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Assessment of the variability of vastii myoelectric activity in young healthy females during walking: A statistical gait analysis

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ABSTRACT

The study was designed to assess the natural variability of the activation modalities of vastus medialis (VM) and vastus lateralis (VL) during walking at a self-selected speed and cadence of 30 young, healthy, females. This was achieved by conducting statistical gait analysis on the surface electromyographic signals from hundreds of strides for each subject. Results revealed variability in the number of activations, occurrence frequency, and onset-offset instants across the thousands of strides analyzed. However, despite the variability, there was one activation occurrence which remained consistent across subjects for both VM and VL. This occurred from terminal swing to the following loading response (observed in 100% of strides). A second, less frequent, activation occurred between mid-stance up to pre-swing (observed in $39.3 \pm 22.4\%$ of strides for VM and in $35.1 \pm 20.6\%$ for VL). No significant differences ($p > 0.05$) were observed in the onset–offset instants or in the occurrence frequency, which suggest a simultaneous recruitment of VM and VL. This "normality" pattern represents the first attempt at developing a reference frame for vastii sEMG activity during walking, that is able to include the physiological variability of the phenomenon and control the confounding effects of age and gender.

1. Introduction

The knee is the key to stance stability, and the muscles of the quadriceps femoris group are the most direct source of extensor control (Perry, 1992). During walking, however, the knee extensor muscles are mainly used to restrain the shock-absorbing flexion during loading response; the quadriceps femoris eccentric contraction in the touching phase of the gait cycle (GC), indeed, represents the primary absorbing mechanism of impact during weight acceptance. In stance, the extensors act to decelerate knee flexion, while in swing they contribute to limb progression (Perry, 1992). Moreover, vastus medialis (VM) and vastus lateralis (VL) play the important role of stabilizing the patella and the knee joint during walking (Grelsamer and McConnell, 1988). Thus, the vastii muscles play a fundamental role in normal walking physiology and in the etiology of common knee pathologies. A VM–VL activity imbalance, observed in thirty-three patients (vs. thirty-three controls) with patellofemoral pain syndrome, was reported as a possible mechanism for abnormal patellar tracking (Cowan et al., 2001). Gender-related differences in both knee kinematic and vastii myoelectric activity were also reported (Chumanov et al., 2008; Di Nardo et al., 2014; Kerrigan et al., 1998; Malinzak et al., 2001). In a recent electromyographic study of ours, involving twenty-two healthy adults (Di Nardo et al., 2015b), females showed a higher VL-recruitment frequency during walking than males. In a study on seventeen young females and seventeen age-matched males (Chumanov et al., 2008), the former group showed higher VL myoelectric activity during the terminal swing and initial running loading transition than the latter. Eventually, in a study on nine females and eleven males (Malinzak et al., 2001), females showed a higher quadriceps activation during different motor tasks than males. It was also observed that advancing age modifies both the activation timing of lower limb muscles (including the vastii), and the activity duration of agonist and antagonist muscles (Hortobagyi et al., 2009; Tirosh and Sparrow, 2005). Thus, there is much evidence that vastii activations change with both age and gender, so that availability of electromyographic reference frame, stratified for age and gender, is desirable.

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Surface electromyography (sEMG) is regularly used to assess the activation patterns of knee extensor muscles during normal and pathological gait (Agostini et al., 2010; Karst and Willett, 1995). Vastii activity begins in terminal swing (around 90% of GC). Early in loading response of the following stride (5% of GC), vastii intensity rapidly increases to a peak of 25% of maximum manual muscle test value, a level of effort that is maintained throughout the remainder of the loading response period. With the beginning of mid-stance, the vastii rapidly reduce their effort, which ceases by the 15% GC point (Perry, 1992). However, activities outside typical activation intervals for VM and VL and, more generally, a large stride-to-stride variability in EMG profiles were also reported (Agostini et al., 2010; Winter and Yack, 1987). Thus, besides the effect of age and gender, a reliable reference frame of vastii recruitment in healthy adults should also consider the natural muscle-activation variability during free walking. The availability of such a tool, simultaneously including natural variability of the phenomenon and controlling for the confounding effect of age and gender, would indeed be useful for discriminating physiological and pathological conditions.

A possible way to create a frame of reference is to use statistical gait analysis (SGA) (Agostini and Knaflitz, 2012) to analyze electromyographic recordings containing several steps from several patients. SGA is a recently developed methodology, which performs a statistical characterization of gait by averaging spatial–temporal and sEMG-based parameters over hundreds of strides, during the same episode of walking. Thus, the aim of the study was to use SGA for the quantitative assessment of natural variability of VL and VM activation modalities. To this aim, electromyographic recordings of thirty healthy, young, females during self-selected walking were analyzed.

2. Materials and methods

2.1. Subjects

Thirty healthy young female adult volunteers were recruited (age 25.1 ± 2.1 years; height 167.9 ± 0.1 cm; weight 57.7 ± 5.0 kg; body mass index (BMI) 19.8 ± 4.1 kg m^{-2}). Exclusion criteria included history of neurological disorders, orthopedic surgery, acute/chronic knee pain or pathology, BMI > 25, or abnormal gait. None of the recruited subjects were involved in competitive sports activities. All participants signed informed consent.

2.2. Signal acquisition

Signals were acquired (sampling rate: 2000 Hz; resolution: 12 bit) and processed by the multichannel recording system Step32 (Version PCI-32 ch2.0.1. DV), DemItalia, Italy. Each subject was instrumented with foot-switches, knee electro-goniometers and sEMG probes on left lower limb. Three foot-switches (DemItalia, Italy; size: 11 × 11 × 0.5 mm; activation force: 3 N) were attached beneath the heel, the first, and the fifth metatarsal heads. An electro-goniometer (Step32, DemItalia, Italy; accuracy: 0.5°) was attached to the lateral side of the lower limb for measuring knee joint angles in sagittal plane.

sEMG signals were detected with single-differential sEMG probes with fixed geometry constituted by Ag/Ag–Cl disks (manufacturer: DemItalia, size: 7 × 27 × 19 mm; interelectrode distance: 12 mm, gain: 1000, high-pass filter: 10 Hz, input impedance >1.5 GΩ, CMRR > 126 dB, input referred noise $\leqslant 1\ \mu V_{rms}$). sEMG signals were further amplified and low-pass filtered (450 Hz) by the recording system.

The skin was shaved, cleansed with abrasive paste and moistened. To assure proper electrode–skin contact, each electrode was dressed with highly-conductive gel. sEMG probes were applied over VM and VL, following the SENIAM recommendations for electrode location and orientation over muscle with respect to tendons, motor point position, and fiber direction (Freriks et al., 2000). Then, after being accurately instructed (Di Nardo and Fioretti, 2013), subjects were asked to walk barefoot over the floor for 6 min at their natural speed and cadence, following the path described in Fig. 1. A time length of 6 min was chosen in order to have an appropriate number of consecutive strides, since Agostini and Knaflitz (2012) indicate that the characteristic gait cannot be quantified in a reliable way by SGA unless at least 100–200 gait cycles are analyzed. This path was chosen to allow the subjects to walk uninterruptedly, without perturbing their natural pace, in order to improve the repeatability of sEMG data (Kadaba et al., 1989).

2.3. Signal processing

Footswitch signals were debounced and converted to four levels, Heel contact (H), Foot Flat contact (F), Push off (P), and Swing (S), then processed to segment and classify the different GCs (Agostini et al., 2014).

Electro-goniometric signals were low-pass filtered (FIR filter, 100 taps, cut-off frequency 15 Hz). Knee angles in the sagittal plane, along with sequences and durations of gait phases derived by the basographic signal, were used by a multivariate statistical filter to detect outlier cycles like those relative to deceleration, reversing, and acceleration. Cycles with improper sequences of gait phases (i.e. different from H–F–P–S sequence) not corresponding to straight walking, and with abnormal timing and knee angles, with respect to a mean value computed on each single subject, were discarded (Agostini and Knaflitz, 2012).

sEMG signals were high-pass filtered (FIR filter, 100 taps, cut-off frequency of 20 Hz) and processed by a double-threshold statistical detector that allows a user-independent assessment of the muscle activation intervals (Bonato et al., 1998). This technique (Bonato et al., 1998) consists of selecting a first threshold ζ and observing m successive samples. If at least r_0 (second threshold) out of successive m samples are above ζ, the presence of the signal is acknowledged. The time instant when the presence of the signal is acknowledged is defined as the onset of muscle activation. The time instant when the presence of the signal is no longer acknowledged is defined as the offset of muscle activation. Values of the three parameters ζ, r_0, and m are selected to jointly minimize the false-alarm probability value and maximize the detection probability for each specific signal-to-noise ratio. The setting of ζ is based on the assessment of background noise level, as a necessary input parameter. Furthermore, the double-threshold detector requires estimating the signal-to-noise ratio in order to fine tune r_0. Background noise level and signal-to-noise ratio, necessary to run double-threshold algorithm, are estimated for each signal by

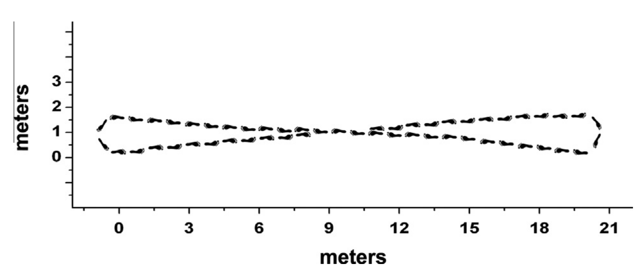

Fig. 1. Schematic representation of the path walked by the recruited subjects during the experiment. From a total of 9787 strides acquired, 38.1% were discarded, due to not following the H–F–P–S foot-switch pattern and/or being outlier cycles relative to deceleration, reversing, and acceleration.