

New Dry Electrodes with Comparable Performance as Standard Electrodes

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Abstract— In a first study we examined the signal quality of dry 13-pin electrodes in an - regarding the surface area - optimized arrangement in comparison to standard wet electrodes using a paradigm based on visually evoked potentials (VEP). The benchmark was the averaged VEP signal amount in relation to a maximum of 960 averaged measurements. The results demonstrate a comparable signal quality between dry and wet electrodes, although the dry electrodes show a much higher impedance.

INTRODUCTION

Dry electrodes are becoming more interesting with mobile and long term measuring of biopotentials. In order to measure non-invasively biopotentials the usual procedure is to place wet electrodes on the skin surface of a person. The problem is the conversion from an ionic conduction within the body to an electronic conduction for the measurement. The skin exhibits a high impedance which is then minimized using a gel under the standard Ag/AgCl-electrode. As showed in [1] the concept of minimizing the impedance to improve signal quality of the electrodes can be misleading. Their analysis based on different model assumptions led to the conclusion of two extreme cases for signal-to-noise improvements: 1. minimize the impedance of the skin-electrode system as preferred in wet electrode scenarios or 2. maximize the impedance as done using capacitive electrodes [2]. The main problem with high impedances is the increased pick-up of environmental noise [3]. Usually this obviously reduces the signal-to-noise-ratio [4], but this is not always the case. Important is also the total signal amount hidden in the measured signal containing always also a “biological” noise[5], which impose a limit which cannot be improved further by reducing the impedance [6], but by increasing the signal amplitude itself.

I. EXPERIMENTAL SETUP

A. The Dry Electrode

In Fig. 1 a single dry pin is shown, made of a copper-zinc base and glazed with a gold layer using a sputter technique. The dry electrode we used (Fig. 2) is composed of 13 of such pins, which are electrically interconnected and allow a good penetration through hair to reach the skin on the head. Their impedance is well below 1M Ω per pin and have a larger total area compared to a single pin, The single pin has a diameter of 0,8mm and the 13-pin electrode of 15mm. We grouped 3 of this electrodes together to further increase the contact area and to derive a single biopotential signal. Our experiments with different

arrangements led us the conclusion that this might be an optimal solution in regards to SNR, flexibility, comfort and cost.

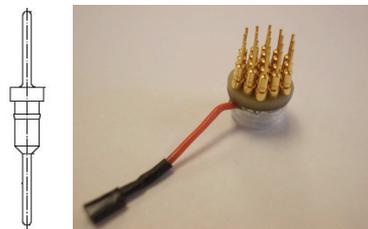


Fig. 1 (on the left) Single pin

Fig. 2(on the right) Single dry electrode

B. Electrode Placement and Paradigm

We measured 6 volunteers (5 male, 1 female) using a newly developed EEG hardware based on the Texas Instrument EEG-Chip AD1299 with a 24bit ADC per channel as well in an EEG shielded environment and later in an unshielded, since in the latter case only the 50 HZ line noise was higher.

The triple dry electrodes were placed on the head according to Fig. 3 using the 10-10-EEG-system with 14 channels (out of 64) and a focus on the position Oz and POz, where the expected VEP signal arises. The CPz-electrode position was used as reference point and Fpz position as ground.

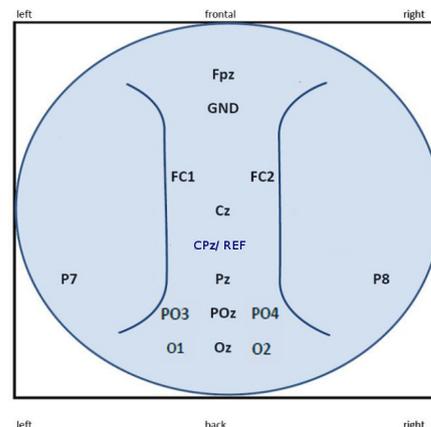


Fig. 3 Electrode placement for the VEP measurements

As a paradigm to measure the signal quality we used visually evoked potentials (VEP) since they are easily reproducible showing a relatively high signal and allow for rather short measuring times.

We used the patterns shown in Fig.4, alternating each 55ms which corresponds to 1,801 Hz.

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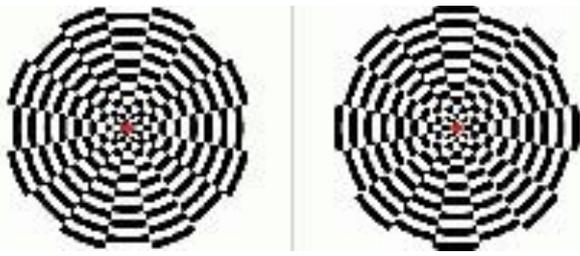


Fig. 4 Alternating visual pattern used for the VEP measurements

II. SIGNAL QUALITY

A. Impedance

The impedance behavior of the dry electrode described previously as a function of frequency is shown in Fig 5. Their impedance values are far away compared to standard wet electrodes but comparable to other dry electrodes [7].

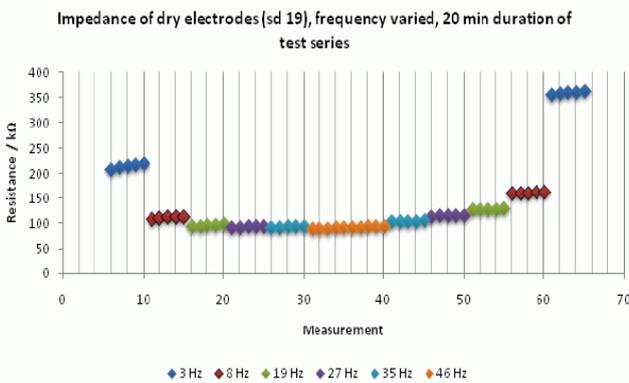


Fig. 5 Impedances of the used dry electrode as a function of frequency

B. Computation of the Signal-to-Noise Ratio compared to the maximum number of averages used

After subtracting the dc component (high-pass; 0,215 Hz cutoff-frequency at 36 dB/ oct) a grand average was calculated. Due to the high number of trials (n=960) the assumption is that the measured signal is indeed induced by the visual stimulation and is a part in the signal-trial signal contribution to the total signal. On that basis we are able to compare the average signal of wet electrodes with the signal after N averages using the dry electrodes. The amount of noise is calculated by subtracting the normed signal averaged over 960 measurements minus the normed signal after n averages.

Fig. 6 shows the noise figure calculated as described as a function of the number of averages for wet versus dry electrodes.

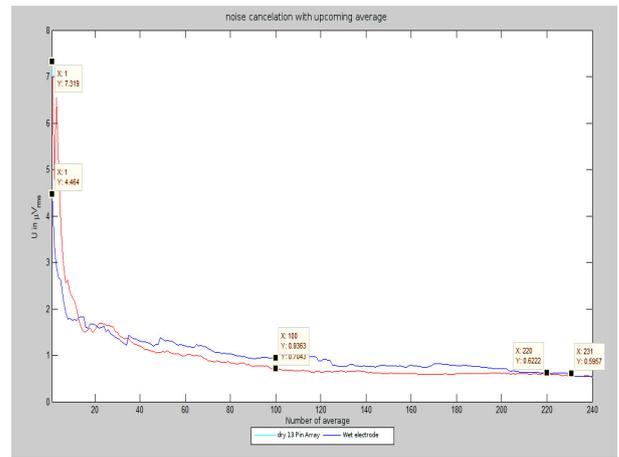


Fig. 6. Noise signal comparison between wet/dry electrodes as a function of the number of averages

It turns out, that using our triple dry electrode arrangement already after a few averages the VEP-signal shows a signal quality comparable to a wet electrode arrangement placed on the same spots on the head. After 10 averages the differences between wet and dry electrode vanishes more and more.

A direct comparison after 10 averages of the VEP signal between the dry/wet electrode arrangements is shown in Fig.7. The P100 wave and also N2 can clearly be distinguished.

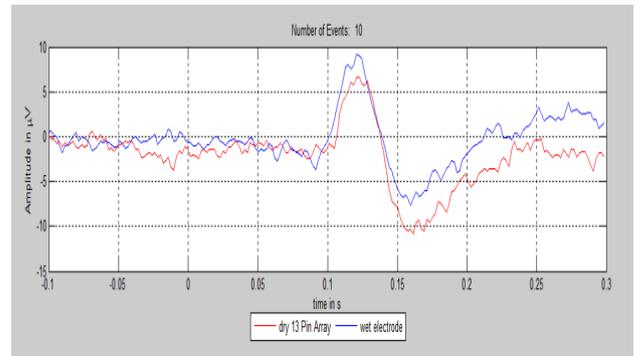


Fig. 7. Direct comparison between wet/dry electrodes after 10 averages of the VEP signal

A look at the power and amplitude spectrum after 50 averages (out of 960 as a maximum) confirms that the signal quality of the dry electrodes is very close to that of the wet ones, the main difference being a higher intersperse power supply hum at 50 Hz and multiples (Fig. 8).

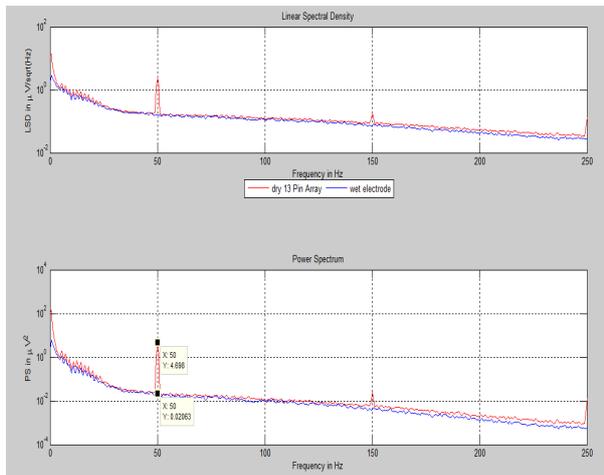


Fig. 8. Top: Amplitude spectra dry electrodes (red) and wet electrodes (blue). Bottom power spectra dry electrodes (red), wet electrodes (blue)

III. CONCLUSION

Our results imply that when using dry electrodes for measuring biopotential signals it might be better to focus on improving the signal itself than to concentrate to reduce the impedance. We could demonstrate that the uncorrelated environmental noise as well as the “biological” noise could be reduced for dry electrode arrangements, giving similar results as with standard wet electrode arrangements, although the dry electrodes show a much higher impedance.

This might be due to the construction and combination of dry electrodes with a low single pin contact area, which is then effectively increased by interconnecting many of these pins and grouping them into a large array. For single-trial experiments like brain-computer-interface this solution is not optimal although first successful experiments were already performed [8]. A better application field might be ambulatory measurements in the clinical field e.g. in the epilepsy diagnostics as this might require much less preparation time..

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REFERENCES

- [1] Y. M. Chi, T. Jung, Senior Member, IEEE & G. Cauwenberghs: Dry-Contact and Noncontact Biopotential Electrodes: Methodological Review, *IEEE Reviews in biomedical Engineering*, VOL. 3, 2010
- [2] A. Lopez and P. C. Richardson, “Capacitive electrocardiographic and bioelectric electrodes,” *IEEE Trans. Biomed. Eng.*, vol. BME-16, no. 1, pp. 99–99, Jan. 1969.
- [3] A. Baba and M. Burke, “Measurement of the electrical properties of ungelled ECG electrodes,” *Int. J. Biol. Biomed. Eng.*, vol. 2, no. 3, pp. 89–97, 2008.
- [4] A. Hassibi, R. Navid, R. W. Dutton, and T. H. Lee, “Comprehensive study of noise processes in electrode electrolyte interfaces,” *J. Appl. Phys.*, vol. 96, no. 2, pp. 1074–1082, 2004.
- [5] H. J. Scheer, T. Sander, and L. Trahms, “The influence of amplifier,

interface and biological noise on signal quality in high-resolution EEG recordings, *Physiological Measure.*, vol. 27, no. 2, p. 109, 2006.

- [6] C. T. C. Ferree, P. Luu, G. S. Russell, and D. M. Tucker, “Scalp electrode impedance, infection risk, and EEG data quality,” *Clinical Neurophysiol.: Official J. Int. Federation Clinical Neurophysiol.*, vol. 112, no. 3, pp. 536–544, Mar. 2001.
- [7] C. Assambo and M. Burke, “Amplifier input impedance in dry electrode ECG recording,” in *Proc. IEEE Annu. Int. Conf. Eng. Medicine Biol. Soc. EMBC*, 2009, pp. 1774–1777.
- [8] T. Sullivan, S. Deiss, T.-P. Jung, and G. Cauwenberghs, “A brain-machine interface using dry-contact, low-noise EEG sensors,” in *Proc. IEEE Int. Symp. Circuits Systems ISCAS*, 2008, pp. 1986–1989.