Brainwave Typing: Comparative Study of P300 and Motor Imagery for Typing Using Dry-Electrode EEG Devices

Hadeel Al-Negheimish[1], Lama Al-Andas[1], Latifah Al-Mofeez[1], Aljawharah Al-Abdullatif[1], Nuha Al-Khalifa[1], and Areej Al-Wabil[2]

Information Technology Dept. [1], Software Engineering Dept. [2]
College of Computer and Information Sciences, King Saud University
Riyadh, Saudi Arabia
halnegheimish@acm.org, aalwabil@ksu.edu.sa

Abstract. This paper presents the findings of an exploratory study comparing two of Brain-Computer Interface approaches, P300 and Motor Imagery, with EEG signals acquired using the Emotiv Neuroheadset. It was conducted to determine the most suitable approach for typing applications based on BCI. Results show that while selection accuracy is similar for both, with mean of 50%, the speed varies greatly, with the former approach being approximately 2 times more efficient in typing. Implications presented in this document are useful for BCI researchers who seek to build brain-controlled Augmentative and Alternative Communication technologies.

Keywords: BCI; Brain Computer Interface; P300; Motor Imagery; Brain Machine Interface; BMI; Augmentative and Alternative Communication; AAC; EEG;

1 Introduction

Brain-Computer Interface has engendered much research in recent years, with focus on providing people with severe motor disabilities, such as amyotrophic lateral sclerosis or spinal cord injury, with an alternative means of control [1]. This research, however, is mostly based on Gel-based signal acquisition devices that are too expensive for the average user. This experiment explores EEG BCI with consumer-market headset, the Emotiv EEG headset [2]. It is part of on-going research aimed to build a BCI typing applications for Arabic-speaking users. Non-invasive electroencephalography (EEG), where EEG signals are recorded from the surface of the scalp, is one of the popular ways to implement BCI. In fact, it has already been used to develop communication systems, where users can spell words via brain activity, and control systems, where they can drive a simulated wheelchair, for example [3].

There are two main approaches for EEG-BCI. First, Evoked Potential; methods of this kind depend on EEG components (features) evoked and time-locked to a specific sensory stimuli, which are also called cue-guided [4]. The most widely used example of this approach is P300 method [5]. Second, Motor Imagery; Methods of this kind use features that are processed in the frequency domain instead of the time domain, as it depends on recording rhythmic activities over the sensorimotor cortex [5]. In this type, instead of needing an external stimulus to generate a command, a user can voluntarily issue a command by controlling his brain activity, by imagining moving a virtual object in a certain direction, for example [4].

P300 is characterized by a positive peak 300ms after the presentation of a stimuli, and is most prominent across the area between the two hemispheres [5]. This method is reportedly most suitable for applications where there is a finite number of options [6].

In an effort towards designing an affordable BCI application, Emotiv's EEG Neuroheadset is used for signal acquisition. This, however, introduces the challenge of limited electrode positions, and low signal-to-noise ratio [7]. Thus, this means that eliciting P300 responses for control may not be the best option. The Emotiv headset is shipped with a Cognitiv Suite that discerns a user's intended action on a physical or virtual object, such as pushing or rotating it. This is done by asking the user to imagine moving the object in the desired way while signals are recorded. Before this can be done, the system must be trained to detect an action, the more actions that are trained, the more difficult it is to control them [8].

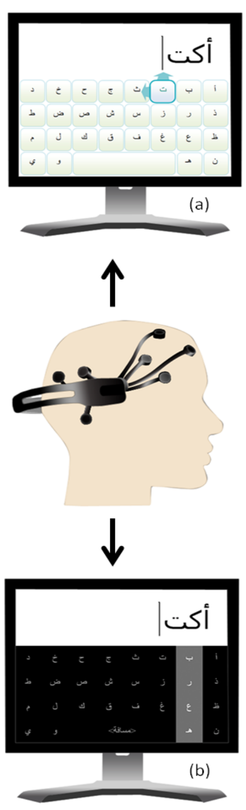
Visual representation of the physical and virtual interface for mind-typing.	**Descriptive representation of the functionality of navigation and selection in the typing program.**
	Mind-typing with Motor Imagery: Navigation on the virtual keypad is conducted with imagery movements in the horizontal and vertical directions. Navigating in the top-down direction rotates vertically when then top of the column of virtual keys is reached. Navigating in the right-left direction rotates horizontally when the left-most virtual key on a row is reached.
	Electrical activity of the brain is recorded by 14-channels on the surface of the scalp.
	Mind-typing with Evoked-Responses: The rows and columns in the matrix display Arabic alphabet and numbers. These flash successively and randomly at a rapid rate, and users select a character by directing and sustaining their attention on the Arabic character when it flashes. The row or column that contains this character evoke a P300 response, whereas all others do not. The system determines the desired row and column which exhibited the highest P300 amplitude to select the desired character for the typing task.

Fig. 1. Conceptual design of a typing application with the two approaches: (a) With Motor Imagery, keyboard is navigated in two directions, plus selection. (b) A traditional P300 matrix with Arabic letters.

This study provides an evaluation of the two Brain-Computer-Interface (BCI) approaches; P300 and Motor Imagery, for typing applications using a dry electrode signal acquisition device, the Emotiv Neuroheadset. The P300 approach is evaluated with P3Speller task provided in the BCI2000 [9] distribution, while the latter is done with the Cognitiv Suite in Emotiv's Control panel. To the best of our knowledge, there is no published work that provides such a comparison.

2 Method

To evaluate both approaches, we measured the dependent variables: accuracy and approximated speed of typing with each value of the independent variable, the approach: P300 and Motor Imagery, using a within-subjects design on 5 subjects. Equipment used comprised of the 14-channel Emotiv EEG headset, and a laptop to run the software for each approach. For the Motor Imagery we used the Cognitiv Suite included with Emotiv's Control panel. As for P300, we used P3Speller module included with the BCI2000 platform. The experiment was divided to three parts, the first two parts were to evaluate motor imagery. With motor imagery, three actions are needed to navigate a virtual keyboard; one for moving across the vertical axis, the other for moving across the horizontal axis, and finally, the third for selecting the desired button. These actions were mapped in the Control Panel to Lift, Left and Push respectively. To evaluate the P300, we used the P3Speller included with BCI2000, adjusting the parameters to make up for the relatively noisy signals produced by the headset. We set the number of sequences in a set of row/column intensifications to 15, the stimulus duration to 125ms, and duration of inter-stimulus interval to 250ms, with a 1.5s pause between each sequence.

3 Results and Discussion

The measures we are interested in are the accuracy and speed of typing for each of the two EEG-BCI approaches. With P300, we calculated accuracy by finding the percentage of the correctly typed letters to the total number of letters in the testing session, where the subjects were asked to spell "COOKIE". Speed was calculated directly by multiplying the stimulus and inter-stimulus duration by the number of flashes in a given sequence.

In Motor Imagery's testing sessions, subjects were given commands to move the virtual box in a random order to control for order effects, whether or not they have managed to move it in the specified direction was recorded. Each testing session contained commands testing each of the actions approximately 4 times. In addition to the time that was needed to complete that session. Each subject has completed at least 10 testing sessions. Accuracy for each subject was found by averaging the accuracies of all testing sessions for that subject. In a traditional 6x6 keyboard, same size as P300's, to navigate from one letter to another we need on average 5 movements, and one more action for selection. Thus, to approximate the speed of selecting a certain letter, we multiplied the average duration of an action (movement) by 6. The average accuracy for all subjects is somewhat similar, but P300 has generally higher values with 40% of the subjects achieving more than 80% accuracy. Variations in typing efficiency were found between the two approaches; P300 can provide typing speed more than twice that of Motor Imagery. Both are far too slow and are in need of improvement.

Preliminary investigations with the Emotiv headset for the two EEG-BCI approaches showed that both achieve more or less the same accuracy, but P300 was more efficient than Motor Imagery. Since the incorrect letters in the former approach resulted from letters adjacent to the target letter distracting the user, it can be argued that using the checkerboard paradigm, where no adjacent locations can flash concurrently, would improve accuracy. Additionally, Motor Imagery is an approach that depends on the adaption of both the user and the system; the user must train himself or herself to control their brain activity to type, much like learning to walk or write for the first time.

Results that were found by this study did not allow the subjects to gain sufficient experience to control the virtual box, which can take a substantial amount of time. Hopefully, this would reduce the generation of false positives, whose presence significantly decreases the usability of keyboards using Motor Imagery.

There remains an issue of how to balance between system and user training in Motor Imagery, increasing the number of system training sessions can lead to distorting the signature of a certain action [8], but improvements in user control should also be propogated to the system. Further investigation is required to establish some threshold.

Additional work is needed to examine the usability of these applications with people with severe motor disabilities. It remains unknown whether they can control an application with Motor Imagery if they had lost control of their limbs prior to learning how to use it [10]. Hence, it is important to find out if our target population would achieve the same results.

Conclusion

This document describes an evaluation of a dry-electrode EEG acquisition device with P300 and Motor Imagery for typing applications. The former approach was deemed more suitable because of its relative efficiency. The document also presented changes that can be introduced to improve accuracy and speed. Further investigation is needed to validate the results for our target population, people with severe motor disabilities.

References

1. T. M. Vaughan and J. R. Wolpaw, "Special issue containing contributions from the Fourth International Brain–Computer Interface Meeting," *Journal of Neural Engineering*, vol. 8, no. 2, p. 020201, Apr. 2011.
2. "Emotiv SDK Research Edition Specifications," Emotiv, 2010.
3. D. J. McFarland and J. R. Wolpaw, "Brain-computer interfaces for communication and control," *Communications of the ACM*, vol. 54, no. 5, p. 60, May 2011.
4. R. Rao and R. Scherer, "Brain-Computer Interfacing [In the Spotlight," *IEEE Signal Processing Magazine*, vol. 27, no. 4, pp. 152–150, Jul. 2010.
5. J. Wolpaw and E. W. Wolpaw, Eds., *Brain-Computer Interfaces: Principles and Practice*, 1st ed. Oxford University Press, USA, 2012.
6. R. Fazel-Rezai, B. Z. Allison, C. Guger, E. W. Sellers, S. C. Kleih, and A. Kübler, "P300 brain computer interface: current challenges and emerging trends," *Front. Neuroeng*, vol. 5, p. 14, 2012.
7. M. Duvinage, T. Castermans, T. Dutoit, M. Petieau, T. Hoellinger, C. De Saedeleer, K. Seetharaman, and G. Cheron, "A P300-based Quantitive Comparison between the Emotiv Epoc Headset and a Medical EEG Device," *Biomedical Engineering / 765: Telehealth / 766: Assistive Technologies*, vol. 764, 2012.
8. "Emotiv Software Development Kit User Manual for Release 1.0.0.3." Emotiv.
9. G. Schalk, D. J. McFarland, T. Hinterberger, N. Birbaumer, and J. R. Wolpaw, "BCI2000: a general-purpose brain-computer interface (BCI) system," *IEEE Trans Biomed Eng*, vol. 51, no. 6, pp. 1034–1043, Jun. 2004.
10. A. Kübler, F. Nijboer, J. Mellinger, T. M. Vaughan, H. Pawelzik, G. Schalk, D. J. McFarland, N. Birbaumer, and J. R. Wolpaw, "Patients with ALS can use sensorimotor rhythms to operate a brain-computer interface," *Neurology*, vol. 64, no. 10, pp. 1775–1777, May 2005.