Development of Dry Textile Electrodes for Electromiography

A comparison between knitted structures and conductive yarns

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Abstract—**The paper presents a practical approach concerning the design, implementation and testing of dry textile electrodes for surface electromyography purposes. Several knitted structures were designed and knitted with conductive yarns, in order to compare the influence of the fabric structure in the electrode performance. The effect of the type of conductive yarn was also studied by comparing three different yarns. It was found that the textile electrodes perform well for sEMG acquisition, with a clear depiction of the muscle activity produced. There are significant differences between the structures tested and there is also some influence from the yarn used.**

Keywords – e-textile; electrode; electromyography; knitting; wearable solutions for physiotherapy

I. INTRODUCTION

Surface electromyography (sEMG) refers to the recording of electrical activity of muscles. sEMG electrodes converts bio signals that results from muscle or nerve depolarization into an electrical potential that is then amplified. Instrumentation to measure EMG signals requires a three-stage system: an input that picks up the electrical potentials from muscle contractions – the electrodes – a signal conditioning stage that conditions and amplifies the signals, and an acquisition stage that converts the signals into audio or visual data to be then analyzed [1].

Several studies have been reported about the development of textile electrodes for various purposes – such as electrocardiography (ECG) – and there seems to be an increase of attention on the creation of textile electrodes to measure sEMG signals. Various techniques have been employed in the fabrication of textile electrodes, such as screen printing [2], weaving [3-7] or knitting [4,8,9].

Although textile electrodes fabricated with different techniques or yarns have been reported in the literature, a comparison between knitted structures and type of loops used (plain knit, float, tuck loop) hasn't yet been addressed.

The present study aims at the development and testing of textile electrodes for sEMG based on knitted structures for optimal monitoring of sEMG and ECG signals during physiotherapy sessions. Various structures have been produced with different yarns and compared in order to understand the influence of these variables on their performance.

A literature review made it possible to identify some requirements for better performance of E-textile electrodes, which were followed. The main requirements are:

- Impermeability: according to Wijesiriwardana & Mukhopadhyay [10], if an electrode has a waterproof membrane, the water vapour is kept between the skin and electrodes surfaces working as an electrolyte, like the conductive gels used in sEMG;
- Density: a material with higher density will have a better electrical conductivity and contact than the same material with a lower density [11]. Hence, the higher the structure's density, the better the performance;
- Elongation and stability: when the electrode stretches, the number of contact points between the skin and the electrode increases, enhancing the interface. Changes in elongation also change the electrical properties of the fabric, which means that the structures must be stretched, but must be kept stable at their desired elongation and position [4,12];
- Roughness: a rough fabric will have less contact points with the skin than a smooth one [13]. Hence, smoother fabrics should provide better performance.

It is important to note that the use of knitting technology makes it possible to design the electrical connections along with the electrodes, for which the jacquard technique presents a clear advantage, since it allows the creation of patterns almost without limits. In his study about the development of facial EMG and EOG (Electrooculography), Paul et al. [11] have suggested that the use of screen printing technology is more compatible with planar electronics than conductive yarn-based techniques. However, just as screen printing makes it possible for electrodes and the conductive tracks to be integrated during a homogeneous fabrication process, this is also possible in knitting, as will be shown here.

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II. MATERIALS AND METHODS

The knitted substrates studied were divided into two groups: (1) structures designed with knit and float loops and (2) structures designed with knit and tuck loops. As will be seen, besides the structure itself, it is also possible to notice the effect of using different types of loops.

Three distinct yarns were also compared: Bekitex, which is a one-ply 80% polyester / 20% stainless steel staple fiber yarn (Bekaert, Belgium), Elitex and Shieldex, which are polyamide silver plated yarns from two different manufacturers (TITV-Greiz and Statex, both from Germany). Conductivity of the silver plated yarns is in the order of tens of Ω/m, whilst the much cheaper Bekitex yarn has a reference value for the resistance of 100 Ω/cm.

A total of 40 structures were designed and divided into two groups of twenty, as stated above, according to the loops used: (1) knit and float loops (LF's) and (2) knit and tuck loops (LC's). The design was done trying to produce smooth fabrics with the highest density technically possible. Five structures of each of the groups were then produced in a Merz MBS circular knitting machine, with normal, non-conductive textile yarns. After fabricating the first samples, those that showed little mechanical strength or other technical problems from the textile point of view were replaced by new structures. The procedure was repeated until ten adequate structures were obtained. The repetition modules of the selected structures is given in figure 1, where the rows represent knitted courses and the columns the number of needles used in this module.

After the ten knitted structures were finally selected, the electrodes started to be fabricated with Bekitex yarn. All electrodes have 34 courses for 56 columns, resulting in a 2cm side square in a jersey fabric. A line of 16 courses for 85 columns was also designed along with the electrode to provide the electrical connection to the conditioning circuit (Figures 2 and 3).

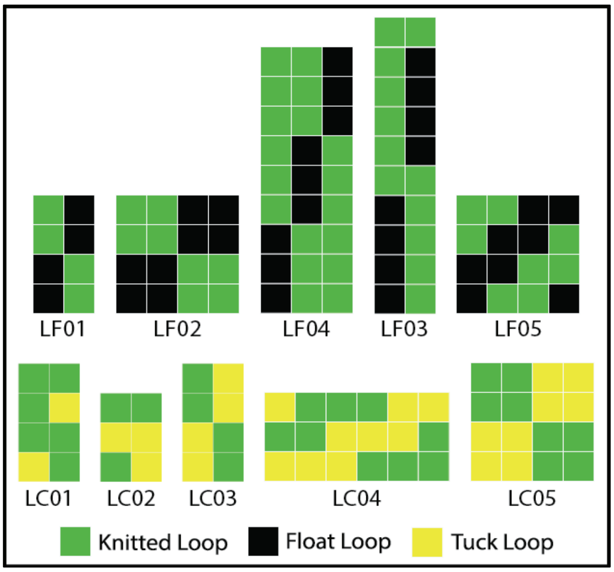

Figure 1. Selected knitted structures LF: Float loop based, LC: Tuck loop based structure

The first electrodes tested were cut and isolated with carbon polyvinyl (PVC) tape to be then attached to the skin with the same material (Figure 2). After tested, the five electrodes with the best performance were produced integrated in a sleeve and silicone was used as a waterproof membrane, since the PVC tape would easily rip off when dressing the sleeve (Figure 3). Other polymeric materials commonly used with textiles are possibilities for use as membrane. The requirements are, besides the ability to waterproof the electrode, which helps retaining moisture and thus improving the skin-electrode impedance, requirements of comfort and mechanical support.

A new test allowed selecting the structure that showed the best results. New sleeves with electrodes based on this structure were then produced, this time using the three types of conductive yarns under consideration: Bekitex, Statex and Elitex.

As part of a wearable solution for sEMG and ECG monitoring during physiotherapy sessions, a set of signal conditioning, acquisition and Bluetooth communication sensor modules (Shimmer3ExG) were used. The ExG module provides a configurable digital front-end, optimized for the measurement of physiological signals, for example 5-lead ECG (Electrocardiography) or 2-channel EMG (Electromyography). The measurement channels of each sensor module were connected to the electrodes with metallic snaps. Using a desktop or mobile application the sensor modules were configured in order to perform the signal acquisition with a maximum of 1024 Samples/s. To improve the SNR a second-order Butterworth high-pass filter at 10 Hz was used, thus the constant presence of signal fluctuation and some motion artefacts were removed.

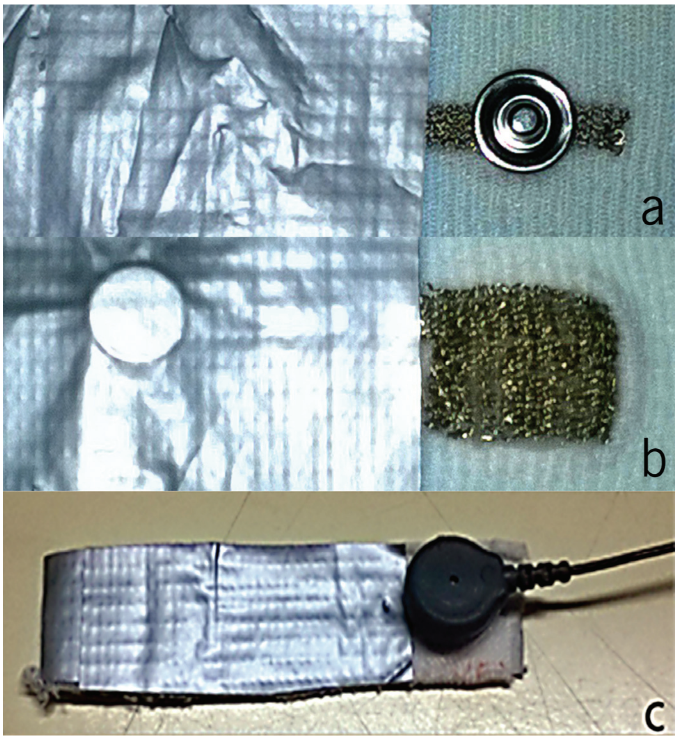

Figure 2. LC01 electrodes prepared individually, with PVC simulating a waterproof membrane: a) front; b) back; c) overview, with connection;

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Figure 3. LC01 Electrodes knitted in a sleeve with silicone as the impermeable membrane: e) front; f) back

The biceps was the muscle chosen to run the tests since it's a large muscle producing larger signals that would be easier to represent.

The exercise produced to test the electrodes consisted of biceps curls executed with a 5 Kg dumbbell, with a complete curl-uncurl cycle. Each completed movement lasted 10 seconds, which is shown in the example depicted in Figure 4 – interval A represents the instant that the dumbbell is being lifted and C is when the arm is moving down to the original position; B and D are static moments, when the arm is flexed and reflexed, respectively.

A study of user comfort during the usage of proposed e-textile wearable solution was also considered, the measurement of temperature variations on the level of the skin and textile level during the exercises was measured in an unobtrusive way using a FLIR E60 thermographic camera mounted at 1m distance to the arm surface under test.

III. RESULTS AND DISCUSSION

Several test session were carried out in order to extract information about the optimal choice of the textile electrodes. With some of them it was possible to obtain signals clearly depicting the muscular activity during the exercise. Figure 4 shows an example of an acquired signal depicting all the phases of the exercise performed.

From the first tests it was possible to observe that the electrodes produced with one of the loop types produced better results than the others, namely the tuck loop used in the LC structures.

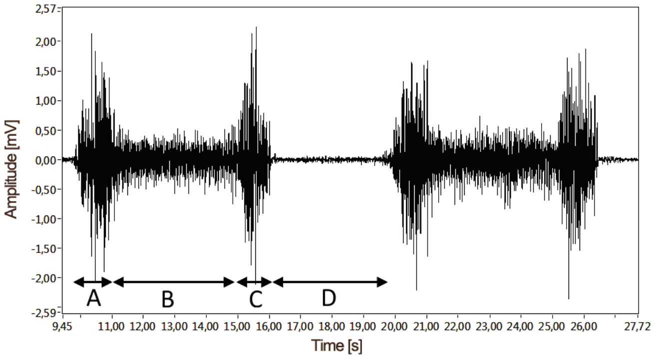

Figure 4. Example of EMG signal with phases of the exercise: A) Dumbbell's lifting up; B) Arm up in static position; C) Moving arm to the original position; D) Arm down in static position

All of them were able to sense EMG signals, whilst only one of the LF electrodes captured good EMG signals – LF03 – although with a lower amplitude. LF01, LF02 and LF04 also showed very weak signals, but with very strong motion artefacts and fluctuation. The LF05 didn't seem to show any EMG signal at all. The better performance of LC knitting fabrics may have resulted from the higher density in principle exhibited by tuck loop based structures.

In the second phase, the best structure among the tuck loop based electrodes was selected, in tests carried out with the sleeve version of all of the LC electrodes. It was possible to observe that the EMG signal is visible in all of them, with some differences in the amplitude of the signal.

It has to be noted that the performance of the signal acquisition was quite variable. The same electrode could exhibit different performance from one moment to the next. Furthermore, generally only one or two minutes after the sleeve was put on would there be a useful signal, which can be explained by a moisture build-up between the skin and the electrode.

After repeated testing, it was observed that the structure showing the most consistent results and strongest signals was clearly the LC01, with a signal varying approximately between -2 and 2 mV. The next electrode with the best amplitude is the LC02, with about half the amplitude (Figure 5). The remaining three samples show lower amplitudes. Figure 5 shows that, besides having higher amplitude, the signal provided by structure LC01 also depicts more clearly the difference between the phases A and B of the exercise (as defined in Figure 4). Furthermore, as can be observed in phase D of the exercise, the signal has less noise present.

One reason why LC01 shows better performance over LC02 is possibly its smoothness, which influences the electrical signal, as stated before. LC01 is softer than LC02, a point that also involves comfort issues. Smooth surfaces are, in principle, more comfortable from the physical as well as from the thermophysiological point of view. They increase heat flow and the area of contact, which not only improves electrical conductivity, but also creates a cooler feeling [13]. However, they slide more easily over the skin, being thus more difficult to stabilize. These aspects are quite relevant in garments that are to be worn in sports.

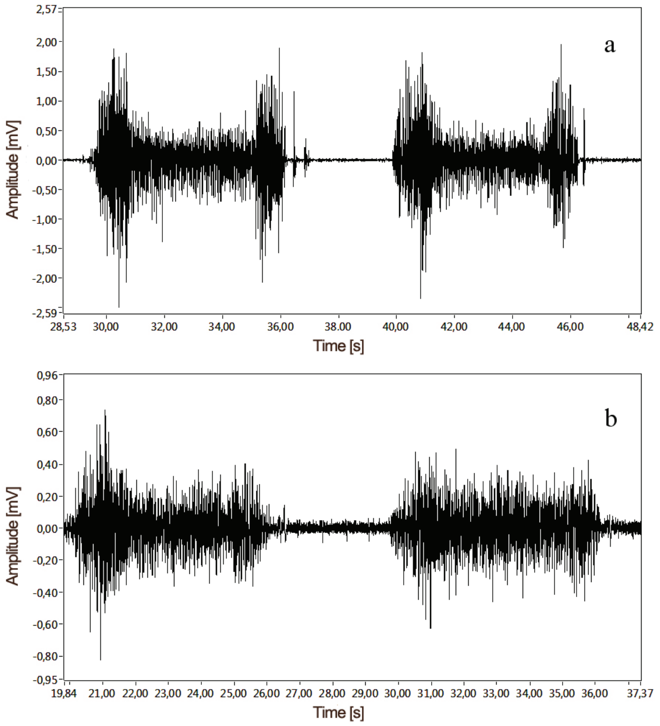

Figure 5. EMG signals taken from LC01 (a) and LC02 (b) electrodes

b

For the reasons described, LC01 was the chosen structure to be produced and tested with the other two yarns. Figure 6 shows examples of the results found. Surprisingly, the results do not show significant differences in amplitude values or noise of the signals.

In fact, only a small increase when using Statex and Elitex yarns is observed. On the other hand, the distinction of the moments A, B and C is more visible when using Bekitex and Statex yarns. Due to their electrical properties, the similarities between the yarns are quite unexpected and will be further analysed in future work. One explanation for this result may be the appearance of moisture due to sweating, between the electrode and the skin, improving the contact between both surfaces and reducing skin-electrode impedance more significantly than the reduction gained by using a more electrically conductive yarn.

The user comfort test results based on remote temperature measurement using the thermographic camera are presented in Figure 7. The thermography image permits to extract the information about the evolution of temperature in different parts of upper limb, which is covered with textile including e-textile electrodes. Good comfort means reduced temperature difference between the textile surface and the temperature at the skin level of the same arm that happens when the heat transfer for skin-air interface and skin-textile-air interfaces presents similar values expressed by temperature values of measured temperatures (T_1 =36.0ºC, T_2 =35.7ºC). Additional tests were performed measuring the temperatures on the skin-air and textile-air interfaces after the EMG tests. The measured temperature differences were less than 0.5ºC.

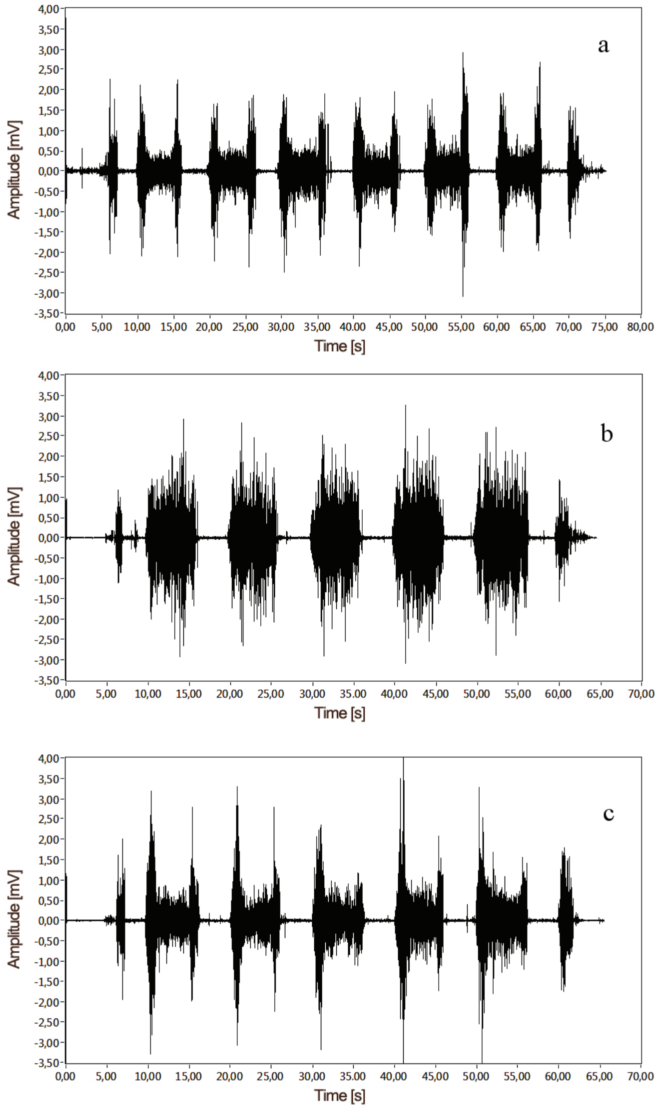

Figure 6. EMG signal taken from three different yarn knitted with the same structure (LC01): a) Bekitex; b) Elitex; c) Statex

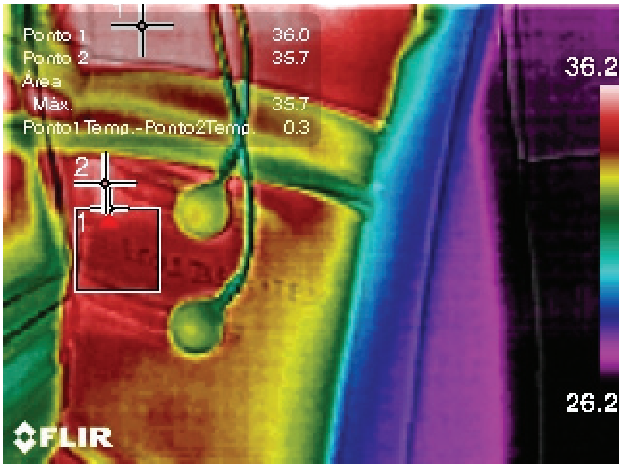

Figure 7. Temperature distribution on different arm regions with and without textile before 1 min training session

IV. CONCLUSIONS

The present study provides a comparison between different knitted structures combining knit loops with float and tuck loops, as well as an evaluation of different conductive yarns for the same knit combination, in the development of dry textile electrodes for EMG.

The results show that, among the structures studied, knitted structures combining knit and tuck loops seem to be the best option for dry textile electrodes. It is also visible that the differences between conductive yarns in terms of signal aren't very significant. Elitex and Statex seem to produce the EMG signal with highest amplitude, but Bekitex may be more suitable for textile purposes, since it is more similar to a conventional textile yarn – It is finer, more flexible and easier to knit than the two first yarns. However, more tests would be needed to take further conclusions. Textile and comfort tests should be made to determine the suitability of the yarns for textile applications.

The tests performed with the thermographic camera that provides temperature distribution at the arm with and without textile underline the appropriateness of the chosen materials considering the thermal comfort during relatively long training sessions.

Although it seems that following the established requisites may improve the performance of the textile electrodes, several tests would be needed to confirm this premise. So far, the tests can only indicate smoother surfaces actually work better than rougher ones if one intends to use them as dry electrodes.

V. FUTURE PERSPECTIVES

The next stage will be to develop a garment for sports and physical rehabilitation incorporating ECG and EMG electrodes. Since the ones fabricated and already tested seem promising, they will be used.

More tests will be conducted to the electrodes, but this time with electrodes already integrated into the garment. Some tests can include the confirmation of the pre-requisites and the performance of the electrodes after washing. Textile characterization in terms of comfort will be also addressed.

Another issue still to be analyzed is biofeedback. As said in the beginning, EMG equipment is a three-phase system, which includes an output signal. If we want to create a garment that makes possible for the person to do their exercise without the help of a professional (e.g. physiotherapist), he will need all the information about his performance and improvement (e.g. to know if he's doing the exercises correctly and suggested about correcting any flaws; track of the exercises and the person's development; share the information with an expert…).

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