Design of a Long Sleeve T-Shirt with ECG and EMG for Athletes and Rehabilitation Patients

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Abstract. Considering the importance of strength training in sports injury prevention and rehabilitation, an e-textile system that assists the athlete's training and rehabilitation was designed. This paper reports the construction of a prototype of a T-shirt with embedded textile electrodes to monitor cardiac and muscle activity. Signal tests were conducted and are presented. It is the authors' intention to study and integrate other textile sensors that may provide useful information to the user.

1 Introduction

Physical activity has proven benefits for the prevention and treatment of health diseases [1], and contributes to prevent sports injuries [2]. Strength training exercises are often prescribed for athletes training, prevention and rehabilitation [3]. Studies have shown positive effects of physical activities, for instance, on people with osteoarthritis of the knee [4], hamstring injuries [5] and low back pain [6], and it has been proved that strength training can reduce the number of sports injuries to one-third [2].

One of the issues related with athletes' injuries is early detection. Athletes may get injured and keep it secret, fearing discrimination, which means that some injuries may seem to have been developed in the weight room, but it most likely occurred in the field and only worsened in the weight room [6].

A system that provides EMG data in real time may help detecting the existing injury and the athlete may have an adequate intervention in due time. In the present study, a system able to collect biometric data in real-time, for sports injury prevention and rehabilitation, is proposed. In this paper, the design and development of a prototype of a T-shirt with knitted electrodes for electromyography (EMG) and electrocardiography (ECG), and respective preliminary tests are reported.

2 Related Work

ECG is used to monitor cardiac activity, while EMG relates to muscle activity, both important parameters to be measured during rehabilitation [7]. In both techniques, surface electrodes can be used. Textile electrodes have been widely reported in literature. Weaving [8], knitting [9] and embroidering [10] with conductive yarns represent few examples of attempts to replace conventional electrodes with the textile counterpart. In a previous study, it has been suggested that tuck loop-based flat knitted electrodes provide better response than the float loop-based counterpart [11]. Capacitive textile electrodes that do not need to be in contact with the skin for ECG [12] and EMG [13] have also been reported.

In the design and commercialization of clothes and garment accessories for humans, biomedical system has nowadays a great importance [14], and several examples proved this trend. Szczęsna et al. [15] developed a prototype of a waistband with textile electrodes for monitoring of cardiac activity. The T-shirt presented by Lage et al. [16] includes seamless knitted electrodes for ECG. Manero et al. [17] used embroidery to embed EMG electrodes in running leggings, to monitor quadriceps muscle activity.

3 Materials and Methods

A long sleeve knitted T-shirt with ECG and EMG knitted electrodes was designed and produced. It comprises four ECG electrodes – LA and RA under the armpit (Lead I), in the chest horizontal line, and the RL and LL in the waistline (Lead II), between the front center and the lateral – and EMG electrodes for *biceps brachii*, *extensor carpi radiali longus*, and *flexor carpi ulnaris*.

The knitted fabric was produced in a seamless knitting machine, which produced knitted fabrics in the form of a tube that can have the size of the torso, for instance, eliminating the need of side seams. For the sleeves, a separated tube was produced and the sleeves were then cut and sewed. The T-shirt was produced in two layers of fabric, the inner layer containing the electrodes and connections and the outer layer being totally black, giving the looks of a conventional garment and protecting the conductive layer. Polyamide/elastane (PA/EA) composes the nonconductive part and a silver coated PA (ELITEX 110/f34) builds the conductive areas.

Garment patterns were cut according to the desired shape and taking into consideration the position of the electrodes, and the pieces were then put together to give shape to the T-shirt. A *Shimmer3 ExG* device was connected to the T-shirt, which is an electronic device that allows the measurement of physiological signals, namely, 4-lead ECG (LA-RA, LL-RA, LL-LA and Vx-WCT) and 2-channel EMG. Metallic snaps, compatible with *Shimmer*'s channels, were inserted in the extremities of the connections. A zipper was placed in the outer layer, to give access to the connection points, therefore, being able to connect the electrodes to the *Shimmer* electronic device. To isolate the circuits from the skin, knitted fabric was cut in shapes appropriate to cover the conductive areas (except the electrodes, which need to be in contact with the skin).

This was done to produce a prototype, for a final version it is intended to use a thermo-plastic polyurethane film to cover the circuits.

Preliminary tests were carried out with dry and wet electrodes, as well as with and without pressure on the electrodes, thus comprehending four different conditions. An elastic band was used to apply pressure on the electrodes. No skin preparation was carried out. The ECG tests were made with a subject seated in a static position, and simulating some strength training exercises (without the weights) that would involve the movement of the arms and shoulder, in order to understand the effect that moving the arms has on the ECG signal. The selected exercises were i) *high-pulley curls*, and ii) *seated front presses*, performed according to the book of Delavier [20]. For sEMG tests, only the biceps electrodes were tested, which were carried out with the subject performing curls with a 5 kg dumbbell. The *Shimmer* device was set for frequency=512Hz (ECG) and 1024 Hz (sEMG), gain=4 (ECG) and 12 (sEMG), and resolution=24 bits (both).

4 Results

4.1 The Prototype

The prototype's dimensions and patterns were specified and the garment was produced using seamless knitting technologies by a knitwear manufacturer. It was soon obvious that a great difficulty exists in this type of material (knitted, elastic) to meet design specifications. The produced sleeve didn't fit the required measurements and it was not possible to have the flexor and extensor electrodes in place. The size of the prototyped sleeve is also larger than the one initially designed, which makes a loose fit, instead of the intended skinny fit that keeps the electrodes in contact with the body. The sleeve was then cut according to the desired measures, only with the biceps electrodes in the correct position.

Fig. 1 shows pictures of the prototyped T-shirt. It can be seen from Fig. 1c that the electrodes and connection tracks (covered by jersey fabric) are in the inside of the T-shirt, being invisible at the outer side (Fig. 1b and d). After dressing the garment (Fig. 1d), it was noticed that the sleeve is too tight over the *brachyorradialis* muscle and the collar is too high, creating discomfort.

Fig. 1. Prototype of the T-shirt

4.2 Performance Tests

ECG Tests. Fig. 2 shows the ECG response on the LA-RA lead with the subject seated and still, for dry and wet electrodes. As can be observed, dry electrodes (Fig. 2a and b) produce a lot of noise and when applying pressure only a small signal is observed (Fig. 2c), with significant low-frequency fluctuation. When the electrodes are wetted with water (Fig. 2c and d) the signal improves notably, even without pressure on the electrode (Fig. 2c).

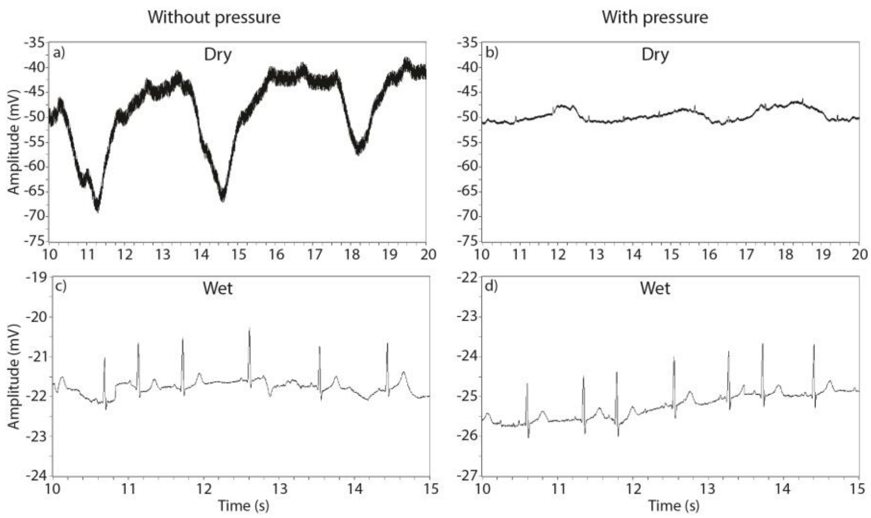

Fig. 2. ECG signals with the person seated, derivation LL-RA

The following tests were conducted with wet electrodes. Fig. 3 shows the ECG signal for exercise i). The signal is smaller without pressure applied, near the noise level, while when applying pressure, cardiac signals are better distinguished from noise.

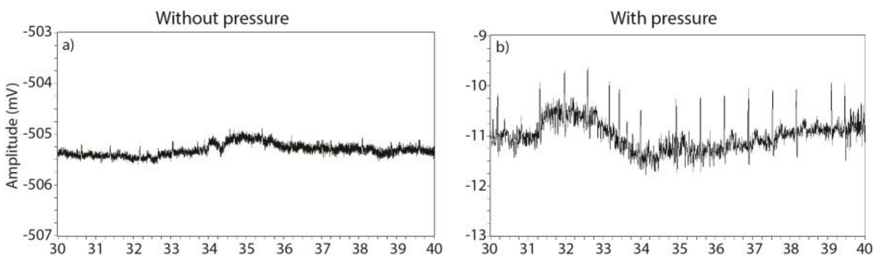

Fig. 3. ECG signal for exercise i), LA-RA derivation of ECG with more and less contact of electrodes with skin

Fig. 4 shows the signal when the subject is performing exercise ii), with and without pressure (Fig. 4b and a, respectively). It can be noticed that, with pressure, the signal is more stable than its counterpart. Differences in the position of the arms can also be noticed. In Fig. 4a, the signal can be divided into three exercise moments: 1) arms down, 2) arms moving up, 3) arms up and 4) arms moving down. Moment 3) shows more noise than moment 1). In Fig. 4b, these moments are barely distinguished – 1) arms down, and 2) arms up – but the movement of the arm doesn't produced the peak seen in Fig. 4a.

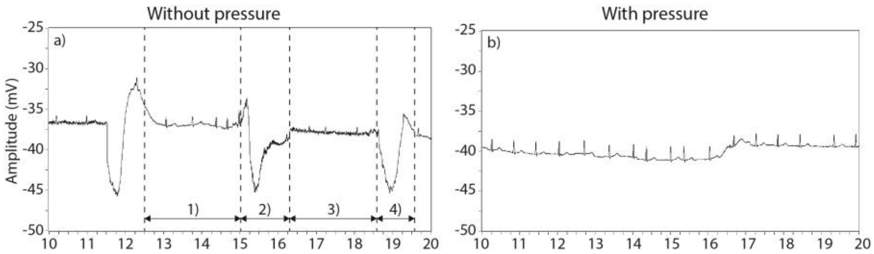

Fig. 4. ECG signal for exercise ii), derivation LA-RA

In the first tests, using this specific T-shirt design, sEMG signals were very weak.

5 Discussion

Wet electrodes showed better results than dry electrodes, as expected, since skin-electrode impedance is much lower, just as the with the conductive gels used in conventional exams. This is not an issue if designing sportswear, given that sweat will wet the electrodes. Before starting exercising, the athlete may pulverize the electrodes with water, but this may not be the case in an everyday scenario. Although we may produce some sweat during the day, the skin is usually dry. For a scenario like this (i.e.: monitoring of home patients), the system must operate correctly with dry electrodes.

As stated before, the electrode pattern was not produced with the required precision, but it is possible to produce the electrode pattern with precision. Seamless knitting machines use specific programs to draw knitting pattern, in which measures aren't defined using metric measures (such as cm or inch), but loops. Outside these programs, designers, pattern cutter and tailors work with metric measures, such as cm or inch. Which means that, before drawing in the specified program, measures in loops need to be taken. The question is: how does one do it? A possible proposal is the following: 1) design and produce the electrode patterns and clothing with the desired measures; 2) produce the knitted fabric with the desired specifications (i.e.: elasticity); 3) take the contexture; 4) convert metrics into loops; 5) use the loops to draw the desired patterns in the seamless program.

The noise present in the ECG signal when exercising results from the shirt being stretched off and losing contact with the body under the armpit, when the arms are lifted. Since the LA and RA electrodes are too close to the armpit, they lose contact with the skin during movements, which means that more favorable positions for the electrodes will need to be found.

Several effects can justify the weak sEMG signal, such as low contact between electrodes and the skin (either the muscle electrodes or the reference electrode), the knitted structure or ambient noise. At least two factors can be excluded: 1) the incorrect distance between the electrodes, since they have the required distance; 2) the conductivity of the tracks, since the resistance between electrode and connection point is less than 10 ohms. Considering that previous studies had resulted in functional EMG sensing [11], further experiments will be carried out to improve this feature.

6 Conclusion

A way of integrating electronic systems into clothing, hidden inside a long sleeve knitted shirt, therefore maintaining the aesthetics of a conventional garment, has been demonstrated. Smart clothing, which mixes apparel and technology, needs to be designed considering not only functional requirements and operability, but also the way the individual expresses himself in society.

Improvements need to be done in order to obtain a good sEMG response, as well as to improve the contact of the ECG electrodes, making sure that the movement artefacts do not affect the signal. This should be achieved, ideally, with the electrodes in dry state. The solution may include other textile structures, materials and ways to create pressure.

Other textile sensors can also be of interest in a garment that is designed to support physical training and rehabilitation, such as temperature, breathing or bending sensors. This shall also be studied and embedded in a future prototype.

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