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Gender differences in the myoelectric activity of lower limb muscles in young healthy subjects during walking

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ABSTRACT

The present study was designed to achieve a comprehensive analysis of gender-related differences in the myoelectric activity of lower limb muscles during normal walking at self-selected speed and cadence, in terms of muscle activation patterns and occurrence frequencies. To this aim, statistical gait analysis (SGA) of surface EMG signal from tibialis anterior (TA), gastrocnemius lateralis (GL), rectus femoris (RF), biceps femoris (BF) and vastus lateralis (VL) was performed in 11 female (F-group) and 11 male (M-group) age-matched healthy young adults. SGA is a recent methodology performing a statistical characterization of gait, by averaging spatio-temporal and sEMG-based parameters over numerous strides. Findings showed that males and females walk at the same comfortable speed, despite the significantly lower height and higher cadence detected in females. No significant differences in muscle onset/offset were detected between groups. The analysis of occurrence frequencies of muscle activity showed no significant differences in BF and RF, between groups. Conversely, in F-group, compared with M-group, GL, TA and VL showed a significantly higher occurrence frequency in the modalities with a high number of activations, and a significantly lower occurrence frequency in the modalities with a low number of activations. These findings indicate a propensity of females for a more complex recruitment of TA, GL and VL during walking, compared to males. The observed differences recommend the suitability of developing electromyographic databases, separated for males and females.

1. Introduction

Gender-specific morphology of pelvis and thigh are widely known [22,26]. These structural differences led to wonder if gender could be also a factor influencing movement patterns during walking. Temporal gait-parameter differences were broadly reported: compared with males, females walk with higher cadence and slightly shorter stride length, although when normalized for height, differences in stride length seem to be not statistically significant [32,35]. Gender-related differences were identified also in movement patterns during walking. An increased sagittal-plane hip flexion and a decreased knee flexion were reported in females in preparation for weight bearing, together with changes in knee-flexion moment and power absorption during pre-swing [23]. An analysis of various walking conditions showed that excursions in frontal and transverse planes were greater at hip and knee for females compared to males [22]. Clear gender differences were also observed in hip kinematics across a variety of walking speeds and surface inclinations, indicating that females displayed greater peak hip internal rotation and adduction, for all walking conditions [10]. Recently, increased hip adduction and knee abduction were observed during the downward and upward phases of the gait task in females, compared with males [31].

Given the identified gender-related differences in joint kinematics, it is likely that gender differences in underlying muscle activities are also present. However, only few studies reported suitable results on the effect of gender on walking, provided by analyzing the electromyographic signals recorded from the lower limb muscles [9–11]. In particular, analyzing the surface electromyographic (sEMG) signal from biceps femoris, rectus femoris, gastrocnemius and tibialis anterior, Chiu and Wang [9] reported that females produce significantly higher muscle activity only in tibialis anterior during walking and Chung and Wang [11] added that the EMG response in tibialis anterior increases with increasing

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Table 1
Characteristics of female (F-group) and male (M-group) subjects.

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
F-group	23.3 ± 1.1	165 ± 3	51.6 ± 3.3	19.0 ± 0.9
M-group	24.3 ± 2.4	181 ± 7	72.7 ± 9.1	22.1 ± 1.8
Statistics	NS	$p < 0.001$	$p < 0.001$	$p < 0.001$

Values are means ± SD. Body mass index (BMI) is defined as the ratio of body weight to the square of height.

walking speed. Thus, the study of tibialis anterior, together with its antagonist muscle for ankle plantar/dorsiflexion, the gastrocnemius, appears to be relevant for analyzing possible gender-related EMG differences, during walking. However, many of the reported kinematics/kinetics differences between males and females during walking [10,22,23,31] concern the role of proximal leg joints. Moreover, different studies [5,27] documented a higher risk of anterior cruciate ligament injury in females, compared to male, suggesting a different workload of muscles crossing knee. So, it can be argued that also proximal muscles may provide significant insights concerning the gender-related differences in muscle activity.

Moreover, it was observed that advancing age modifies the timing of onset/offset activation of lower limb muscles and the duration of the activity of agonist and antagonist muscles [21,38]. This suggests the suitability of developing electromyographic databases, separated for young and old subjects.

The purpose of this study was to perform in healthy young subjects a comprehensive analysis of the gender-related differences in the myoelectric activity of lower limb muscles during walking at self-selected speed and cadence, in terms of activation patterns of each muscle and of its occurrence frequency. The goal of this study was pursued by performing the technique of statistical gait analysis (SGA) [3] of sEMG signal acquired from tibialis anterior (TA), gastrocnemius lateralis (GL), rectus femoris (RF), biceps femoris (BF) and vastus lateralis (VL). SGA is a recently developed methodology, which performs a statistical characterization of gait by averaging spatial–temporal and sEMG-based parameters over numerous strides (hundreds), during the same walking trial. Since this method depends on the accuracy of the process used to detect muscles onset/offset, this study is based on the availability of robust techniques for the detection of muscle activation intervals [7,37], and specific tools for SGA.

2. Materials and methods

2.1. Subjects

Twenty-two young healthy Caucasian volunteers were recruited. Subjects were divided into two groups: 11 females (F-group) and 11 males (M-group). Mean age, height, weight and body mass index (BMI) are given in Table 1. Exclusion criteria included history of neurological pathology, orthopedic surgery, acute/chronic knee pain or pathology, flat feet and BMI ≥25, or abnormal gait. Participants signed informed consent.

2.2. Signal acquisition

Signals were acquired (sampling rate: 2 kHz; resolution: 12 bit) and processed by the multichannel recording system Step32, DemItalia, Italy. Each subject was instrumented with foot-switches, knee electrogoniometers and sEMG probes on both lower limbs. Three foot-switches (size:11 mm × 11 mm × 0.5 mm; activation force:3 N) were attached beneath the heel, the first and the fifth metatarsal heads of each foot. An electro-goniometer (accuracy:0.5°) was attached to the lateral side of each lower limb for measuring knee joint angles in sagittal plane.sEMG signals were detected with single differential probes with fixed geometry constituted by Ag/Ag-Cl disks (manufacturer: DemItalia, size:7 mm × 27 mm × 19 mm; electrode diameter:4 mm; interelectrode distance:8 mm, gain:1000, high-pass filter:10 Hz, input impedance >1.5 GΩ, CMRR > 126 dB, input referred noise ≤ 1 μV_{rms}), and with variable geometry constituted by Ag/Ag-Cl disks (manufacturer: DemItalia, minimum interelectrode distance:12 mm, gain:1000, high-pass filter:10 Hz, input impedance >1.5 GΩ, CMRR > 126 dB, input referred noise ≤ 200 nVrms). sEMG signals were further amplified and low-pass filtered (450 Hz) by the recording system. An overall gain, ranging from 1000 to 50,000, could be chosen to suit the need of the specific muscle observed.

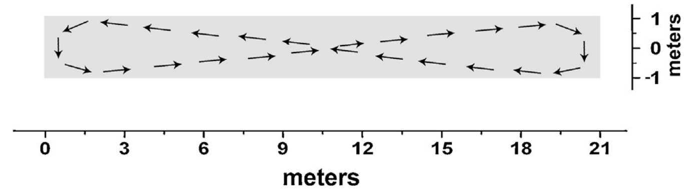

Fig. 1. Schematic representation of the path walked by the recruited subjects during the experiment.

Before positioning the probes, the skin was shaved, cleaned with abrasive paste and then wet with a soaked cloth. To assure proper electrode–skin contact, electrodes were dressed with highly conductive gel. Probes with fixed geometry were applied over GL, TA and BF and probes with variable geometry were applied over RF and VL, following the SENIAM recommendations for electrode location and orientation over muscle with respect to tendons, motor point and fiber direction [20]. Subjects were asked to walk barefoot over the floor for 5 min at natural speed and cadence, following the path schematized in Fig. 1 [13]. The possibility of cross-talk was checked for by visual inspection of raw data. Cross-talk was suspected when two muscles in the same limb section showed simultaneous activity with similar amplitude modulation. In particular, cross-talk of VL on RF activity was suspected during loading response, as reported in [13]. Moreover, since sEMG activity from peroneus longus was not acquired, a possibility has been considered, that crosstalk between TA and peroneus longus may affect the analysis, as indicated by Campanini et al. [8]. Thus, as suggested [8], the test was repeated with slightly different electrode locations on TA.

2.3. Signal processing

Footswitch signals were debounced, converted to four levels, heel contact (H), flat foot contact (F), push off (P), swing (S), and processed to segment and classify the different gait cycles [1].

Electro-goniometric signals were low-pass filtered (FIR filter, 100 taps, cut-off frequency 15 Hz). Knee angles in sagittal plane along with sequences and durations of gait phases derived by the basographic signal, were used by a multivariate statistical filter, to detect and discard outlier cycles like those relative to deceleration, reversing, and acceleration. The multivariate statistical filter tests knee angles and gait phase durations from every stride of subject's walking, comparing them with the mean value computed on each single subject. When knee angles and/or gait phases in the single stride are significantly different (Hotelling t-test, $\alpha = 0.05$) from mean value, corresponding stride was discarded [1,3].

sEMG signals were high-pass filtered (FIR filter, 100 taps, cut-off frequency of 20 Hz) which basically removes movement artifacts, and processed by a double-threshold statistical detector that allows a user-independent assessment of muscle activation intervals. The statistical detector includes also a preliminary data processing: whitening filter and identification of an auxiliary time series, as reported in [7]. This technique [7] consists in selecting a first