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Measurement of noise and impedance of dry and wet textile electrodes, and textile electrodes with hydrogel

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Abstract—**Textile sensors, when embedded into clothing, can provide new ways of monitoring physiological signals, and improve the usability and comfort of such monitoring systems in the areas of medical, occupational health and sports. However, good electrical and mechanical contact between the electrode and the skin is very important, as it often determines the quality of the signal. This paper introduces a study where the properties of dry textile electrodes, textile electrodes moistened with water, and textile electrodes covered with hydrogel were studied with five different electrode sizes. The aim was to study how the electrode size and preparation of the electrode (dry electrode / wet electrode / electrode covered with hydrogel membrane) affect the measurement noise, and the skin-electrode impedance. The measurement noise and skin-electrode impedance were determined from surface biopotential measurements. These preliminary results indicate that noise level increases as the electrode size decreases. The noise level is high in dry textile electrodes, as expected. Yet, the noise level of wet textile electrodes is quite low and similar to that of textile electrodes covered with hydrogel. Hydrogel does not seem to improve noise properties, however it may have effects on movement artifacts. Thus, it is feasible to use textile embedded sensors in physiological monitoring applications when moistening or hydrogel is applied.**

I. Introduction

WEARABLE measurement systems are emerging in the field of biomedical engineering and health care, as new electrode materials have been developed and the measurement units have become miniaturized. Several applications have benefited from the new textile electrode materials and wearable electronics [1]. They have enabled wearable monitoring of several physiological signals, also continuously and wirelessly [2-6]. In addition, monitoring and recording body postures and gestures has become more feasible, as textile materials allow a greater freedom of movement than the older recording systems [7, 8]. The performance of textile electrodes has been evaluated for use in e.g. respiration and electrocardiogram (ECG) monitoring [3, 4] and compared with commercial ECG-electrodes in [3, 8, 9]. However, the effect of textile electrode size has not been addressed.

In the work presented here, the aim was to study how the measurement noise and skin-electrode impedance change when changing electrode size or electrode preparation. The study was conducted with textile electrodes of five different sizes: diameters 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm; and with three different electrode preparations: dry textile electrode, textile electrode moistened with water, and textile electrode covered with hydrogel. The noise level was determined from of a basic bipolar biopotential measurement on the leg (upper thigh) of a 25-year old female volunteer, and the skin-electrode impedance was measured simultaneously. For comparison, ECG from lead I was recorded, with textile electrodes covered with hydrogel, and with commercial gel electrodes.

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II. Methods

A. Textile electrodes and electrode preparation

The textile electrodes were realized with polyester yarns covered with silver. The electrodes were embroidered with the conductive yarn in circles and with five electrode diameters: 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm. In addition, one large electrode (diameter 30 mm) was embroidered as a ground electrode for the measurements. The textile electrodes are illustrated in Fig. 1.

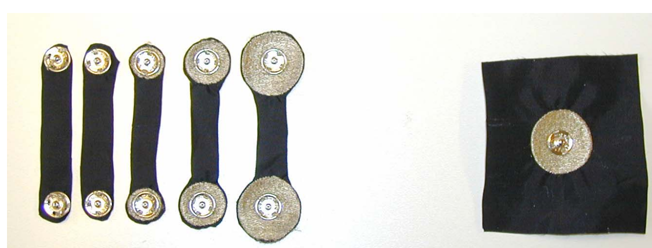

Fig. 1. Textile electrodes used for measuring noise and skin-electrode impedance (grounding electrode on the right side). Electrode diameters are: 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm. Measurement leads are connected to the textile electrodes with conductive snap fasteners.

Measurements were conducted with five electrode sizes and with different electrode preparations: dry electrode, electrode moistened with tap water, and electrode covered with hydrogel membrane. Salt water was another option as the moisturizer, but tap water was chosen because its good availability, as the emphasis is on wearable systems in which the usability is important. The hydrogel membrane (ST&D Ltd., Belfast, U.K.) is a material created for improving the skin-electrode contact: the membrane is sticky on both the surfaces, and it contains ions which affect the flow of charge across the interface.

A. Measurement of noise level and skin-electrode impedance

1) Measurement setup

The measurement of noise level and skin-electrode impedance was conducted with a commercial amplifier (SynAmp by Compumedics NeuroScan, El Paso Texas, USA). The measurements were conducted as bipolar measurements, where the recording electrode pair was placed horizontally on the frontal part of the subject's thigh and the grounding electrode on the outer side of the subject´s knee. The data was sampled at 2500 Hz with frequency range from 0.05 to 500 Hz. The gain was adjusted to 1000 or 500, depending on the noise level.

The thigh was chosen as the recording site, as it enables placing several electrodes on the same area, and on the same muscle. Thus it can be assumed that the possible EMG signal is similar in all measurements and the noise level between measurements can be compared with each other. During the measurements, the subject was laying relaxed for minimizing and stabilizing the effect of the EMG signal.

Also the effect of variations in skin properties needed to be minimized. Skin reacts to any material which comes in contact with it, e.g. by increasing the superficial blood circulation and by inducing perspiration, which affect the skin-electrode impedance. In order to measure signals from areas having similar skin properties, the electrode position was shifted between different measurements.

In addition, the stabilizing time of the electrode-skin contact was kept constant in the measurements. After placing an electrode on the skin, the skin-electrode contact stabilizes and becomes better within the first 10 to 15 minutes. To standardize the stabilizing time, all measurements for this work were conducted 5 minutes after placing the electrode on the skin. The electrodes were fastened with a textile strap, which provided a constant attachment to the skin.

The measurements were conducted with 5 textile electrode pairs of different sizes, and with three different electrode preparations. First, signals were measured with dry electrodes, then with electrodes covered with hydrogel, and finally with electrodes moistened with water.

The skin-electrode impedance was determined with the integrated impedance meter of the SynAmp before recording the signal.

2) Determining the noise level

The noise level was determined from the biopotential measurements by processing the signals in Matlab. The noise amplitude and the power spectral density (PSD) of the signal were calculated. The PSD was calculated in order to see the spectral components of the signal.

Interestingly, some of the signals contained an artifact related to the heartbeat. This artifact was proven to result from the mechanical pulse wave caused as the blood is pumped to the circulatory system, as it occurred synchronously several milliseconds after the ECG QRS complex. This was tested by simultaneous measurement of ECG lead I. In order to obtain the actual noise level, these pulse artifacts were manually removed from the signal, and the RMS noise was calculated from the remaining signal. The PSD was calculated from the original signals containing the pulse artifact.

III. RESULTS

Fig. 2. illustrates the RMS noise as a function of electrode size (diameters: 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm), with dry textile electrodes, wet textile electrodes, and textile electrodes covered with hydrogel. The noise of dry textile electrodes is high. However, in the case of wet textile electrodes, and textile electrodes covered with hydrogel, the RMS noise level is quite low and similar in both of them. To illustrate better the behavior in wet textile electrodes and electrodes covered with hydrogel, Fig. 3. shows them more specifically by enlarging Fig. 2.

Fig. 3. shows that in gel electrodes, in which the behavior is the most reliable, the noise level increases when decreasing the electrode size. In wet textile electrodes, the noise level behaves nonlinearly, apparently due to different amount of water or unstable mechanical contact.

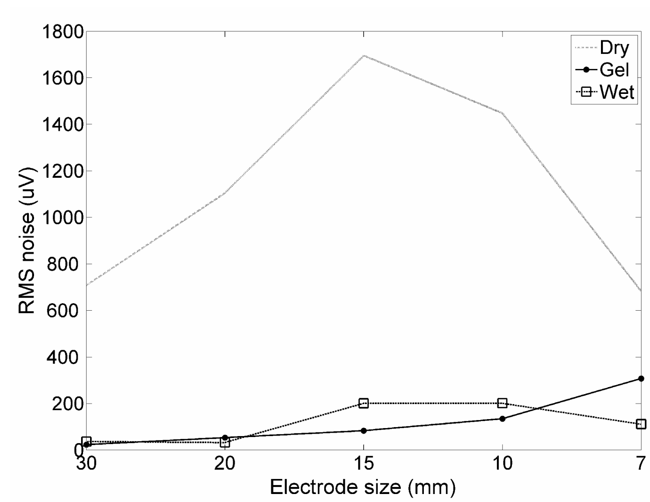

Fig. 2. RMS noise as a function of electrode size (diameters 7 mm – 30 mm), in dry textile electrodes, wet textile electrodes, and electrodes covered with hydrogel.

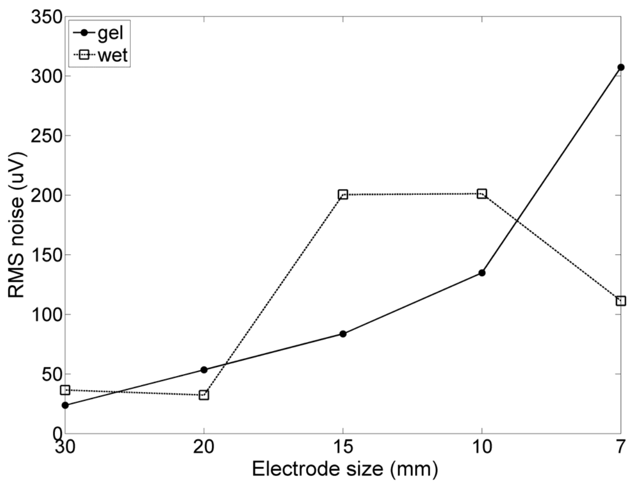

Fig. 3. RMS noise as a function of electrode size (diameters 7 mm – 30 mm) in wet textile electrodes, and electrodes covered with hydrogel, enlargement of Fig. 2.

Table 1. illustrates skin-electrode impedances measured with the integrated impedance meter of the SynAmp. These values show that the impedance decreases as the electrode size increases. The only exception is the low impedance of 7 mm wet textile electrode.

TABLE I
SKIN-ELECTRODE IMPEDANCE WITH DIFFERENT ELECTRODE PREPARATION AND SIZE

		Electrode size (diameter)				
		30 mm	20 mm	15 mm	10 mm	7 mm
Electrode preparation	Dry	>100kΩ	>100kΩ	>100kΩ	>100kΩ	>100kΩ
	Wet	~25 kΩ	~50 kΩ	~50 kΩ	~70 kΩ	~ 40 kΩ
	Gel	~35 kΩ	~80 kΩ	>100kΩ	>100kΩ	>100kΩ

Fig. 4. shows the power spectral density (PSD) of signals recorded with a) dry textile electrodes, b) wet textile electrodes, and c) textile electrodes covered with hydrogel. Each figure represents results from five different electrode sizes: 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm. The power line noise (50 Hz in Finland), which is often coupled in biopotential measurements can be detected from all curves.

In dry electrodes, the noise level is practically the same in all electrode sizes. Only in the largest electrode (30 mm) the noise is lower. In wet textile electrodes, the noise level is highest and the same in 10 mm and 15 mm electrodes, and lowest and the same in 20 mm and 30 mm electrodes. In 7 mm electrode, the noise level is surprisingly low. Probably, the changing amount of water causes these results. In textile electrodes covered with hydrogel, noise decreases as the electrode size increases. Thus, textile electrodes with hydrogel provide the most consistent results.

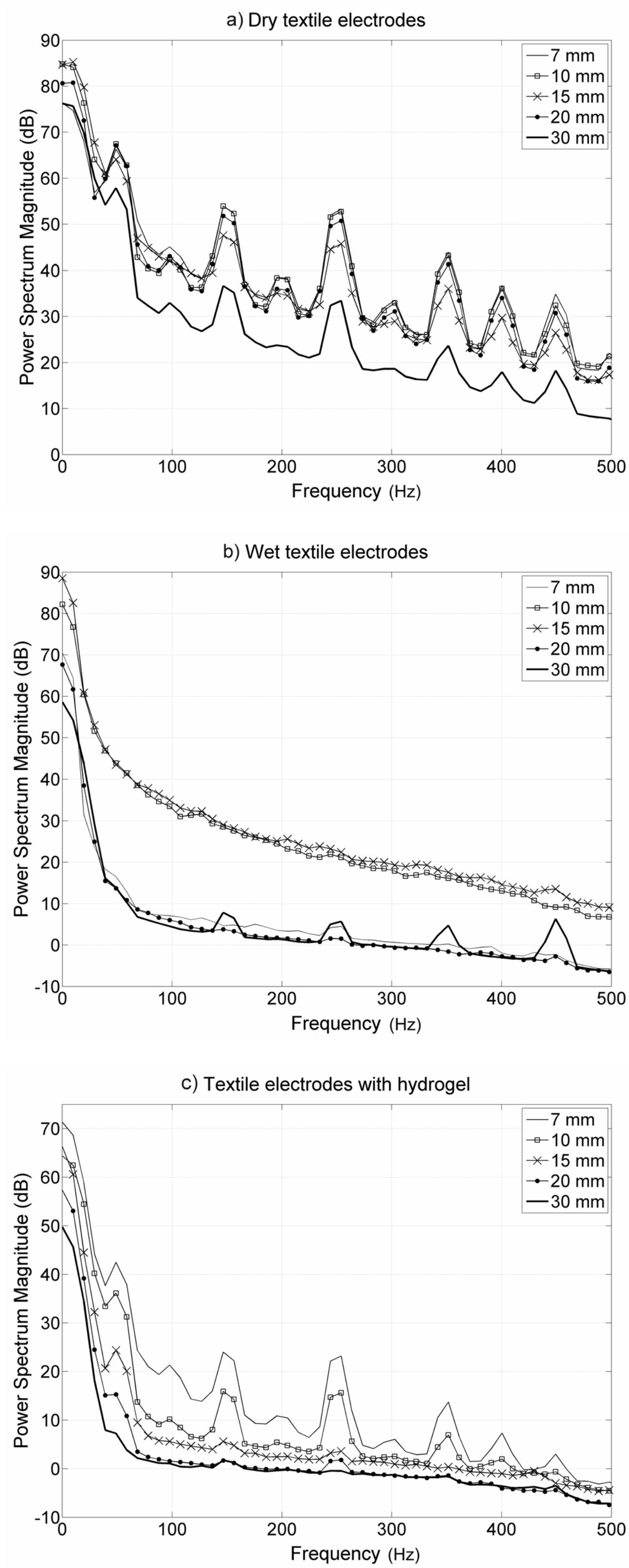

Fig. 4. PSD of biopotential signals recorded with a) dry textile electrodes, b) wet textile electrodes, and c) textile electrodes covered with hydrogel. Five different electrode sizes: 7 mm, 10 mm, 15 mm, 20 mm, and 30 mm.

Fig. 5. illustrates ECG lead I recorded with a) commercial gel electrodes and b) textile electrodes covered with hydrogel. Signal quality is good with both electrodes, even though noise is lower in the commercial electrode.

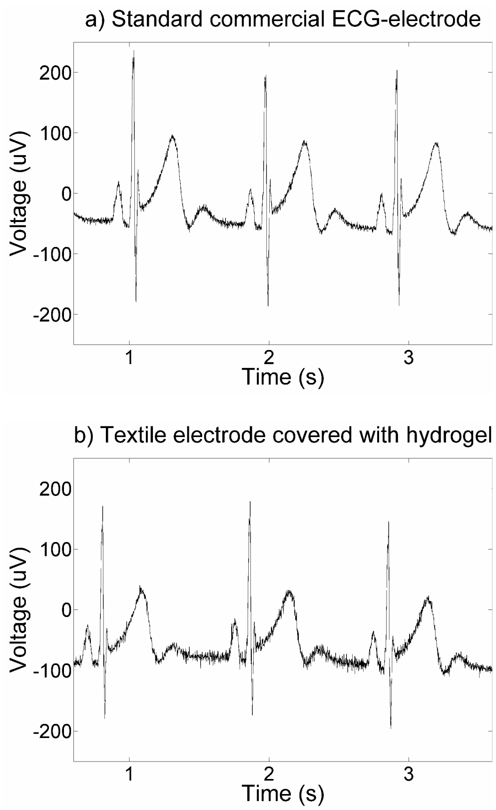

Fig. 5. ECG lead I recorded with a) standard commercial ECG electrodes (AMBU®, Blue Sensor) and b) textile electrodes covered with hydrogel.

IV. Discussion

The results show that the noise level in dry textile electrodes is notably higher that in textile electrodes moistened with water, and textile electrodes covered with hydrogel. There is no significant difference in the performance of wet textile electrodes, and textile electrodes covered with hydrogel. This indicates that wet textile electrodes are suitable for biopotential measurement. Even though hydrogel does not seem to improve noise properties, it may have effects on movement artifacts. Textile electrodes with hydrogel provide the most consistent results: noise level decreases as electrode size increases.

The impedance measurements indicate that the skin-electrode impedance of dry textile electrodes is too high for biopotential measurements. In wet textile electrodes and electrodes covered with hydrogel, the skin-electrode impedance increases when decreasing the electrode size. However with small electrodes with hydrogel the impedance remain quite high.

When assessing the measurement procedure, the amount of water seems to affect the results obtained from wet textile electrodes. Thus, for further research the amount of water used for moisturizing the electrodes has to be standardized more accurately. Another factor affecting the results is EMG signal. Even though the subject was lying relaxed during the measurement, there is always some spontaneous EMG activity in the muscle. However, the thigh was considered as a good location, as it provides a large area and a possibility to attach all electrodes on the same muscle, but on unprepared skin. Namely, it is important that the skin is intact when placing the electrodes, as the skin properties considerably affect the skin-electrode impedance and noise.

The results from this study give preliminary information about the performance of electrodes with different size and preparation. Yet, the results do not give absolute values of the noise or PSD, as the measurements were only made with one person. However, they give information about the relative changes in noise level, when changing the electrode size and preparation. In order to further validate the results, the study will be conducted with repeated measurements from different subjects. Another plan for further study is to conduct the measurements with legs from cadavers. This would enable studying electrode noise and also movement artefacts, without the presence of EMG signal. Nevertheless, it has to be taken into consideration that the properties of cadaver tissue (e.g. skin), differ from those of living tissue.

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