FIGUR8

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# **Defining How Muscle Activation is Captured:** Validation of Surface-Mechanomyography (sMMG) to Evaluate Muscular Contraction Timing by Comparison with Electromyography

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## Introduction

FIGUR8 surface-mechanomygraphy (sMMG) sensors placed on the skin across the surface of a muscle can quantify muscle output. More specifically, they measure the physical muscle bulk deformation that occurs during contraction. Electromyography (EMG) is the clinical standard for detection of muscle activity.[1,2] However, the well-established challenges in EMG data collection and analysis methods limit its reliable application in wearable wide-spread neuromuscular control screening.[3,4,5] Validation of the FIGUR8 device for accurate evaluation of muscular contraction could provide quantifiable feedback for clinicians without the drawbacks of other available methods. The following study was performed to investigate the ability of the FIGUR8 sMMG sensor to detect timing patterns of muscle contraction by comparing to simultaneous data capture of traditional EMG.

## Current Quantification Of Muscle Activation: Electromyography

EMG measures the electrical activity of muscles. The output generated from the EMG signal is in volts (V). Surface EMG is the clinical standard for identifying muscle activation during dynamic activities (Figure 1).[1,6] It is used during activities to assess an athlete's neuromuscular control. Therefore, dynamic EMG is the current method for evaluating muscle activation used to maintain dynamic control of the body during a functional activity.[6,7,8,9]

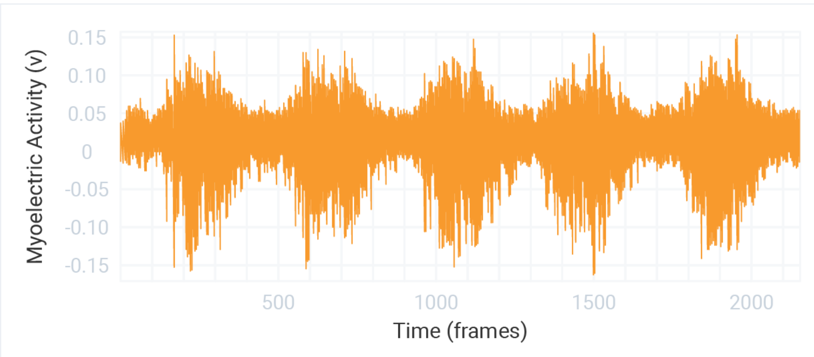


**Figure 1.** *Top: EMG raw output.*

## Quantification of Muscle Activation with the FIGUR8 Device

The FIGUR8 sMMG sensor measures the physical change in muscles' shape during a contraction. The sensors are applied over the largest portion of a muscle bulk (Figure 2).

- The output is based on the linear displacement of the sensor and is displayed in millimeters (mm).
- The sMMG sensor sensitivity demonstrates a resolution of 50 μm ± 0.5%.

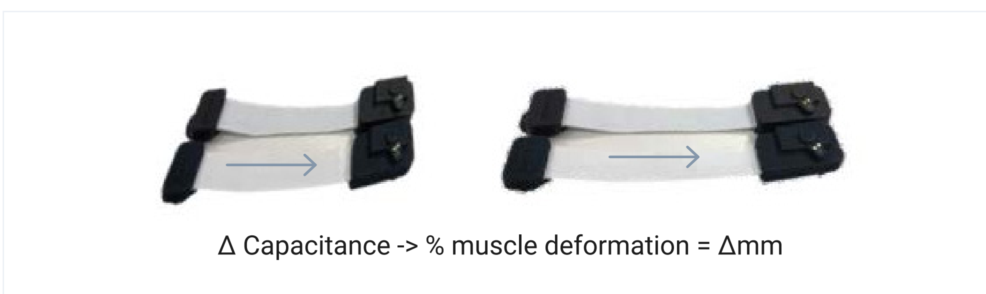


**Figure 2.** *Illustration of the FIGUR8 sMMG sensor application for muscle output.*

## Measurement Device Comparisons During A Muscle Contraction

- EMG measures myoelectric activity (Figure 3).
- The FIGUR8 sMMG sensor measures physical change in the muscle's shape (Figure 3).

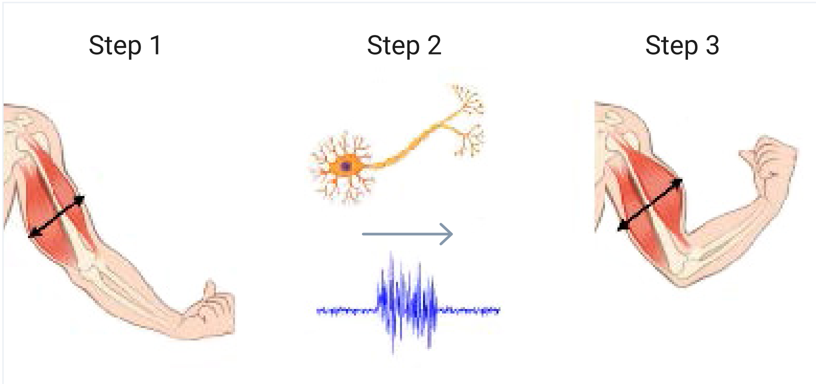


**Figure 3.** *Illustration of the steps from 1) cognitive decision to bend the elbow followed by 2) the electrical impulse across an axon and the resulting EMG activity to 3) the physical contraction of the muscle resulting in movement.*

### Purpose of the Study

To investigate the ability of a novel FIGUR8 sMMG Sensor to detect timing patterns of muscle contraction and compare time events to those collected through traditional EMG.

We established 2 study aims to evaluate the FIGUR8 sMMG sensor during a common neuromuscular control screening activity, the Repeated Unilateral Partial Squat (RUPS).

- Aim 1: Assess the differences of muscle activation timing between EMG and a FIGUR8 sMMG sensor.
- Aim 2: Evaluate the within-subject variability of muscle activation timing from EMG and a FIGUR8 sMMG sensor.

## Methods

### Participants

Ten healthy participants volunteered for this study (mean age: 25 ± 7 yrs) and completed 14 trials total of a repeated unilateral partial squat task with a sMMG sensor and an EMG sensor simultaneously applied to the dominant leg quadriceps muscle (Figure 4).

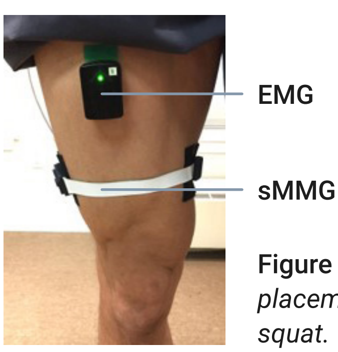


**Figure 4.** *Illustration of sMMG and EMG sensor placement during the repeated unilateral partial squat.*

### Equipment Set-up

The EMG device recorded wirelessly at 120hz. The FIGUR8 sMMG sensor recorded data using iOS app at 50hz streamed via Bluetooth Low Energy to a mobile device.

### Data Collection Activity

The Repeated Unilateral Partial Squat activity (RUPS) was performed by each participant. The partial squat is an activity commonly used to qualify neuromuscular control.[10,11] The ability to control the body and supporting leg throughout the dynamics of this activity requires strength and coordinated timing of muscle activity. Stability and efficiency of movement are challenged as the participant controls changes in position across the kinematic chain involving the hip, knee and ankle joints. To perform this activity, a participant stands with one leg at the edge of a 20-cm box/step with hands on hips and the other leg dangling off the side of the box/step, but not touching it (Figure 5.)

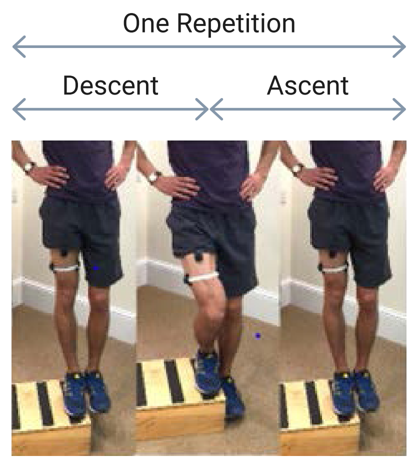


**Figure 5.** *Illustration of one repeated unilateral partial squat movement.*

After receiving instruction to maintain good control and balance while standing on one leg, the participant moves at a comfortable, controlled pace into a slight squat stance, lowering the non-support leg straight down so that the foot comes close to floor, but does not touch. The subject then returns to the starting upright standing position. For each trial the participant repeats the partial squat 5 times in a row. This is repeated 3 separate times. If the person stepped down or touched the ground, the trial was not used for analyses.

The FIGUR8 sMMG sensor has previously demonstrated the ability to detect the magnitude of quadriceps displacement during the RUPS activity with excellent correlation during test-retest reliability testing, $ICC_{3,1}$=0.91 (0.18-0.99).[12] However, there was interest in assessing the ability of the sMMG sensor to measure the timing of muscle activation during this same activity.

### Data Processing

Raw EMG data was recorded using Delsys EMG units. The signal was then filtered using a 6th order Butterworth low pass filter at 3 Hz. Additionally, a Teager–Kaiser energy operator (TKEO) was applied to further smooth the signal and aid in determining accurate muscle activation points (Figure 6).[13] sMMG data was recorded using FIGUR8 sMMG sensors and did not require any filtering.

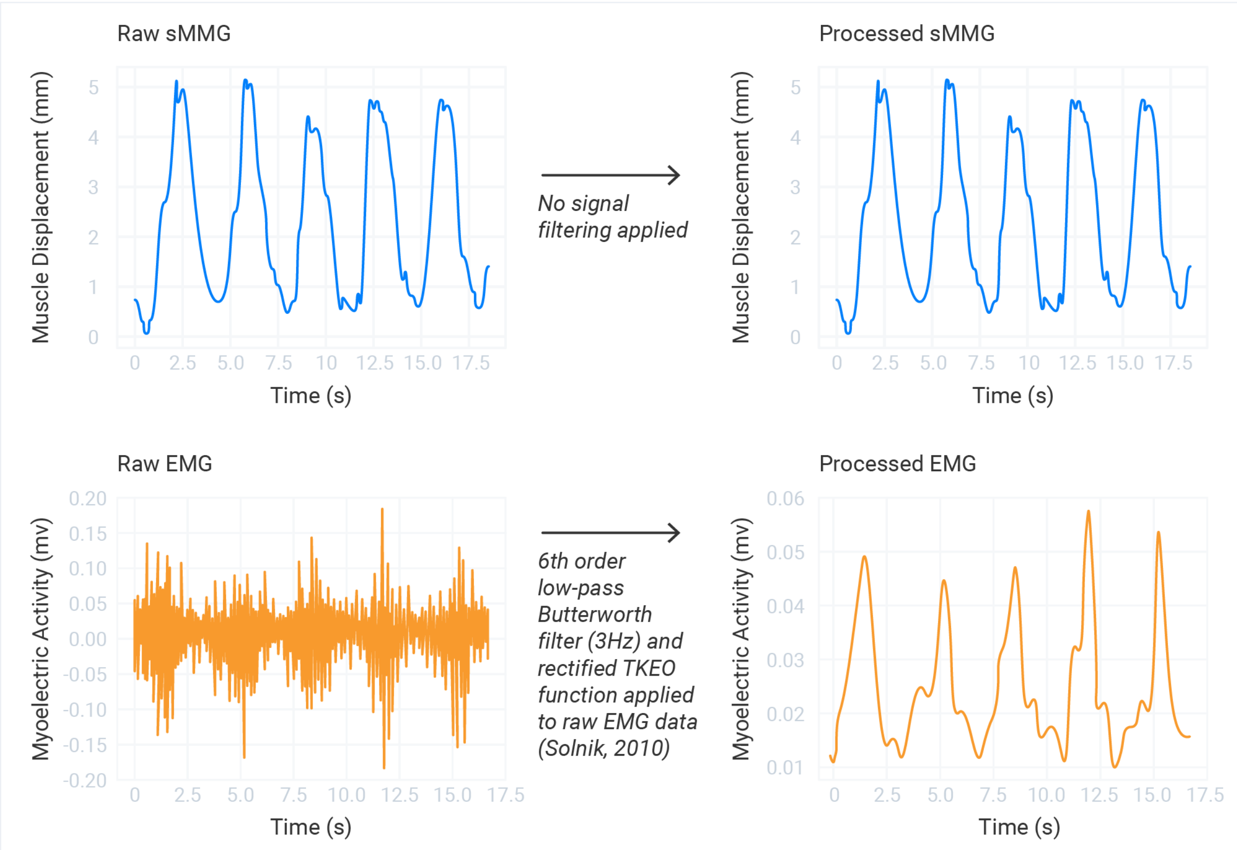


**Figure 6.** *Illustration of five repeated unilateral partial squats.*

## Data Analyses

The clinically relevant time points of muscle contraction including activation and peak contraction were identified for the processed EMG and raw sMMG sensor data. The second, third and fourth repetitions of the unilateral partial squat in each trial was selected for analysis. An average of 3 trials per subject were included in analyses.

In order to determine activation points, a calibration trial was recorded with the subject standing at rest. This resulted in two baseline values, one for sMMG and one for EMG. Then, the standard deviation was calculated for each modality's calibration trial. The threshold for muscle activation was established at 3 times the standard deviation of the specific modality's calibration trial above the minimum value for each repeated unilateral partial squat (Figure 7).[13,14,15]

The time of muscle activation was recorded at the time point when the threshold of activation was surpassed for each individual partial squat. The time of peak contraction was recorded at the time point of the maximum sMMG or EMG output after the threshold of activation had been exceeded for each partial squat.

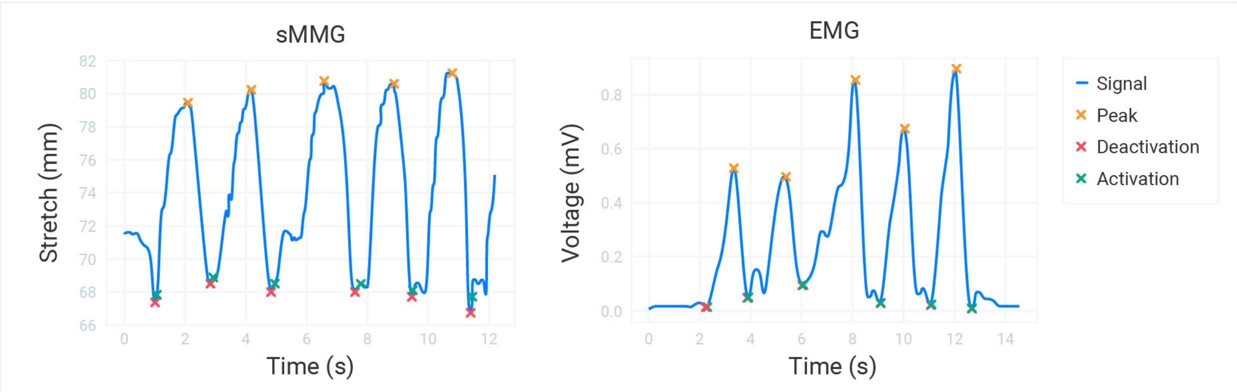


**Figure 7.** *Example of relative muscle contraction timing using sMMG sensors (left) and EMG sensors (right) for 5 repeated unilateral partial squats. It is important to note that by using two different sensor types, the time indexes do not align. Timing was compared on a relative basis by comparing the durations of each individual unilateral squat contraction. Time from activation to peak was analyzed for each contraction.*

A statistical analysis was performed to determine the significance of the muscle timing data. Paired T-test analyses assessed differences in the timing of key phases of muscle contraction for the sMMG and EMG sensors. T-test analyses were also used to assess differences in within-subject variance in timing of each muscle contraction phase.

## Results

The results of relative muscle activation timing from EMG and the FIGUR8 sMMG sensors support our study aims. The relative timing of quadriceps muscle activation to peak muscle contraction during the partial squat did not differ significantly between EMG (1.100 ± 0.390s) and sMMG sensors (1.221 ± 0.490 s), p=0.103 (Figure 8).

No significant difference in within-subject variation was noted for timing of quadriceps muscle activation to peak (p=0.208) between modalities (Table 1).

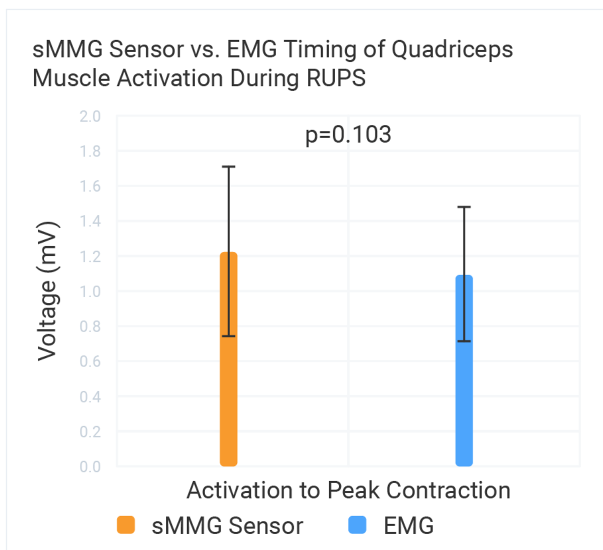


**Figure 8.** *Comparison of FIGUR8 sMMG sensor muscle activation to EMG timing of muscle activity.*

| sMMG Sensor (seconds) | EMG (seconds) | p value |
|---|---|---|
| 0.067 ± 0.619 | 0.131 ± 0.184 | 0.218 |

**Table 1:** *Within subject variation of timing via sMMG Sensor and EMG of muscle activation to peak contraction phase during a set of individual partial squats.*

## Conclusions

Study results support the use of the FIGUR8 sMMG sensor for evaluation of muscle activation timing during neuromuscular control screening. The findings reveal similarities in time signatures between the sMMG and EMG sensors for assessing quadriceps activation during a standard neuromuscular assessment activity. These findings suggest the ability of the sMMG sensor to detect the key time points of muscle activation and peak contraction. The observation that average within-subject variation in the timing of the activation to peak phase was not significantly different between the two modalities further increases confidence in these results.

The results are also consistent with physiological expectations. The electrical signal sent to a muscle causing it to contract and the resulting physical contraction of the muscle happens in extremely rapid succession. Foundational animal physiological studies have demonstrated that the electrical response due to the depolarization of a muscle occurs prior to the mechanical response, which is followed by force production.[16] Therefore, it is expected that there will be a very slight difference in the timing of muscle activation measured via EMG and sMMG. This is exactly what the results of this study found. The electrical activity measured by EMG slightly precedes the physical muscle deformation measured by the sMMG sensor, and due to the speed of neuromuscular signal transfer that creates a physical contraction, these captured differences in timing are not statistically different.

sMMG sensor detection of the time of muscle activation to peak contraction is of clinical interest. During the muscle activation to peak contraction time period of the partial squat, the quadriceps muscle is undergoing eccentric contraction, where the muscle contracts while elongating under load to help lower the body into a squatting position.[17] The ability of the sMMG sensor to detect specific time periods of muscle contraction could allow for future analysis of different types of muscle contraction during an activity such as eccentric contraction (muscle lengthening) and concentric contraction (muscle shortening).[17,18] This detection is important to clinicians and coaches since athletes performing sport specific maneuvers may have a greater risk for injury during movements that specifically emphasize eccentric or concentric contraction.[18,19] Therefore, there is interest in assessing neuromuscular control during a specific type of muscle contraction as part of screening activities. This differentiation is currently difficult and time consuming to quantitatively assess using other commercially available methods.

FIGUR8 sMMG sensors can be used for quick on-the-field or in-the-clinic neuromuscular control assessments.

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