeusenW, Neuracle Inc.) to a well-established, wired laboratory EEG amplifier (Synamps2, Neuroscan Inc.), using a repeated measurement (seen in Fig. 1). The mobile EEG amplifier weighed 77 g (size 8.5×5.5×1.5 cm^3), was tightly attached to the cap, and had Wi-Fi wireless connectivity. Conversely, the reference EEG wired amplifier weighed 1500 g (size 21.8×18.7×4.5 cm^3), and was connected with a cable to the recording PC. EEG signals were recorded via eight electrodes placed at PO5, PO3, POz, PO4, PO6, O1, Oz, and O2, referenced to CPz and grounded to FPz. Impedances were kept below10 kΩ prior to recording using conductive paste. The EEG signals were sampled at 250 Hz and filtered using a 50-Hz notch filter.

SSVEP-based BCI speller: This study employed a 12-target SSVEP-based BCI speller with a 3×4 matrix. Each cell in the speller flickered between white and black at a unique, constant frequency. Twelve 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 half days 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 (i.e. 8-15 Hz) was 8 Hz. A frequency range of 8-88 Hz was selected for the filter banks. In the implementation of bandpass filter, an additional bandwidth of 2 Hz was added to both sides of the passband for each sub-band.

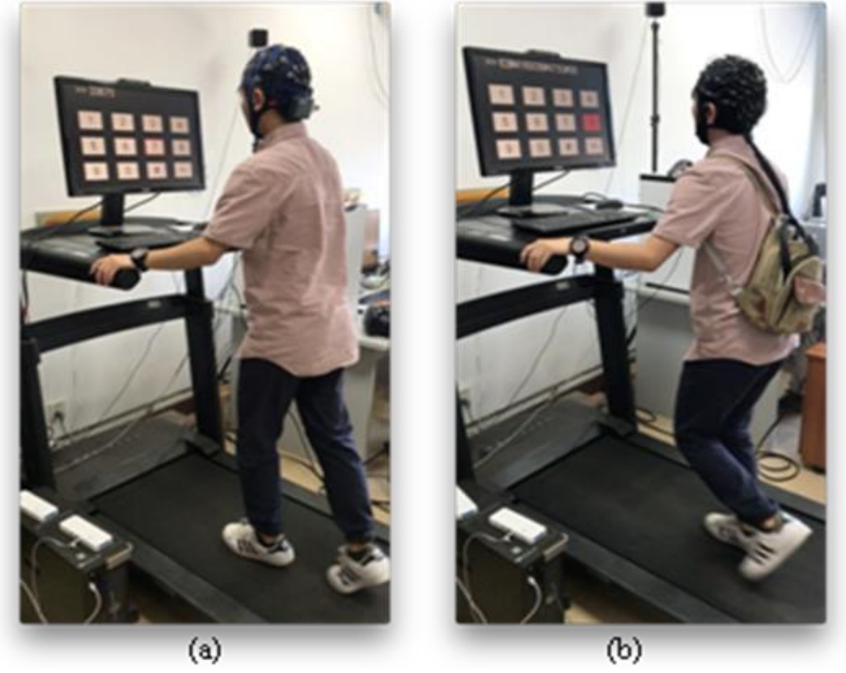

Fig. 1. The visualization of the setup for both EEG systems.
(a) NeusenW, Neuracle Inc.;
(b) Synamps2, Neuroscan Inc.

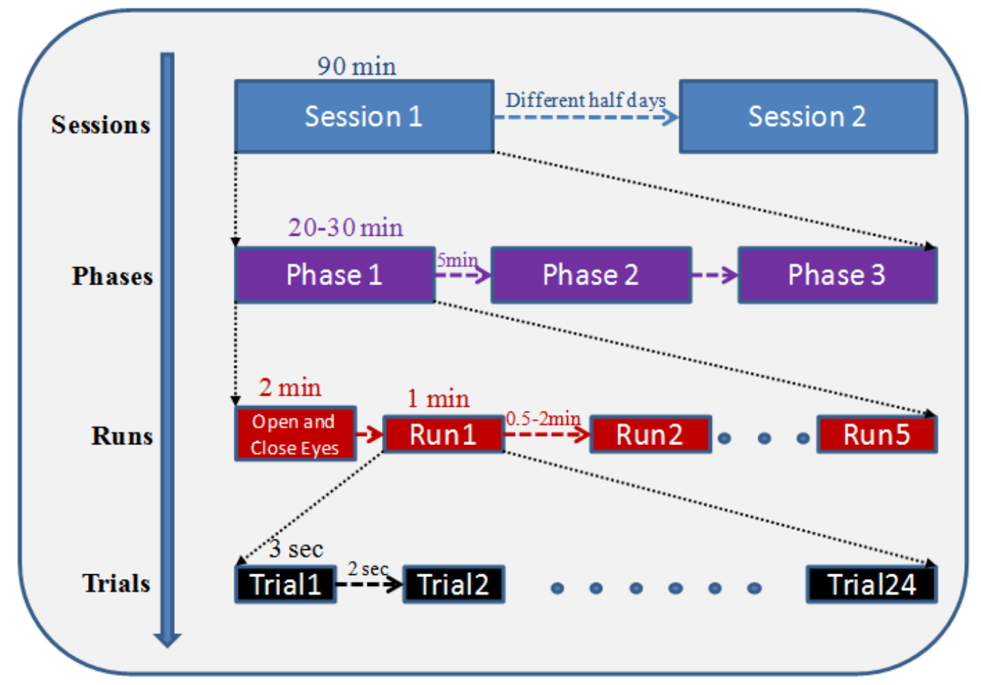

Fig. 2. Experimental session structure.

Results

Copy-spelling performance: Although the stimulus time 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 time-period for SSVEP online detection. As shown in Table 1, in the standing and walking conditions, the average online accuracies achieved by the two 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 comparing to that of the referenced EEG system (56.95%). Moreover, we also compared the classification accuracies between the two EEG systems using the offline analysis approach (seen in Fig. 3). As shown in Fig. 3, the accuracies of both EEG systems were similar to each other in standing and walking conditions, while the accuracies of the mobile EEG system were consistently higher than those of the reference EEG system in the running condition.

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 six 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 response of the second and third harmonics are weaker with increasing movement speed, the SSVEP harmonics of referenced EEG system were obviously weaker than the mobile EEG system. These results indicated that the mobile EEG system may be more robust to high-frequency non-task related components.

Table 1. Online accuracy (%) for the copy-spelling task.

Participant	Standing		Walking		Running	
	Neuracle	Neuroscan	Neuracle	Neuroscan	Neuracle	Neuroscan
S1	94.17	93.33	96.67	93.33	68.33	45.00
S2	100	100	100	99.17	79.17	78.33
S3	100	100	98.33	99.17	90.83	54.17
S4	98.33	95.83	98.33	96.67	57.50	31.67
S5	98.33	99.17	100	100	97.50	90.83
S6	84.17	92.50	84.17	86.67	57.50	41.67
AVG	95.83	96.81	96.25	95.84	73.14	56.95
T-Test	H: 0, P: 0.5564		H: 0, P: 0.5750		H: 1, P: 0.0067	

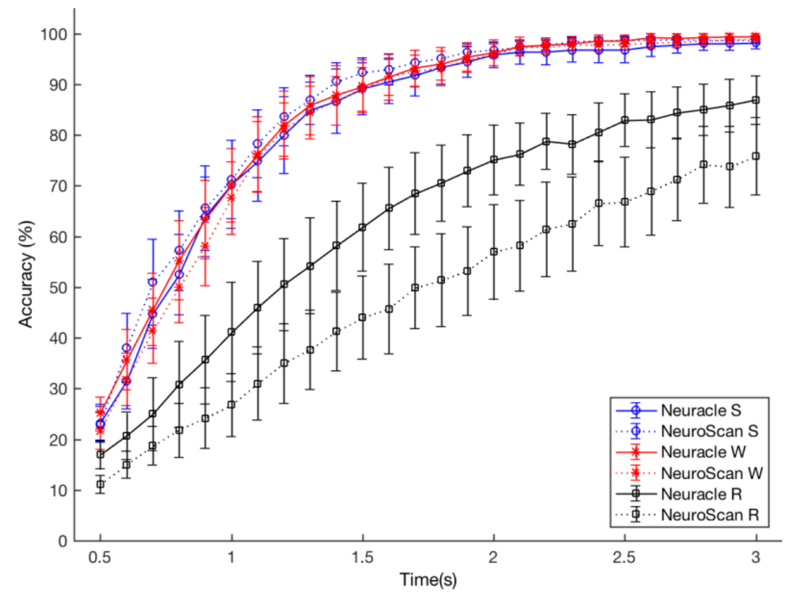

Fig. 3. Comparisons of offline classification accuracies.

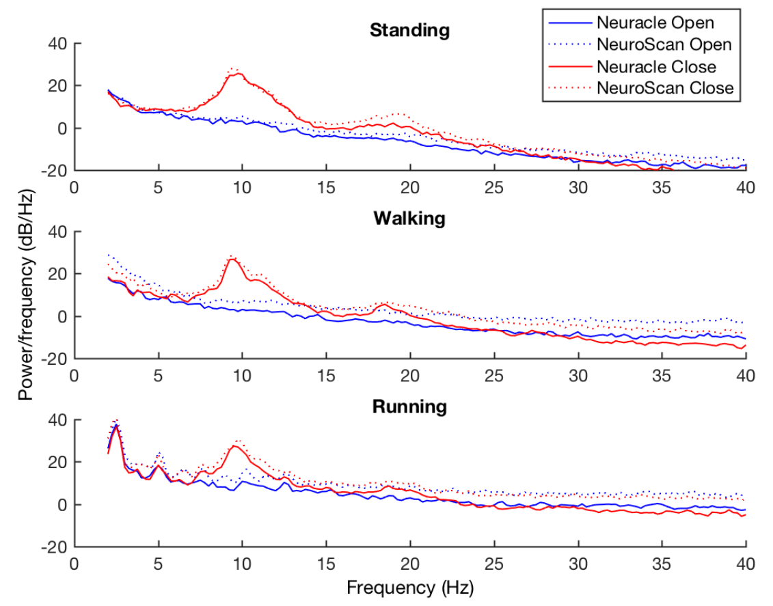

Fig. 4. Frequency spectra of the EEG signals recorded during the eyes open/eyes closed tasks.

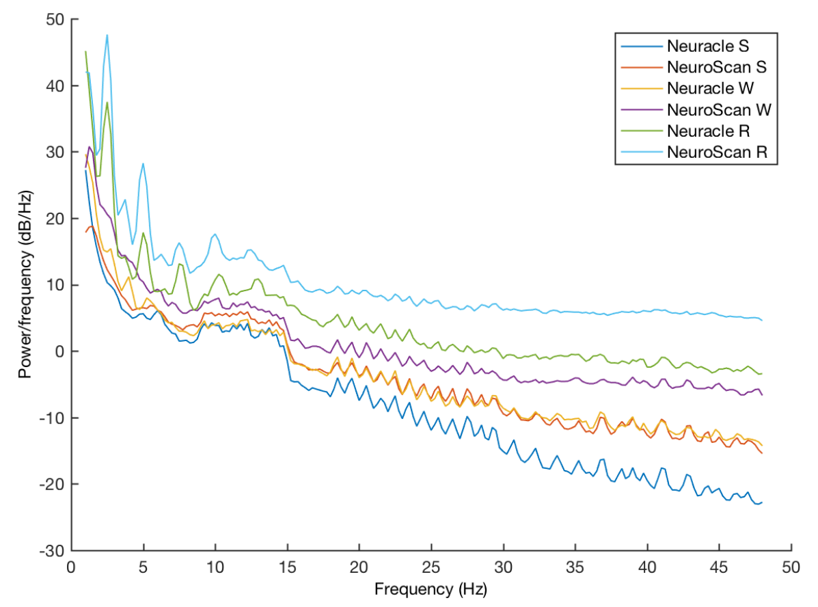

Fig. 5. Frequency spectra of the EEG signals recorded during the SSVEP tasks.

Conclusions and Discussions

In this paper, we compared the EEG signal quality recorded by a new mobile EEG system to that of a state-of-the-art wired laboratory EEG system. Specifically, alpha wave and SSVEP signals were recorded during standing, walking, and running conditions. In both standing and walking conditions, similar results were obtained with the testing and reference EEG systems, in terms of spectral amplitudes of alpha wave and classification accuracies of an SSVEP-based BCI speller. However, better performance was achieved by the mobile EEG system compared with the reference wired EEG system in the running condition. 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 outperform wired EEG systems in running condition, 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 electrodes cables.

References

[1] G. Muller-Putz, J.D. Millan, G. Schalk, and K.R. Muller, “The plurality of human brain-computer interfacing,” *Proc. IEEE*, vol. 103, no. 6, pp. 868-870, 2015.
[2] M. Bandad, H. Zarshenas, and M.A. Auais, “Application of BCI systems in neurorehabilitation: a scoping review,” *Disabil. Rehabil. Assist. Technol.*, vol. 10, no. 5, pp. 355-364, 2015.
[3] S. Debener, R. Emkes, M. De Vos, and M. Bleichner, “Unobtrusive ambulatory EEG using a smartphone and flexible printed electrodes around the ear,” *Scientific Reports*, vol. 5, pp. 16743, 2015.
[4] X. Chen, Y. Wang, M. Nakanishi, X. Gao, T. Jung, and S. Gao, “High-speed spelling with a noninvasive brain-computer interface,” *Proc. Nati. Acad. Sci. USA*, vol. 112, no. 44, pp. E6058-E6067, 2015.
[5] X. Chen, Y. Wang, S. Gao, T. Jung, and X. Gao, “Filter bank canonical correlation analysis for implementing a high-speed SSVEP-based brain-computer interface,” *J. Neural Eng.*, vol. 12, pp. 046008, 2015.