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Abstract
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Short communication

Normalisation of a biarticular muscle EMG signal using a submaximal voluntary contraction: Choice of the standardised isometric task for the rectus femoris, a pilot study

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ABSTRACT

Background: Electromyography (EMG) signal amplitude is often altered by factors related to the participants and the measurement system. To overcome this issue, a normalisation of the EMG signal amplitude can be performed. Recently, it has been demonstrated that a submaximal voluntary contraction (subMVC) normalisation approach, inspired by grade 3 of manual muscle testing, could produce reliable results. However, rectus femoris (RF) normalisation resulted in low reliability. While the normalisation task chosen for this biarticular muscle was to maintain a knee extension against gravity (ISO-K), a hip flexion isometric task (ISO-H) could also be applied.

Research question: This pilot study aimed to assess the impact of the normalisation task on the RF EMG signal quality and related intra-rater within-day reliability during ISO-K and ISO-H, and intra-rater between-day reliability of the EMG signal amplitude during gait.

Methods: Twenty-four asymptomatic participants were asked to perform ISO-K and ISO-H tasks with both legs and then to walk at self-spontaneous speed, in two identical sessions one week apart. A wireless EMG system was used to record the EMG signal of bilateral RF during each task.

Results: Signal-to-noise ratio during ISO-K and ISO-H was >15 dB in respectively 51% and 98% of all task repetitions. Intra-rater within-day reliability was acceptable using ISO-K (ICC = 0.71 (0.57; 0.83)) with high %SEM of 35%, and excellent using ISO-H (ICC = 0.94 (0.90; 0.96)) with high %SEM of 34%. Intra-rater between-day reliability during gait was acceptable using ISO-K (ICC = 0.74 (0.61; 0.81)) with a high %SEM of 49%, and excellent using ISO-H (ICC = 0.87 (0.76; 0.93)) with a high %SEM of 38%.

Significance: The reliability (ICC) of RF EMG signal normalisation was higher using ISO-H than using ISO-K. However, even if signal-to-noise ratio was notably improved using ISO-H, %SEM remains high whatever the normalisation task used. Some additional improvements might thus still be needed to obtain a normalisation protocol allowing more reproducible measurements.

1. Introduction

Clinical gait analysis (CGA) can be coupled with electromyography (EMG) signal analysis to highlight the impact of musculoskeletal system impairments, related to the neuromuscular motor control, on the abnormal movements observed in patients with complex gait disorders [1]. In particular, the level of muscle activation may be of primary importance, but its relationship with the EMG signal amplitude is often altered by several factors related to the participants and the measurement system [2]. To overcome this issue, a normalisation of the EMG signal amplitude can be performed [3,4]. In particular, submaximal voluntary contraction (subMVC) normalisation approaches can be applied to populations with pain or muscle selectivity issues due to central lesions [5]. This approach has to be applied cautiously, as variations, e.g. in posture, may occur between sessions and participants [2]. Recently, Tabard-Fougère et al. [6] demonstrated the reliability of a subMVC approach inspired by grade 3 of manual muscle testing (normalisation task between-day reliability: ICC > 0.75). However, even if this approach seems promising from a practical perspective, it requires additional developments to ensure a substantial added value to CGA.

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particular, rectus femoris (RF) normalisation appeared to be less reliable (ICC < 0.75, %SEM > 50%) than for other muscles (ICC > 0.90, %SEM < 25%). While the normalisation task chosen for this biarticular muscle was to maintain knee extension against gravity, a hip flexion isometric task could be applied. This pilot study was oriented toward the choice of the normalisation task required for the RF. The first objective was to assess quality and amplitude intra-rater within-day reliability of EMG signals recorded during two normalisation tasks: isometric hip flexion (ISO-H) and isometric knee extension (ISO-K). The second objective was to compare EMG signal amplitude intra-rater between-day reliability during gait after its normalisation resulting from these tasks.

2. Material and methods

2.1. Participants

Twenty-four asymptomatic participants (9 W/15 M, 35.8 ± 12.8 years, 173.5 ± 8.3 cm, 67.5 ± 11.3 kg) were recruited on a voluntary basis from Geneva University Hospitals. The sample size was previously defined through a power analysis (power > 80%, \( \rho_0 = 0.39 \) ) [7]. Participants were not recruited if they had a history of significant lower extremity injury in the previous year. The local ethics committee approved this study (n° PB_2017-00636). All participants gave their written informed consent prior to inclusion in the study.

2.2. Experimental protocol

Measurements were conducted at the Willy Taillard Laboratory of Kinesiology (Geneva University Hospitals, Switzerland). Participants were asked to perform two isometric tasks per leg (total 20 legs) (Fig. 1). ISO-K consisted in maintaining knee extension (not beyond 0°) while sitting [6], ISO-H consisted in keeping thigh horizontal and shank vertical while standing. Both postures were set manually by the operator while asking the participant a full leg relaxation. Both tasks were held for 3 s between each repetition. Both tasks required RF contribution in maintaining the related body segment (thigh or shank) in a position perpendicular to the gravity. Participants were then asked to walk at self-spontaneous speed on a 10-m straight level walkway (10 gait cycles per session [8]). All participants took part in two identical sessions one week apart and managed by the same operator.

2.3. Data recording

A wireless EMG system sampled at 1000 Hz (TRIGNO, Delsys Inc., USA, bandwidth 20–450 Hz, CMRR > 80 dB at 60 Hz, input impedance < 10 ohm, baseline noise < 750 nV RMS, effective EMG Signal Gain 909 V/V ± 5%) was used to record bilateral RF EMG signal. Skin preparation and sensors location followed SENIAM recommendations [9]. To identify gait cycles, 5 reflective cutaneous markers were placed on each foot following the CGM 2.4 model [10]. Their 3D trajectories were recorded using a 12-camera optoelectronic system sampled at 100 Hz (Oqus7+, Qualisys, Sweden).

2.4. Data processing and analysis

EMG signals and 3D marker trajectories were recorded and labelled within the Qualisys Tracking Manager software (QTM 2019.3, Qualisys, Sweden). Raw data were exported in c3d file format (https://www.c3d.org) and processed under Matlab (R2019b, The MathWorks, USA) using the Biomechanics ToolKit (BTK) [11]. EMG signals were full-wave rectified, and smoothed (2th-order Butterworth lowpass filter, 3 Hz cutoff). Marker trajectories were gap-filled and filtered (2nd order Butterworth filter, 6 Hz cut-off).

Mean EMG envelops amplitude was computed during the middle three seconds of each task repetition (MT) to avoid signal artefacts related to leg motion. Mean value was preferred to peak value because the normalisation tasks did not correspond to maximal contraction, but to the ability of the muscle to keep a standardised position against gravity [6]. Mean baseline amplitude was recorded at the beginning of each record (MN). EMG signal quality was assessed by computing the signal-to-noise ratio \( SNR = 20 \log_{10} \left( \frac{MN}{MT} \right) \) [12]. Intra-rater within-day reliability of the mean EMG envelops amplitude was computed using an intra-class correlation coefficient ICC(1,1) between the 3 task repetitions performed during the same session [13].

Gait cycles were defined through manual identification of foot strike and foot off events based on 3D marker trajectories [6]. Peaks of EMG envelopes were normalised for each gait cycle by dividing with mean MT (from ISO-K or ISO-H). Intra-rater between-day reliability of the average across gait cycles was computed using an intra-class correlation coefficient ICC(1,3). Standard error of measurement (SEM), related percentage (%SEM) and levels of agreement with Bland and Altman plots were also computed.

Analyses were performed using R v.3.1.3 software. An ICC > 0.75 was described as excellent, 0.40 < ICC ≤ 0.74 as acceptable, and ICC ≤ 0.39 as poor [14]. A %SEM > 10% was considered as high, 5% < %SEM ≤ 10% as moderate, and %SEM ≤ 5% as low.

3. Results

After visual inspection of raw EMG signals during gait, four legs were
excluded from the analysis. Fig. 2 illustrates the filtered EMG signal and related envelop (black lines) obtained during 3 consecutive isometric tasks, during the knee extension isometric task (ISO-K) and hip flexion isometric task (ISO-H), respectively. Right: EMG envelop during one gait cycle after ISO-K and ISO-H normalisation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. Illustration of the rectus femoris EMG signals observed in one participant. Left and middle: Filtered rectus femoris EMG signal (blue lines) and related envelop (black lines) obtained during 3 consecutive isometric tasks, during the knee extension isometric task (ISO-K) and hip flexion isometric task (ISO-H), respectively. Right: EMG envelop during one gait cycle after ISO-K and ISO-H normalisation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Intra-rater within-day reliability of the mean EMG envelop amplitude was acceptable (ICC = 0.71 (0.57; 0.83)) using ISO-K with a high %SEM of 35%, and excellent (ICC = 0.94 (0.90; 0.96)) using ISO-H with a high %SEM of 34%. Intra-rater between-day reliability during gait was acceptable using ISO-K (ICC = 0.74 (0.61; 0.81)) with a high %SEM of 49% and levels of agreement ranged between −2.3 and 2.7, and excellent using ISO-H (ICC = 0.87 (0.76; 0.93)) with a high %SEM of 38% and levels of agreement ranged between −1.4 and 0.8 (Fig. 3A/C/D).
4. Discussion

This study highlights normalisation task impact when a subMVC approach is used on the RF EMG signal during gait.

As pointed out by Besomi et al. [2], participant posture using a subMVC approach has to be defined cautiously. By demonstrating a lower intra-rater within-day reliability, ISO-K may be more subject than ISO-H to posture variations. This can be explained in particular by hamstring stiffness, a parameter that may have varied between participants, and that may restrain knee extension in a sitting posture.

Furthermore, EMG signal quality during ISO-K was lower than during ISO-H, and often inferior to the exclusion threshold of 15 dB proposed by Sinderby et al. [12]. In such conditions, EMG onset detection during ISO-K may be altered and thus led to wrong subMVC values. This can be explained by the involvement of higher weights of lower-limb segments to be supported by RF during ISO-H, leading to a higher muscle activation. Another explanation can be related to electrodes placement as it is known that RF activity is greater in its proximal part during hip flexion and greater in its distal part during knee extension [15], due to two distinct motor nerve branches [16,17].

Without a consistent mean EMG envelop amplitude through the repeated contractions during the normalisation task, it is not surprising to observe that ISO-K led to lower intra-rater between-day reliability than ISO-H. Indeed, ISO-K related posture was defined at a range of motion boundary where muscle activations may be higher than the ones requested to maintain straight leg. More generally, the present results highlight that the choice of the task used to normalise the EMG signal must be done carefully to ensure a good to excellent within-day reliability, even more for a biarticular muscle such as the RF.

These results must be interpreted carefully. First, our results suggest that ISO-H should be preferred instead of ISO-K to normalise the RF EMG signal following SENIAM recommendations for electrodes placement. However, both tasks had relatively high %SEM (> 40%) compared to other muscles (< 25%) [6]. This is consistent with previous results [6] that also report high %SEM (> 50%) for the RF, which may suggest a notable contraction variability of this muscle. Furthermore, this observation may vary in other populations if anatomical variations appear at the motor nerve branches location. Second, by increasing SNR during normalisation task, ISO-H tends to lead to lower normalised signal values during gait. A direct consequence is that a slight variation of the signal leads to a higher %SEM compared to ISO-K. Third, the results of this pilot study must be verified on specific pathologic populations (e.g. children with cerebral palsy and/or typical development) and the approach discussed from a clinical applicability point of view.

5. Conclusion

In the context of CGA, the reliability (ICC) of RF EMG signal normalisation was higher using a subMVC recorded during hip flexion (ISO-H) than during knee extension (ISO-K). However, even if signal-to-noise ratio was notably improved using ISO-H, %SEM remains high whatever the normalisation task used. Some additional improvements might thus still be needed to obtain a normalisation protocol allowing more reproducible measurements.

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Competing interests

The authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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