EMG-pants in Sports: Concept Validation of Textile-integrated EMG Measurements

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Abstract: Background: Textile-integrated EMG measurements are attractive for professional or keen amateur athletes or can be beneficial in rehabilitation or ergonomics. There are several systems commercially available, but independent validation studies are scarce. This study validates the concept of using textile-integrated electrodes embedded in garments for EMG recordings of the thigh. Method: a self-produced prototype of EMG-pants using stainless steel electrodes was developed. 28 participants performed isometric exercises on an Isomed 2000 device. Measurements of textile-integrated electrodes were compared with measurements using standard electrodes based on the SENIAM-standard. Results: textile-integrated sensors exhibit linear behaviour and measurements are comparable to measurements with standard electrodes. Discussion: the results of this study show that textile-integrated sensors are a valid tool for measuring isometric muscle activation. For certain research topics or for use in training, the easy application and use of textile-integrated EMG may be preferable to more scientific tools. Further work is required to address the validity of EMG-pants for dynamic muscle activation.

1 INTRODUCTION

In the past, measuring muscle activity required expensive equipment and appropriate experience in its application. The integration of sensors that measure muscle activity into garments or wearables provides individuals with an easy-to-use approach and thus opens up the technology for new fields of application in sports, medicine, rehabilitation, and ergonomics. Electromyography (EMG) is the standard method for measuring muscle activity. It is differentiated into two main kinds of EMG: surface EMG and intramuscular EMG. Only surface EMG systems are suitable for integration into a sports garment because intramuscular EMG is invasive. In surface-EMG, electrodes are applied to the skin surface to measure muscle activation. For more details on the principles of muscle activation and the basics of EMG measurements, the reader is encouraged to refer to standard literature, e.g. the recommendations of the Seniam Project (Freriks & Hermens, 2000) or the EMG-Fible (Konrad, 2011).

The recently published review paper by Guo et al. (2020) summarises research into textile electrodes between 2007 and 2018, listing 41 publications. Of these, only 14 papers were published in peer-reviewed journals, showing that textile-integrated surface EMG and its application remains a niche subject. Publications relating to sports applications are even rarer. Excluding papers about the material or system design, only four publications focus on garments specifically designed for use in sports (the authors did not assign the system design paper of Finni et al. (2007) "sports" category, even though, the Myontec Mbody pants, shown in Figure 1 (left), subsequently resulted from it). Of these four papers, two (Colyer & Mc Guigan, 2018; Tikkanen et al., 2012) used commercial products (Myontec) in the study, the other two (Ribas Manero et al., 2016; Shafti et al., 2017) used the same custom-made pants (same research group; papers published at the same conference).

Two examples of commercially available products for measuring muscle activity in consumer

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Figure 1: Commercially available spots garments for tracking muscle activity of the thighs by Myontec (left) and Athos (right). Pictures taken from the websites www.myontec.com and shop.liveathos.com on the 21/03/2020.

sports garments by Myontec (Finland) and Athos (USA) are shown in Figure 1. Both companies provide pants, as well as shirts, for measuring muscle activity.

The company Myontec is a spin-off of the University of Jyväskylä of the group of Prof. Taija Finni (Juutinen). The company lists 11 publications on the website backing the design, functionality, and validity of their product, including the three publications mentioned above. Athos names one publication (Lynn et al., 2018) to prove the validity and reliability of their product. Three of the authors are employed by the manufacturer.

The publications supporting the applicability of those products may well be biased due to conflicts of interest. As these products are health-related, independent validation is necessary. In general, there is a lack of studies comparing textile-based EMG garment solutions with established scientific systems. The few existing papers largely validate textile electrodes not yet integrated in a garment. For example, Li et al. (2011) and Sumner et al. (2013) confirm that measurements with textile electrodes are comparable to ones with standard EMG electrodes. Both studies are limited due to the fact that only six individuals were tested.

2 VALIDATION STUDY

The purpose of this study is to validate the concept of using textile electrodes embedded in garments. Self-designed EMG-measuring pants incorporating stainless steel electrodes are tested.

2.1 Prototype

In this study self-produced EMG-pants for measuring quadriceps and hamstrings activation using stainless steel electrodes are tested. Stainless steel electrodes are cheaper than the more commonly used silver electrodes and therefore would be an attractive alternative. The electrodes consist of a polyester fabric, with stainless steel wires (Ø=0.05 mm²) wound twice around the polyester threads. For the quadriceps, the skin contact area of each of the two electrodes is 30 mm x 165 mm. For the hamstrings, the skin contact area of each of the electrodes is 30 mm x 105 mm. The dimensions were chosen to optimally match the respective muscle regions. A textile patch was applied to prevent skin contact (visible in Figure 2 top-left picture) over an additional area of 30 mm x 30 mm of each electrode. In this area a button was attached to route the signals to the outside of the pants for attachment of an EMG sensor module. The commercially available Myon EMG Mobile System (Myon, Switzerland) was used as sensor module for signal amplification and wireless transmission to the computer. As the measuring-pants used were not compression pants, standard compression pants made by 2XU was used as a second layer to improve electrode-skin contact. The prototype is shown in Figure 2. Sizes available were S, M, L and XXL. A pre-test showed good washability of the electrodes. Three electrodes were washed in four handwash cycles using chlorine-free washing solutions. The electrodes showed no change in electrical resistance. Similarly, the use of disinfection spray did not alter the electrical resistance (measured after the pants were dry again).

2.2 Methodology

2.2.1 Participants

In total 28 participants (9 female/19 male) between 20 and 35 years of age (mean 25.3 years) were enrolled in the study. Before the start of the experiment all participants gave their informed consent. The participants were free of injuries, had not undergone ACL surgery and had no orthopaedic or neuromuscular damage to the knee or leg muscles. Table 1 summarises the activity levels of the participants.
Participant acquisition was based on the personal environment and by advertising the study at the university.

Table 1: Number of days per week with sports activity.

	None	1-2 times	3-4 times	> 4 times
Male	2	6	8	3
Female	1	3	2	3

2.2.2 Study Design

Each participant underwent five test scenarios in a randomised order, with each scenario involving one of the following electrode settings:

1) Quadriceps: standard electrodes; application of electrodes as recommended by SENIAM as shown in Figure 3 in the left picture. Short pants not interfering with the electrodes.
2) Quadriceps: standard electrodes; row-application; application of electrodes corresponding to the arrangement of the textile electrodes in the measuring pants as shown in Figure 3 in the middle picture. Short pants not interfering with the electrodes.
3) Quadriceps: measuring pants with textile-integrated electrodes.
4) Hamstrings: standard electrodes; Application of electrodes on the biceps femoris and the semitendinosus, as shown in Figure 3 in the right picture.
5) Hamstrings: measuring pants with textile-integrated electrodes.

EMG measurements were taken for isometric muscle activation for five activity levels using a standard EMG system by Myon (Switzerland) as shown in Figure 5. The data acquisition rate was set at 1000 Hz. The knee's flexion/extension moment was recorded using an Isomed 2000 dynamometer (D&R Festl GmbH, Germany). Activity levels were 100%, 80%, 60%, 40% and 20% of maximum voluntary performance of a flexion/extension knee moment. Figure 4 shows a typical test protocol. The participants always started with an application of 100% maximum voluntary performance, followed by stepwise lowering of the moment and a second maximum voluntary performance with two more decreases.

Measurements on the quadriceps were performed with an angle of 60° between femur and tibia and measurements on the hamstrings with an angle of 90° between femur and tibia (180° would be a straight leg). Those angles were chosen as a compromise between comfort, optimal angle for the respective muscle to generate maximum force and the need to prevent interaction between the seat and the sensor areas.

A graphical feedback interface helped the participants to control the activity level. They were asked to maintain each activity level for 3 sec.

The test procedure steps for each participant were:

1) Selection of the most appropriate size of pants.
2) Adaption of the settings of the Isokinet to the participant.

Followed by repetitive steps for the five randomised test scenarios:

3) Skin preparation according to SENIAM standards.
4) Application of electrodes/pants.
5) Warm up (flexion/extension movements against a small force).
6) Test according to the protocol in Figure 4.

2.2.3 Data Processing

All measurements, except the hamstring measurement of one participant, were completed and included in the analysis. The EMG data was rectified and filtered using a second order Butterworth low pass filter (cut-off frequency 200 Hz) and a root mean square (window size 20 ms) filter. The sum of the signals from the three electrode-pairs of the quadriceps, respectively two electrode-pairs of the hamstrings (see Figure 3), were calculated to allow comparison with the signals from the measuring pants. The signal was cut to segment the activity levels, using thresholds of 8 Nm for quadriceps and 11.3 Nm for hamstrings measurements, which is equal to 90% of the smallest respective moment

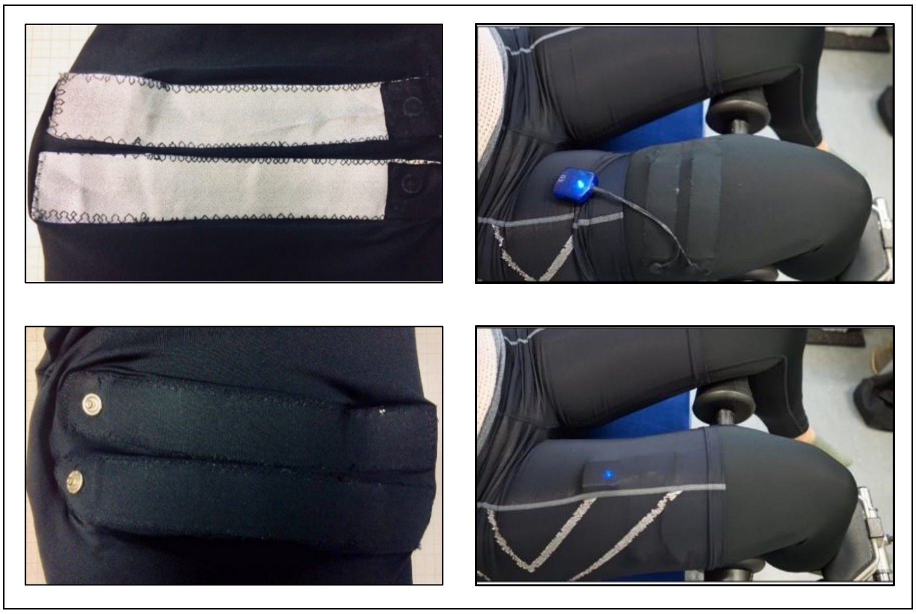

Figure 2: EMG-pants prototype using stainless steel electrodes (top-left). The electrodes are connected via buttons on the outside of the pants (bottom-left) to a sensor module (top-right) by Myon (Myon EMG Mobile System: amplifier, wireless transmission). Standard compression pants were used as a second layer (bottom-right) to improve electrode-skin-contact.

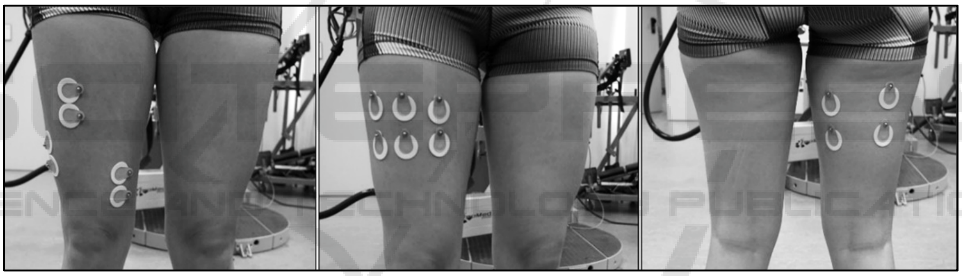

Figure 3 Left: SENIAM recommended application for the quadriceps. Middle: row-application; electrodes applied to the quadriceps corresponding to the electrode layout of the measuring pants. Right: hamstring application (SENIAM).

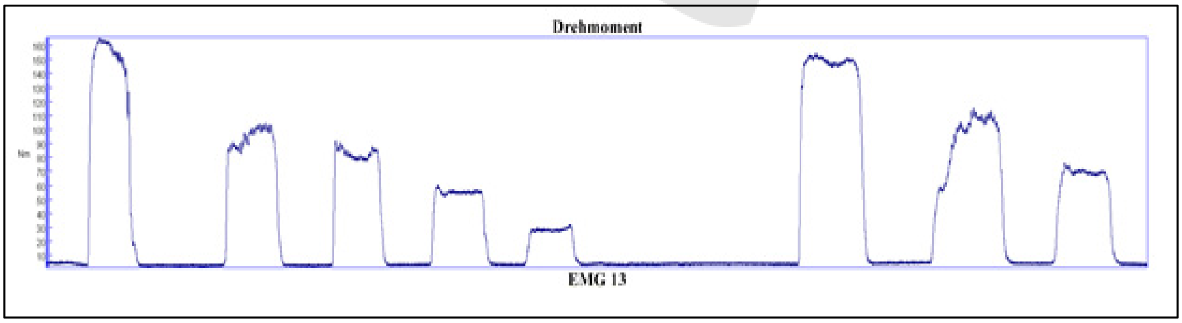

Figure 4: Typical test record, starting with 100% maximum voluntary performance, followed by stepwise 20% decreases and a second maximum voluntary performance with two decreases.

measured across all participants. A mean value was calculated for each activity level measurement. EMG values and values of flexion/extension moments were normalised using the higher of the two maximum voluntary performances of the respective flexion/ extension. For each measurement, a linear regression (least-square-method) of normalised-EMG vs. normalised-moment was calculated.

Average EMG and flexion/extension moment was calculated for each participant for the SENIAM-application and the pants. To reduce the influence of the applied flexion/extension moment, also the EMG/moment ratio (EMG normalised by the moment) was calculated. Bland-Altman plots (Bland & Altman, 1986) were used to compare the two measurement methods.

2.3 Results

In Figure 5 and Figure 7 the EMG measurements are plotted against the applied flexion/extension moment for each activity level of all participants. For hamstrings and quadriceps, the absolute values of the pants are smaller than the values of the SENIAM-electrode-application. The row-application of standard electrodes on the quadriceps results in the highest EMG values. As observable in the normalised data in Figure 6 and Figure 8, all measurement methods have a similar linear behaviour.

For the hamstrings, the measurement amplitude for pants is about 60% of the SENIAM amplitude.

In Figure 9, the Bland-Altman plot for the average EMG values of each participant is shown. The mean difference between the two systems is 0.237 V, with a width of the 95% limits of agreement of 0.591 V. In the Bland-Altman plot in Figure 10 the EMG-signal/moment ratio is compared. The mean difference is 0.0043 V/Nm, the width of the 95% limits of agreement is 0.0102 V/Nm. It is also notable that the difference between the systems increases with increasing muscle activity.

3 DISCUSSION

The aim of this study was to validate the concept of using textile electrodes embedded in garments.

Even though the surface of the textile-integrated electrodes is bigger, signal amplitudes of the textile-integrated electrodes are smaller compared to standard electrodes. Moreover, the Bland-Altman plots demonstrate an increasing difference between the signal amplitude of the textile-integrated electrodes and standard bipolar electrodes for increasing muscle activation. As both systems showed a comparable linear behaviour, this increasing difference does not impact a feasible textile solution and could easily be addressed by increased amplification of the signal. Also, by using gel or wetting the electrodes, signal attenuation could be decreased (Pani et al., 2019). In this study a very simple textile prototype was used. Different materials or more sophisticated textile sensors or improved integration of the sensors in the garments could also lead to reduced signal attenuation.

The large electrode surface of our system does not permit statements about individual muscles, but it could be even more suitable for the recording of muscle regions. This is reflected by the fact, that the row-application of electrodes, which correspond to the arrangement of textile electrodes in the pants achieved higher signals than the SENIAM-application (in both cases the sum of three pairs of electrodes).

Even though stainless steel electrodes are washable and corrosion-resistant, they might not represent the optimum solution for the integration in pants. Applications using gold, silver, nickel, copper or carbon-filled silicon can be found (Awan et al., 2019; Guo et al., 2020; O'Brien et al., 2019). The choice of material is influenced by multiple and varying factors such as price, location of integration, carrier textile, expected mechanical properties (e.g. flexibility due to the required range of motion), and biocompatibility. Textile and materials research is highly active in developing better materials suited for wearable and textile integration (Gehrke et al., 2019; Lee et al., 2020). Our electrodes were made of polyester threads around which metallic threads were wound. Such threads can break and thus loose conductivity. Also, they become uncomfortable for the user because the broken threads penetrate the skin. There are more suitable production methods, e.g. coating, for producing electrodes directly on or in the textile.

When performing EMG measurements, multiple interfering influences must always be taken into consideration: crosstalk, individual anatomical and physiological differences, subcutaneous fat and fatigue to name but a few. EMG-pants will have to overcome with all these. In this study, an influence of the dynamometer electric motor was apparent. However, because the influence was comparable in all measurements, we considered it acceptable.

The study cohort generally practice sports, had a mean age of 25.3 and a mean body-mass-index of 24.2. Therefore, it does not represent the population in general. Further tests are required especially involving heavier participants. As surface-EMG is highly influenced by subcutaneous fat, its applicability to heavier persons will certainly be limited. Therefore, wide use of EMG-wearable textiles in health and rehabilitation will not be without challenges. For sports applications, especially for professional or keen amateur athletes, such systems could be beneficial in training and injury prevention.

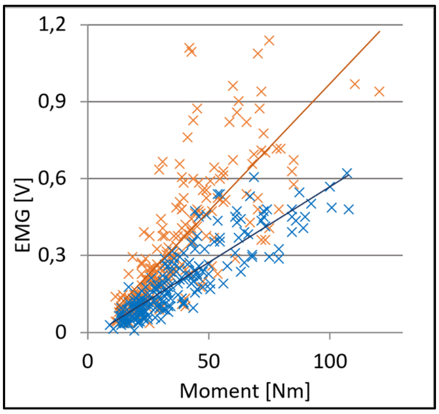

Figure 5: Hamstrings: regression of non-normalised values of EMG and flexion moment. Orange: standard electrodes (SENIAM). Blue: pants.

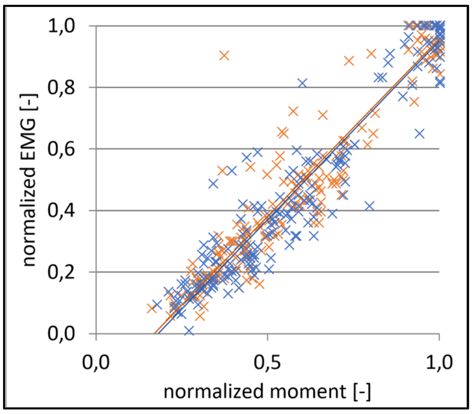

Figure 6: Hamstrings: regression of normalised values of EMG and flexion moment. Orange: standard electrodes (SENIAM). Blue: pants.

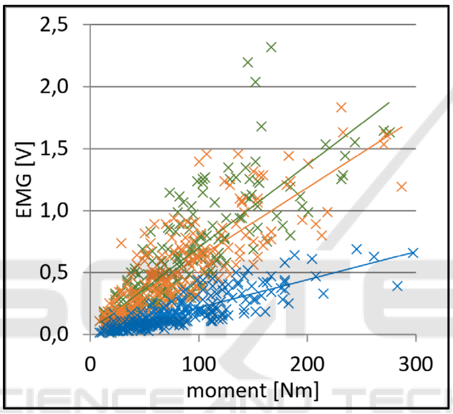

Figure 7: Quadriceps: regression of non-normalised values of EMG and flexion moment. Orange: standard electrodes (SENIAM). Green: standard electrodes applied in a row. Blue: pants.:

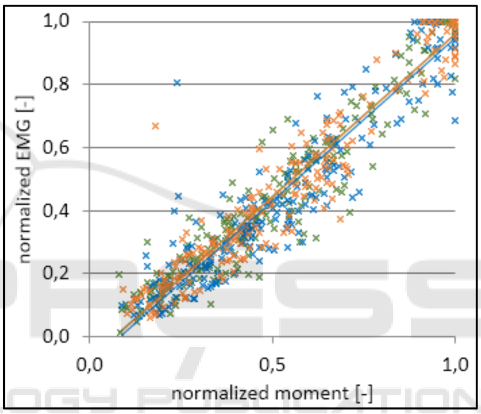

Figure 8: Quadriceps: regression of normalised values of EMG and flexion moment. Orange: standard electrodes (SENIAM). Green: standard electrodes applied in a row. Blue: pants.

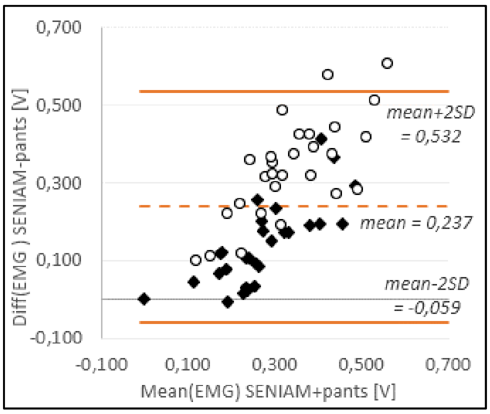

Figure 9: Bland-Altman-Plot of rectified, average EMG signal of each participant; dots: hamstrings; squares: quadriceps.

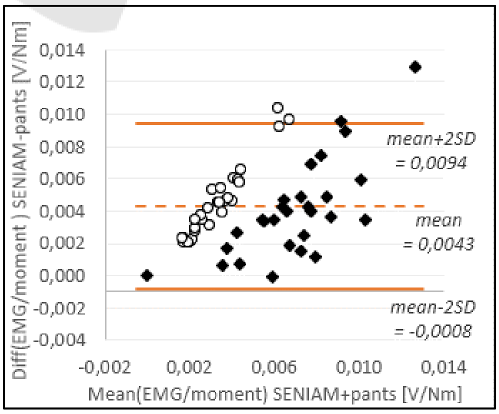

Figure 10: Bland-Altman-Plot of ratio (EMG-values/applied moment) of each participant; dots: hamstrings; squares: quadriceps.

We tested our self-produced EMG-pants in an isometric setting. Therefore, the interpretation of results is only valid for the use of such garments in similar settings e.g. isometric training and rehabilitation. Nevertheless, there might be some transferability of results to EMG measurements of more dynamic movements. Future research must prove the validity of such measurements because dynamic measurements are per se subject to more interfering artefacts (Farina, 2006). In addition to those artefacts, which also apply to measurements using standard electrodes, motion artefacts resulting from electrode-skin displacement might have a strong impact on the feasibility of garments with textile-integrated electrodes (Zhang et al., 2011).

4 CONCLUSIONS

The measurements of isometric muscle activation with our self-produced textile-integrated EMG-sensors and measurements with standard electrodes were comparable. Especially when comparing larger muscle groups, EMG-garments are an easy-to-use tool for the researcher, athletes or patients undergoing rehabilitation. Scenarios such as recording the ratio of quadriceps and hamstrings activation, which do not need a normalisation procedure, enable athletes to use the approach without having qualified knowledge about electrode application procedures and data processing.

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