Reliability of Measuring Lower-Limb-Muscle Electromyography Activity Ratio in Activities of Daily Living With Electrodes Embedded in the Clothing

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Context: Using technical clothes with electrodes embedded in the clothing makes it possible to record the electrical activity produced by the activity of the skeletal muscles in activities of daily living. Objective: To investigate the reliability of measuring lower-limb left-right electromyography (EMG) activity ratio with smart shorts during stair descent, stair ascent, and repeated unloaded squats in healthy working-age subjects.

Methods: Seventeen women (mean age 25.5 y) and 17 men (mean age 29.9 y) participated in this test–retest protocol carried out twice on the same day.

Results: Intraclass correlation coefficient (ICC) varied from .65 to .80 in the different activities. Mean difference and limits of agreement (LOA) between the repeated measurements were for descending stairs –0.8%, LOA –6.2% to 4.7%; for ascending stairs –0.9%, LOA –6.5% to 4.7%; and for squats –0.2%, LOA –5.4% to 4.9%. The coefficient of repeatability for descending stairs was 5.6%, for ascending stairs 5.7%, and for squats 5.3%.

Conclusions: This study in healthy subjects showed that the left-right EMG activity ratio in activities of daily living can be reliably measured with smart shorts. In future research, the feasibility of technical clothes as a follow-up method in rehabilitation should be investigated in greater detail.

Keywords: smart shorts, EMG, technical clothes

With technical clothes it is possible without using wires to record the electrical activity produced by the skeletal muscles in activities of daily living (ADL) outside laboratory facilities. Finni et al found that electrodes sewn into the clothes are a valid and reliable tool for measuring maximal isometric knee extensions.

Muscle strength deficit is a typical symptom after lower-limb injury. During the rehabilitation process the contralateral uninjured lower limb serves as a reference and the aim of the rehabilitation is to regain symmetrical lower-limb function. Technical clothing, such as smart shorts, may serve as a practical method to monitor the recovery of lower-limb muscle electromyography (EMG) activity ratio (left vs right lower limb) in ADL. However, not enough is known about the reliability of measuring the lower-limb muscle EMG activity ratio with smart shorts. We therefore conducted a study aiming to measure the reliability of smart shorts measurements in stair descent and ascent and repeated unloaded squats in healthy subjects.

Material and Methods

In March 2016, healthy working-age female and male subjects (N = 34) were selected from among the Arcada University of Applied Sciences staff and students in Helsinki. Subjects who suffered from pain or other symptoms in the lower limbs during the preceding 2 weeks were excluded. Furthermore, subjects with surgically treated lower-limb injuries during the preceding 3 years, as well as patients with any general disabling illness, were excluded.

Participants provided written informed consent. All 3 tests—stair descent, stair ascent, and repeated unloaded squats—were carried out twice during the same day, in the same order with a pause of at least 30 minutes between the first and the second test periods. Subjects took the smart shorts off between these periods. Before starting the tests, the researcher moistened the electrodes of the smart shorts before the subject put them on and checked that the smart shorts fitted the subject well. One test period lasted on average 30 minutes.

Stair climbing tests consisted of 22 stairs with a height of 16 cm and a depth of 30 cm. The subjects started the descent test on the researcher’s command and stopped at the bottom of the stairs. Thereafter they started to ascend the stairs at the researcher’s command and stopped at the top of the stairs. The last test was to perform 10 unloaded squats.

EMG measurements were carried out with Myontec’s Mbody technical shorts (Myontec Ltd, Kuopio, Finland) according to manufacturer’s guideline. The electrodes and all the wires were sewn into the fabric of the shorts. The EMG signal from the shorts to the Mcell module passed through a narrow steel thread. The shorts were made of fabric similar to that used in running clothes.

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The Mcell module contained an amplifier, a microprocessor with software, a memory for the data, and a Bluetooth smart contact. The module collected the EMG data with a 1000-Hz frequency selection and a 50- to 200-Hz string. The EMG information went through the module wirelessly to the computer program Muscle Monitor (Myontec Ltd, Kuopio, Finland) for analysis.

As a clinical solution, Muscle Monitor software represented lower-limb EMG activity as a relative (percentage) ratio between the left and right lower limbs. The mean relative left lower-limb EMG activity (=100% – right lower-limb relative EMG activity in percentages) in each activity comprised an average data sample and was used as outcomes in our analyses.

The ethics committee of the Hospital District of Helsinki and Uusimaa approved the study protocol.

**Statistical Analyses**

The statistical analysis was done with Statistical Package for the Social Sciences 23.0 (Norusis/SPSS, Inc, Chicago, IL). The reliability of the measurements was evaluated by calculating the intraclass correlation coefficient (ICC) and its 95% confidence intervals (CI) with a 1-way random model. The Bland-Altman method was used to analyze the limits of agreement (LOA) between the 2 measurements. In Figures 1 to 3, the solid line represents the mean difference (bias) and the broken lines represent the LOA intervals (1.96 × SD) for the mean difference. The coefficient of repeatability (CR) is twice the SD of the differences of the test–retest between the pairs. CRs were calculated with MedCalc Statistical Software version 16.8 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2016).

**Results**

Seventeen females (mean age 25.5 ± 10.0 y) and 17 males (mean age 29.9 ± 11.9 y) participated in the study. There was no difference between genders in mean body-mass index (kg/m²; male mean 23.9 ± 2.7 vs female mean 23.5 ± 2.4). As expected, the mean relative ratios (percent unit) of EMG activity in the various tests between left and right lower limbs were on the same level, indicating symmetric muscle activity in the lower limbs. The ICCs were .76 (95% CI, .58–.87) for stair descent, .65 (.41–.81) for stair ascent, and .80 (.64–.89) for repeated unloaded squats.

Figures 1 to 3 show the Bland-Altman plots for the various tests. In each figure the x-axis shows the mean of the first and second measurements, and the y-axis shows the difference between these measurements (second – first).

The mean difference and the LOA between the repeated measurements were as follows: descending stairs mean –0.8%, LOA –6.2% to 4.7%; ascending stairs –0.9%, –6.5% to 4.7%; and unloaded repeated squats –0.2%, –5.4% to 4.9% (see Figures 1–3). CRs were 5.6% for descending stairs, 5.7% for ascending stairs, and 5.3% for unloaded repeated squats.

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**Figure 1** — Bland-Altman plots showing differences from mean (second – first measurement) for lower-limb electromyography (EMG) activity when descending stairs in 34 subjects.
Figure 2 — Bland-Altman plots showing differences from mean (second – first measurement) for lower-limb electromyography (EMG) activity when ascending stairs in 34 subjects.

Figure 3 — Bland-Altman plots showing differences from mean (second – first measurement) for lower-limb electromyography (EMG) activity at repeated unloaded squats in 34 subjects.
Discussion

We studied the test–retest reliability of thigh area EMG activity among healthy subjects measured with subjects wearing smart shorts. Our study showed that the lower-limb muscle EMG activity ratio could be reliably measured with smart shorts in everyday activities.

Injuries of the lower limbs may cause muscle strength and function imbalance between the injured and noninjured lower limbs or between the knee-extensor and -flexor muscles. Anterior cruciate ligament (ACL) reconstruction surgery patients with a knee-extension strength deficit of more than 15% in the injured compared with the contralateral lower limb have been reported to have impaired lower-limb function. A recent consensus “statement” recommended symmetrical quadriceps and hamstring muscle strength as important outcomes for successful recovery after ACL injury or reconstruction. While technical clothing may serve as a practical method to monitor recovery after injury, the relationship between lower-limb muscle strength and EMG activity among injured patients should be studied in the future.

In their systematic review, Wasielewski et al investigated the effectiveness of EMG biofeedback as a rehabilitation method in various knee problems. The authors found potential improvements in knee extensor torque and functional outcome with EMG biofeedback in participants with surgical knee conditions. In our study, subjects performed everyday physical activities, which are typical in physiotherapy and in the assessment of physical ability. The usability of the clinical application of smart shorts where patient and physiotherapist are able to visually monitor relative muscle activation between the left and right lower limbs online should also be studied in the future.

The fact that we used healthy subjects can be seen as a limitation of the study. Nevertheless, we found it necessary to investigate the reliability of the method among these subjects without pain and other symptoms before testing smart shorts on patients. The mean test–retest difference in all 3 tests was under 1%, indicating no systematic bias between the repeated measurements. On an individual level the test–retest difference was less than 8% in every case, and the CRs were from 5.3% to 5.7%. One other limitation is that we did not calculate sample size. However, neither gender nor age affected the reliability, and the first author (DB) carried out all the measurements. We therefore assume that a higher number of subjects would not have changed our conclusion.

In conclusion, our study among healthy subjects showed that left-right muscle activity ratio in activities of daily living can be reliably measured with smart shorts. Technical garments with wireless data transfer and mobile applications seem to be a promising follow-up method in rehabilitation. In future, the feasibility of such methods in different patient groups should be investigated in greater detail.

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References