P300 Brain-Computer Interface Performance:

A dry electrode study

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***Abstract*— Most brain-computer interfaces (BCI) are based on one of three types of electroencephalogram (EEG) signals: P300s, steady-state visually evoked potentials (SSVEP), and event-related desynchronization (ERD). EEG is typically recorded non-invasively using active or passive electrodes mounted on the human scalp. The common setup requires conductive electrode gel to get the best entrance impedance and noise ratio. However, electrode gel is inconvenient, uncomfortable, and entails setting problems that are especially pronounced when trained users are not available. Some work has introduced dry electrode systems that do not require gel, but often entail reduced comfort and signal quality. The principal goal of this study was to compare the performance of dry vs. gel-based electrodes in a very common BCI system: P300 spelling.**

Keywords- Brain Computer Interface; BCI; Dry electrodes; P300 speller;Gel electrodes.

I. INTRODUCTION PER CERT

BRAIN - Computer Interfaces (BCIs) allow new communication channels based on different mental states. In a typical BCI, a user performs voluntary mental tasks that each produce distinct patterns of electrical activity in the electroencephalogram (EEG). Using monitoring systems and on-line signal processing software, it is possible to identify which mental tasks a user performed at a specific time. Most modern BCIs rely on one of three types of mental tasks, which are associated with different types of brain activity:

- Imagined movement, which produces event-related desynchronization (ERD) [1] and [2];
- Attention to oscillating visual stimuli, which produces steady-state visually evoked potentials (SSVEP) [3];
- Attention to transient stimuli, which produces the P300 event-related potential [4], [5] and [6].

Noninvasive BCIs are hampered by the need for conductive gel to get a good contact between electrodes and the user's scalp. The gel is uncomfortable to many subjects, and must be washed out of the cap and hair after each use. This procedure increases the time and inconvenience needed for each EEG recording session. Also, after a few hours, the gel dries and new gel has to be applied [7]. These problems reduce the appeal of EEG-based technologies to most users, and can be especially pronounced for severely disabled users – even though these are the people who need BCIs most.

Numerous articles that survey different end users have further confirmed that dry electrodes are a very high priority. Casson [8] surveyed neurologists and found that almost 90% agreed there is a clinical need for "wearable electrodes". Huggins [9] surveyed 61 ALS patients and found one of their main concerns was "set-up simplicity". Zickler [10] surveyed severely disabled users and found that major issues included "possibility of independent use" and "easiness of use". Blain [11] presented a focus group study with 8 ALS patients and 9 carers. One of their main concerns was a more convenient way to sense brain signals.

However, early dry electrodes had various problems, including reduced signal quality, inadequate robustness to movement, electrical artifacts, cost, and comfort. A second generation of dry electrodes based on an active system is used to study the difference in signal quality and robustness against artifacts.

In the following sections, we will first introduce the system components of the IntendiX P300 speller software; describe its characteristics and the workflow of our experiment. Then, we will provide our results comparing dry and gel electrodes obtained from 23 patients.

II. METHODS

A. *Experimental procedure*

23 subjects (6 female, age: 22-60) participated in the study. All subjects were free of medication, had normal vision, and no history of central nervous system abnormalities. Subjects sat in front of a laptop computer.

The laptop used the intendiX row/column (RC) speller shown in Figure 1. The RC speller presented 50 characters (the 26 letters of the English alphabet, integers from 0 to 9, and 14 special characters). Subjects were instructed to mentally count each time a target character flashed while ignoring other flashes. Subjects were first asked to spell the word "WATER" for calibration and then spell the word "LUCAS" (only the accuracy results of spell "LUCAS" are reported in this paper). The system randomly highlights one column or row for 100 ms, followed by a 60 ms dark time

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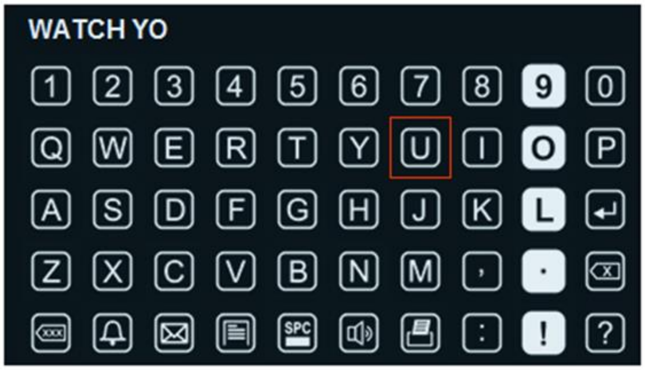
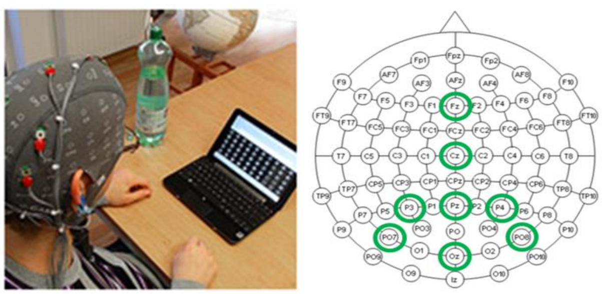


Figure 1. The intendiX spelling matrix. The phrase "WATCH YO" is feedback from the subject's spelling. The target letter "U" is indicated by a red box.



(a) (b)

Figure 2. Left panel (a) shows a subject using the system with active g.BUTTERfly electrodes. The right panel (b) shows the electrode montage used with both gel and dry electrodes. The ground is on the left mastoid, and the reference is on the right mastoid.

between these flashes. Each row and column was highlighted 15 times for each letter, resulting in 225 flashes per trial, and 1125 flashes for a five-letter word. Signal processing software extracts ERPs (100ms to 700ms) after each flash and uses linear discriminant analysis (LDA) to classifier the most important P300 response. The intendiX system then presents the target character on the monitor, and the highlighting restarts so the user can spell the next letter.

P300 BCIs are relatively fast. The first BCI to exceed 100 bits/min was shown by P. Brunner in 2011 [12].

B. *Hardware and software*

IntendiX P300 software (from g.tec medical engineering GmbH, Austria) provides a full personal EEG-based spelling system. This application generates the visual simulation, calculates the parameters for the classification and processes the data to extract a target character.

Figure 2 shows the electrode configuration for the P300 speller. The EEG were acquired using a g.USBamp (24 Bit biosignal amplification unit from g.tec medical engineering GmbH, Austria) with a sampling frequency of 256 Hz. EEG electrodes were placed using the international 10/20 electrode system. EEG recordings based on gel electrodes

TABLE I. ACCURACY COMPARISON

Row-Column Speller accuracy (%)	Gel electrodes (N=81) [4]	Dry electrodes (N=23)
100	72.8 %	69.6 %
80-100	88.9 %	87.0 %
60-79	6.2 %	8.7 %
40-59	3.7 %	4.4 %
20-39	0.0 %	0.0 %
0-19	0.0 %	0.0 %
Average Accuracy of all subjects	91.0 %	90.4 %

a. Table I summarizes subjects' accuracy for gel electrodes in an earlier study [4] and dry electrodes in the present study.

were conducted with active g.BUTTERfly electrodes (golden ring electrode type with a hole in the middle to inject the gel);EEG recordings based on dry electrodes instead used active g.SAHARA electrodes (8 gold-coated pins with 7 mm length mounted in a circular arrangement, diameter 15 mm) [13].

III. RESULTS

No significant differences were found between gel and dry electrodes. The raw data look similar for both electrode types, including the noise created by eye blink artifacts and some high frequency activity.

An accurate study of the evoked potentials shows that, in both cases, the evoked potential (EP) reaches its maximum of about 6 µV after about 340ms.

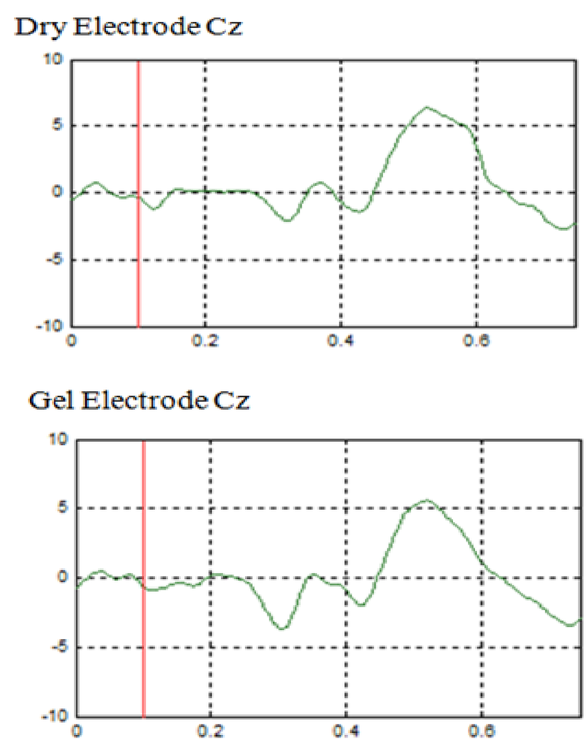


Figure 3. P300 response for dry and gel electrodes. The y-axis is acaled with +/-10 µV, with the x-axis in seconds.

The EP looks very similar for the dry and gel based electrodes; see Figure 3. This figure shows the P300 response for dry and gel electrodes in the copy spelling run of 1 subject. Each run had 5 characters flashed 30 times, 15 rows and 15 columns. The comparison of the training and copy spelling run shows that the EP is very stable over time.

Table I summarizes the BCI performance results. One column presents the results with dry electrodes from the present study. Another column summarizes gel electrodes from a large group study with gel based electrodes (N=81) [4]. N specifies the number of subjects summarized on each column.

IV. DISCUSSION

We show that the used dry electrode sensor concept can be used for P300 based BCI systems. Dry electrodes do not use gel, resulting in higher skin impedance as well as greater comfort and convenience. The higher skin impedance can increase vulnerability to artifacts below 3 Hz.

To test the usefulness of dry electrodes for the P300 BCI we conducted a group study with 23 subjects, and compared the EPs (for 1 subject) and accuracies (for all subjects). The latencies and amplitudes of the P300 appeared to be similar for dry and gel based electrodes.

In this case, dry electrodes require about the same setup time as gel electrodes. P300 active electrodes can be mounted in about 3 minutes, and dry electrodes require about 1 minute or below. However, after the cap is mounted, dry electrodes need a few minutes to adjust, and therefore the preparation time is comparable to active electrodes.

The biggest advantage of dry electrodes is that no abrasive and conductive gel remains in the hair. Therefore, the time consuming cleaning of patient's hair is avoided. Another big advantage is that the electrodes do not get in contact with water for cleaning and therefore the lifetime is enhanced. None of the subjects reported discomfort from the dry electrodes.

V. CONCLUSION

The results of the study have important consequences. Dry electrodes speed up the cap mounting process, enhance user acceptance, increase the possible recording time, and therefore bring the technology closer to many people. Although the dry electrodes show higher signal power below 3 Hz resulting from low frequency drifts, we did successfully show that the P300 speller works.

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