Write, Read and Answer Emails with a Dry 'n' Wireless Brain-Computer Interface System*

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Abstract— **Brain-computer interface (BCI) users can control very complex applications such as multimedia players or even web browsers. Therefore, different biosignal acquisition systems are available to noninvasively measure the electrical activity of the brain, the electroencephalogram (EEG). To make BCIs more practical, hardware and software are nowadays designed more user centered and user friendly. In this paper we evaluated one of the latest innovations in the area of BCI: A wireless EEG amplifier with dry electrode technology combined with a web browser which enables BCI users to use standard webmail. With this system ten volunteers performed a daily life task: Write, read and answer an email. Experimental results of this study demonstrate the power of the introduced BCI system.**

I. INTRODUCTION

First experiments to measure the electrical activity of the human brain were started in the year 1924 by Hans Berger. In the year 1929 he reported the measurement of the electroencephalogram (EEG) from several patients [1]. However, he had great problems to visualize the signals because of primitive electrodes and signal plotting devices. More than 40 years later the idea emerged to use the EEG to control computers [2], nowadays well known as brain-computer interface (BCI). Unfortunately, the signal acquisition and the performance of the used computers were still a bottleneck. It took another 15 years to develop a practically usable BCI [3]. With this approach it was possible to spell words just by concentrating on randomly highlighted elements of a letter matrix. A prominent positive potential in the EEG approximately 250-500 ms post target stimulus [4] is the main control signal for this so-called P300-based BCI. Such a system enables healthy as well as users with motor impairment to communicate [5], [6], [7], [8], [9], [10]. Many software improvements have been introduced concerning: the signal processing (e.g., different classification methods [11], [12]) and the paradigm presentation (e.g., checkerboard flashing pattern [13], binomial flashing pattern [14], and famous faces highlighting [15]). On the signal acquisition side there was an evolution from passive gel-based electrodes, i.e., they require the application of abrasive, conductive gel between electrode and skin, to active gel-based electrodes, without the necessity to abrade the skin because the signal is pre-amplified at the electrode. Finally, in the last years dry electrodes were developed [16], [17].

Within the project BackHome we tested and evaluated one of the latest hardware developments. Namely the g.Nautilus, a wireless EEG signal amplifier with dry electrodes from Guger Technologies OG, Graz, Austria (http://www.gtec.at). Participants had to write, read and answer emails using a very popular webmail client with this device.

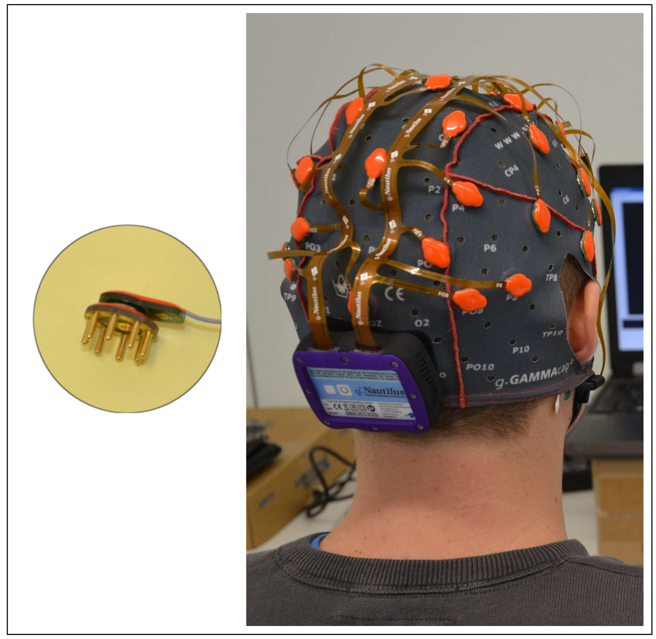

Fig. 1. A participant wearing the g.Nautilus system with dry electrodes. A close-up of the 7mm dry electrode is shown in the yellow circle.

II. MATERIALS AND METHODS

A. Participants

Ten volunteers (3 female; mean age 23.9 $\pm$ 1.2 years) participated in this study. All stated that they have no history of neurological or psychiatric disorders. The study protocol was approved by the ethics committee of the Medical University of Graz and the subjects gave written, informed consent before the experiment. Eight of the participants had no prior experience with BCIs.

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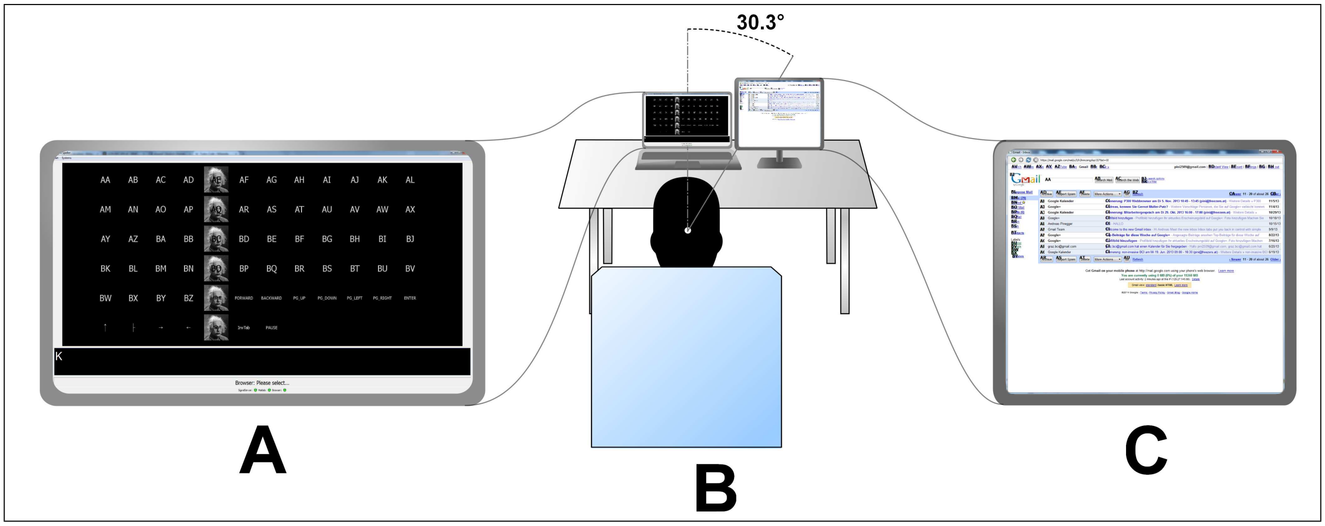

Fig. 2. (A) Screen displaying the user interface for feedback and P300 stimulation. (B) Sketch of the experimental design. The angle between the participant, the laptop, and the monitor was 30.3°. (C) Screen for the web browser.

B. Data Acquisition

The g.Nautilus biosignal amplifier uses the ZigBee wireless technology to transmit the EEG signals with 24 bit resolution. Thirty-four electrodes, a reference channel, ground and 32 electrodes at pre-configured positions, are connected to the amplifier, see Fig. 1. Dry electrodes with two different pin lengths (7 and 16 mm) are available to adapt them to different hair lengths and shapes of users' heads. The operator has to find the optimal type of electrodes for each participant to get the best signal quality. The signal of each EEG channel is highly oversampled in order to keep the signal to noise ratio (SNR) high at the offered sampling rates of 250 Hz and 500 Hz.

In the presented study the signals from Fz, Cz, Pz, PO7, PO8, and Oz were sampled at 250 Hz and bandpass filtered between 0.5 and 30 Hz.

The whole g.Nautilus system consists of a headset with dry EEG electrodes (Fig. 1 yellow circle), a medium size EEG cap, and a base station for connecting it to the host computer. The device is charged with a Qi charging station. Qi is a wireless power transmission standard (http://www.wirelesspowerconsortium.com). This has the advantage that the device just has to be placed on the power transmission pad without the need to connect any wires.

C. Experimental Design

The participants were seated in a comfortable chair approximately 65 cm away from two computer screens (39.5 cm and 43 cm diameter), see Fig. 2 (B). One screen was centered in front of the participants. At this screen a P300 matrix was displayed to control a web browser (see Halder et al., under review), which was shown on a second screen placed right beside the first one, see Fig. 2 (A) and (C). The web browser automatically detects all possible links, buttons, and text fields of the currently shown website and marks them with letters. These letters were sent to the BCI for selection with a P300 spelling device. By sending back the desired element to the web browser the corresponding link, button, or text field was selected. In case the element was a text field the matrix automatically changed to a matrix with letters from the Latin alphabet, text manipulation, and control entries.

The P300 user interface and the signal processing in Matlab (MathWorks, Natick, USA) were presented in [18]. Elements of the matrix were highlighted with famous faces [15]. The aforementioned best electrode length selection was done by visual inspection of the measured EEG.

Calibration was performed with fifteen highlightings per row and column. Each flash had a duration of 50 ms and the time between flashes was set to 175 ms. The participants were asked to copy-spell ten letters. After the last letter the optimal number of sequences (each row and column flashed once) for feedback was calculated (number of sequences to achieve one hundred percent accuracy plus two; minimum eight, maximum fifteen sequences).

The task for the participants was to write an email to a given address and to reply to an automatically generated email from that address afterwards. First, they had to choose an address and spell "EINKAUFEN" (engl. "SHOPPING") into the subject field. Then, write "GEH BITTE HEUTE EINKAUFEN." (engl. "PLEASE GO SHOPPING TODAY.") into the message field and finally, send the message. At the end of this first part they had to select a "PAUSE" element to pause the system and wait for the reply. If the user selected this element, no further selections were sent to the web browser until the same element was selected again. The text of the answer mail was "MILCH AUCH?" (engl. "MILK TOO?"). After reading the mail the participants had to leave the pause mode and answer the new mail with the word "JA" (engl. "YES").

The whole email task needed a minimum of 52 selections and was aborted if the goal was not reached within 78 selections. The minimum instead of the actual number is given because

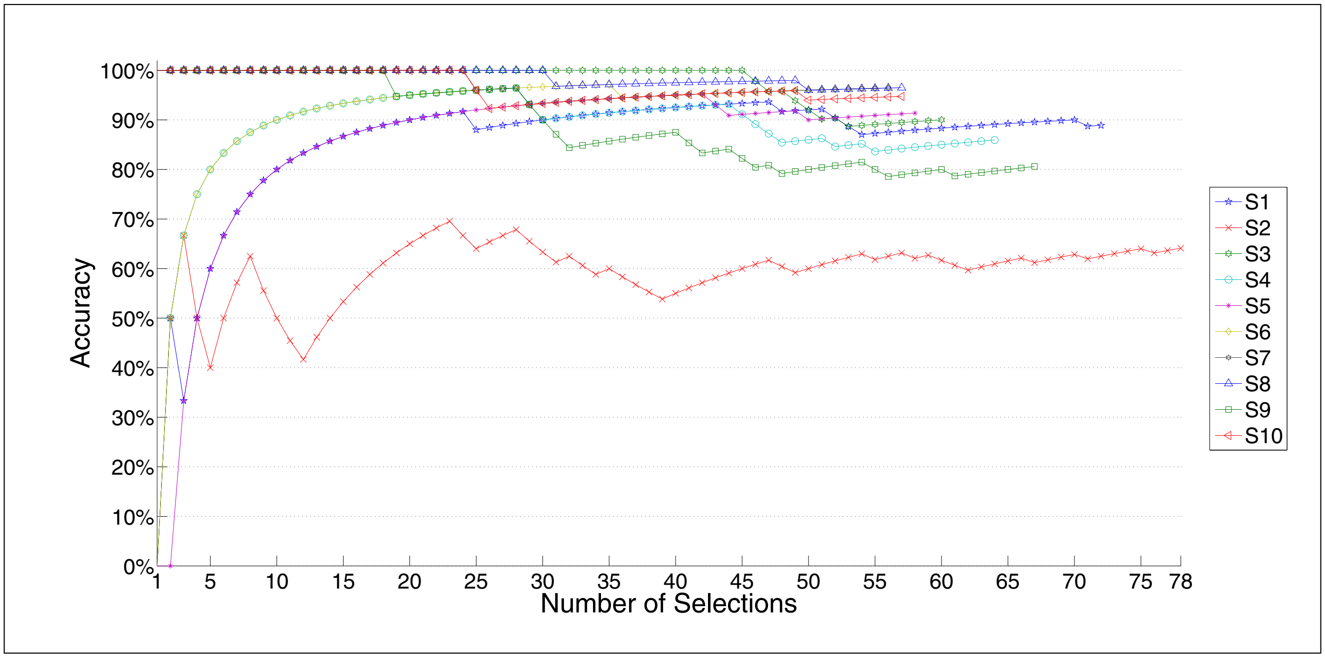

Fig. 3. Comparison of spelling accuracies from different participants over number of selections. The minimal number of selections was 52.

the user was asked to correct mistakes and thus the actual number of selections was unknown before the completion of the task.

D. Evaluation Metrics

After completing the BCI tasks all participants were asked to complete several questionnaires. Satisfaction was evaluated using a visual analog scale (VAS). The extended Quebec Evaluation of Satisfaction with Assistive Technology (eQUEST) version 2.0 [19] and a custom usability questionnaire were used to evaluate the usability of the soft- and hardware.

III. Results

Different electrode pin lengths were used for the participants. Only the six used electrodes of all 32 were adapted to the participants needs. Two participants needed just short electrodes, five only long electrodes, and three needed a mixture of both electrode types. The time between the instruction of the participant and the start of the calibration was on average 14 (SD 5) minutes.

A. Efficiency and Effectiveness

After calibrating the classifier the number of highlighting sequences for the online session was calculated for every participant. The participants needed on average 12 (SD 3, range 8–15) highlighting sequences.

A comparison of the accuracies after a certain number of selections is shown in Fig. 3. Nine participants completed the online task within the maximum allowed value of 78 selections. They had an average accuracy of 92.1% (SD 4.8). The time to complete the task including pauses varied between 38 minutes (S6) and 79 minutes (S1) with an average time of 58 (SD 16) minutes to complete the task. The accuracy of the participant S2 who did not complete the task was 66.7% after 95 minutes. Five participants started the online session with one or two errors. However, later on four of them (S1, S4, S5, S6) had very few errors. Only the accuracy of participant S2, who did not complete the task, stayed continuously below 70%, see Fig. 3. The participant with the longest period without making any error was S3 with 45 correct selections in a row from the beginning.

The average accuracy of all participants was 89.5% (SD 9.2).

B. Satisfaction

Overall device satisfaction (VAS score) was 7.5 (SD 2.3; not at all satisfied: 0, absolutely satisfied: 10).

The items which received scores below 4 (quite satisfied) in the eQuest were “aesthetic design” (3.4), “comfort” (3.8), and “effectiveness” (3.9). Highest rated items were the “adjustment of the hardware” (5.0) and the “reliability” (5.0). The items that were rated as most important by the study participants were “effectiveness” (n=5), “comfort” (n=5), and “learnability” (n=5). Most participants negatively remarked that the electrodes hurt after a while and criticized the low speed of the system.

Using the system design questionnaire, three users remarked that their eyes hurt after a while.

IV. Discussion

In this study, the performance of a new wireless EEG amplifier system with dry electrodes was evaluated and tested with an actual web browsing task.

The reached accuracies of the participants who completed the online task were between 84.9 % and 96.5 %. This performance is comparably high. Only one participant (S2) did not finish the task within 78 selections. A possible reason could be that the used short electrodes did not fit well enough which resulted in the signal to noise ratio being too low. Another interesting issue to be noted was that one participant (S8) paused the system and had to go urgently to the restroom after 47 selections. Afterwards the user selected the pause-leave element and finished the task with only one error. This would absolutely be impossible with a wired EEG amplifier system.

The needed highlighting sequences calculated after the calibration were nearly evenly distributed over the possible range (8–15). This result indicates that there is space to further improve the signal processing pipeline to better fit the requirements of a wireless dry electrode system. Originally, the software was designed for EEG amplifiers with active gel-based electrodes and was just slightly adapted. Other filter parameters and classification methods [12] could result in a decrease of needed highlighting sequences and consequently a reduction of needed time to spell a symbol.

According to the VAS the participants were very satisfied with the system. Only two participants rated the system below 7 and one of them did not finish the task.

The evaluation of the eQUEST showed that the users find the headset very conspicuous and they criticize the aesthetic design. Another low rated point in the eQUEST was the comfort of the headset. Nearly all the participants remarked that they felt the pressure of the dry electrode pins after a while and they had pressure marks on the forehead after the measurement. Another low rated point was the effectiveness. However, healthy people tend to compare assistive device systems with their normal communication and control devices. Compared to these systems the speed of current BCIs will always be low. All participants rated the "adjustment of the hardware" with the highest possible value. Compared to passive systems with abrasive electrode gel the development of dry electrodes is a huge improvement. However, there are still problems to be solved. It would be almost impossible to use such a system in a room where people are moving around, the induced artifacts would be dominant and would cover the EEG.

The participants rated "effectiveness" and "comfort" among the three most important as well as unsatisfied items. Consequently, the further development of the system should go in that direction.

In conclusion, this study shows that the introduced wireless EEG amplifier system with dry electrodes in combination with the BCI system and the BCI web browser works with very high accuracy. Despite the moderate speed of the system, the healthy users reported a very high overall satisfaction.

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