Dry Electrodes for Electroencephalography Headsets

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Abstract and Introduction:

Electroencephalography, or EEG, is the field of measuring and recording the brain's electrical activity [1]. Although it is already widely used to study the brain and its disorders, the EEG measuring protocol can still be improved. Currently, the conventional EEG is read using "wet" electrodes (containing wet gel) placed on the scalp. The use of this electrolytic gel, though effective, brings about significant room for improvement in the EEG. The gel tends to cause itching and occasionally allergic reactions, and the frequent renewal of the gel is labor-intensive, hence expensive. While also being messy, the gel dries out within a few hours, restricting any long-term measurement from being taken. For uses such as in nascent wireless EEG headsets [2], being able to measure for long periods of time are very important. For that reason, the current study presents the design of a different type of electrode, a "dry" electrode, in which no gel is necessary. These dry electrodes instead employ needles to create contact with the conductive regions of the skin. Once designed and fabricated, the electrodes are tested in commercial neuroheadsets, and then compared to the standard wet ones.

Figure 1: A dry electrode.

Experimental Methods:

In order to realize functional dry electrodes, a three step fabrication process was used. First, the electrodes were designed through computer modeling (SolidEdge) with their backsides designed to fit the neuroheadset electrode holders. Next, the designs were made into prototypes through a 3D printing process, using the polymer FullCure720. These prototypes were then coated with four metals: TiW (10 nm), copper (50 nm), TiW (10 nm), gold (50 nm), as seen in Figure 1. This deposition would allow for the ionic current within the body to pass through to the metal coating of the electrode. Gold was chosen as the outer layer due to its high electrical conductivity and biocompatibility [3].

Once the dry electrodes were fabricated, they were placed into the neuroheadsets and tested for functionality, and then compared to the wet electrodes. Three tests were performed to compare the two types of electrodes. The first test involved reading the signal quality as displayed by software provided with the headsets. The second test measured the accuracy of facial expressions being read by the software. Finally, the third test measured the EEG of a subject repeating three different actions ten times: blinking, looking right, and looking left.

Results and Discussion:

The first test sought to compare the signal quality of the dry electrodes to that of the standard wet electrodes. When the wet electrodes were tested, the contact quality displayed a good signal — or at least 80% of the signal quality that would be measured in medical grade biosensors — for each of the electrodes, as expected. When tested with the dry electrodes, the sensors showed the same response — good signals for each location on the headset. Therefore, the dry electrodes performed comparably well to the wet electrodes in terms of signal quality.

The next test evaluated the neuroheadsets' ability to read facial expressions. Each of the ten sensible expressions (from blinking to smiling to raising eyebrows) were tested 25 times and recorded for every successful response. This was done for both dry and wet electrodes in order to get an accurate comparison. Although the results are varied, they showed that the dry electrodes allowed the facial expressions to be read at 64% accuracy, while the wet electrodes were only at 61% (Figure 2). Although 3% is not a significant difference, it can be seen that the dry electrodes allow reading of facial expressions at least as well, if not better, than the wet electrodes.

The third and final test involved recording the test subject's EEG while performing a 3-action test. The three actions —

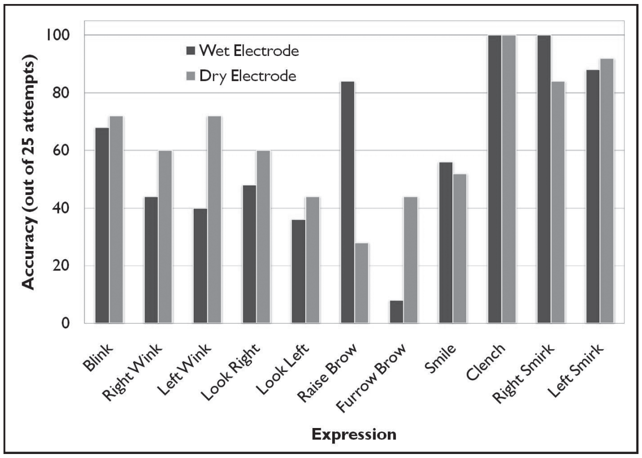

Figure 2: Facial expression test results.

blinking, looking right, and looking left — were repeated ten times for both the wet and dry electrodes. The wet results (Figure 3) showed three distinct responses based on the action. For blinking, there are significant peaks in each of the electrode channels, while in both directional tests, one half of the brain responded more prominently. When the subject looked right, the right half of the brain showed more significant response, and vice versa for when the subject looked left. When this data was compared to that of the dry electrodes (Figure 4), mixed results were noted. In the case of blinking, the channels behaved relatively similarly in both cases. For the directional tests, however, the dry electrodes did not respond the same way. When looking to the right, some of the channels (AF4, F8, FC6) still performed similarly, while others (F4, T8) were stagnant. Comparable behavior occurred when looking to the left.

From these results, it is evident that dry electrodes have a high potential to replace wet ones, at least in the application of neuroheadsets. They eliminate the need for any electrolytic gel, thereby providing long term measurements.

Future Work:

Despite the promising results, there is still work to be done. The amount of noise recorded in the EEG from the dry electrodes should be addressed, perhaps by designing different dimensions of electrodes based on their location in the headset. This way, increased stability on the scalp may promote less motion artifact. Once this issue is addressed, dry electrodes in EEG headsets can be realized.

Acknowledgements:

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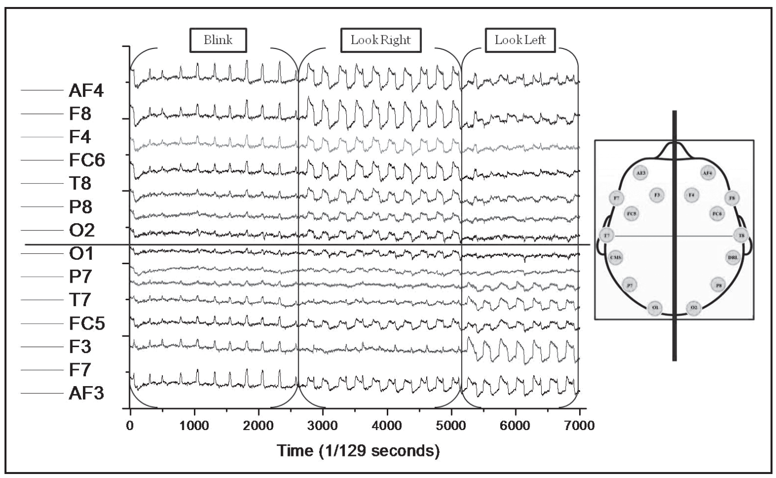
References:

[1] Webster, J. G., and Clark, J. W. (1992). Medical Instrumentation: Application and Design. Boston, MA: Houghton Mifflin Company.

[2] EPOC Neuroheadset. (2010). Retrieved 08 02, 2011, from Emotiv: http://emotiv.com/store/hardware/epoc-bci/epoc-neuroheadset/

[3] Voskericiana, G. et al. "Biocompatibility and biofouling of MEMS drug delivery devices." Biomaterials (2003): 1959-1967.



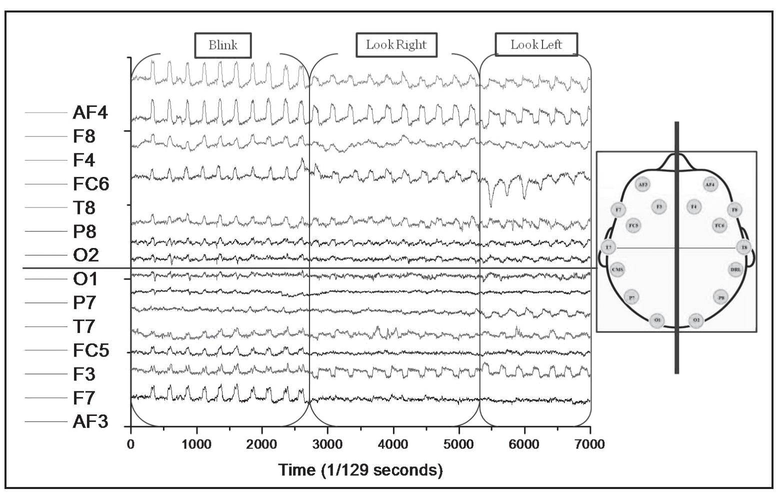


Figure 3, top: Wet electrode EEG results with headset map.
Figure 4, bottom: Dry electrode EEG results.