Journal of Biomechanics 41 (2008) 3127–3132

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Contraction mode shift in quadriceps femoris muscle activation during dynamic knee extensor exercise with increasing loads

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ARTICLE INFO

Article history:
Accepted 2 September 2008

Keywords:
Vastus medialis
Vastus lateralis
Rectus femoris
EMG
Frequency

ABSTRACT

The objective of the present study was to examine the superficial quadriceps femoris (QF) muscle electromyogram (EMG) during dynamic sub-maximal knee extension exercise between young adult men and women. Thirty subjects completed, in a random order, 2 sub-maximal repetitions of single-leg knee extensions at 20–90% of their one-repetition maximum (1RM). Vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) muscle integrated EMG (IEMG) during each sub-maximal lift was normalized to the respective 1RM for concentric, isometric and eccentric modes. The EMG median frequency (f_{med}) was determined over the isometric mode. Men attained a significantly ($p<0.05$) greater knee angular velocity than the women during the concentric mode ($83.6\pm19.1^{\circ}$/s and $67.4\pm19.8^{\circ}$/s, respectively). RF IEMG was significantly lesser than the VM ($p=0.014$) and VL ($p<0.001$) muscles, when collapsed across all contraction modes, loads, and sex. Overall IEMG was significantly greater during the concentric ($p<0.001$) and isometric ($p<0.001$) modes, than the eccentric mode. Men generated significantly ($p=0.03$) greater VL muscle IEMG than the women, while the opposite pattern emerged for the RF muscle. VM f_{med} (105.1 ± 11.1 Hz) was significantly lesser than the VL (180.3 ± 19.5 Hz) and RF (127.7 ± 13.9 Hz) muscles across all lifting intensities, while the men (137.7 ± 10.7 Hz) generated greater values than the women (129.0 ± 11.4 Hz). The findings demonstrate a reduction in QF muscle activation across the concentric to eccentric transition, which may be related to the mode-specific velocity pattern.

1. Introduction

The quadriceps femoris (QF) muscle is composed of four distinct portions that differ in structure (Willan et al., 2002), biomechanics (Farahmand et al., 1998), morphology (Travnik et al., 1995), activation (Alkner et al., 2000; Pincivero and Coelho, 2000; Pincivero et al., 2006) and function (Goh et al., 1995). Evidence suggests that during voluntary isometric contractions, vastus lateralis (VL) muscle activation is greater than the vastus medialis (VM) and rectus femoris (RF) muscles at low-to-moderate intensities, as hypothesized to be due to its larger size (Alkner et al., 2000; Pincivero et al., 2006; Pincivero and Coelho, 2000); however, contrary studies report equivalent activation across all contraction intensities (Grabiner et al., 1991; Bilodeau et al., 2003).

With respect to dynamic contractions, recent evidence demonstrates a shift towards VL muscle activation during the transition from concentric to eccentric modes similarly in men and women (Pincivero et al., 2006). Furthermore, lower levels of electromyogram (EMG) amplitude during eccentric, than concentric and isometric modes (Griffin et al., 1993; Kellis and Baltzopoulos, 1998; Pincivero et al., 2006; Tesch et al., 1990; Westing et al., 1991), reflect a difference in motor unit recruitment (Kossev and Christova, 1998; Nardone et al., 1989) and enhanced force generating capacity. Given that women have a greater proportion of slow-twitch muscle fibers than men (Simoneau and Bouchard, 1989), sex-specific myoelectric patterns may be reflective of slower action potential conduction velocity in these fibers (Kupa et al., 1995). As a result, the analysis of the raw EMG signal in its frequency domain may reveal a propensity of higher values in men, than women (Cioni et al., 1994; Pincivero et al., 2001, 2002). However, in terms of examining EMG amplitude during sub-maximal knee extensor exercise, when normalized to an individuals' maximal voluntary contraction, differences between men and women may not be evident (Pincivero et al., 2003). Therefore, the objective of the present study was to examine the surface EMG-contraction intensity relation of the different QF muscle components during different modes (i.e., concentric, isometric

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0021-9290/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2008.09.003

and eccentric) of dynamic knee extension exercise between healthy young men and women. It was hypothesized that: (1) VL muscle EMG amplitude will be greater than the VM and RF muscles during all modes of knee extension exercise across low-to-moderate lifting loads, while converging at near-maximal loads (Alkner et al., 2000; Pincivero et al., 2003; Pincivero and Coelho, 2000), (2) men and women will demonstrate similar QF muscle EMG amplitudes across all contraction modes and loads (Pincivero et al., 2003), and (3) VL muscle f_{med} will increase more in men than women across the spectrum of lifting loads, whereas VM and RF muscle f_{med} will not display lifting load dependency (Cioni et al., 1994; Pincivero et al., 2001, 2002).

2. Methods and materials

2.1. Subject and procedures

Subjects consisted of 30 healthy adults ($n = 15$ men, mean ± SD, age = 25.1 ± 4.0 years, height = 178.3 ± 7.8 cm, body mass = 78.8 ± 11.8 kg; $n = 15$ women, age = 22.9 ± 3.2 years, height = 166.1 ± 4.9 cm, body mass = 58.7 ± 6.1 kg). All subjects were physically active and were familiar with inertial exercise, but were not actively participating in a regular resistance program involving this exercise at the time of the study. All subjects provided written informed consent as approved by the Institutional Review Board at the Eastern Washington University.

Following sub-maximal cycling (5 min), subjects performed a one-repetition maximum (1RM) of a single-leg (right) knee extension task and two sub-maximal repetitions to pre-determined percentages of their 1RM. A minimum rest period of 2 min separated all exercise bouts, during which, subjects were allowed to freely move the exercising leg or rest it on a chair.

2.2. Inertial knee extension exercise

Inertial knee extension exercise was performed on a commercially available cam-type resistance apparatus (Pro Leg Extension, Power Systems, Inc., Knoxville, TN). Subjects first performed two sets of sub-maximal (five to seven repetitions) repetitions for familiarization purposes, with a load that was subjectively determined by one investigator and feedback from the subject. The 1RM was determined by trial and error as the maximum amount of weight a subject could lift once, but failed to achieve full knee extension on the second repetition, as previously established (Pincivero et al., 2006). Subjects were specifically instructed to: (1) lift the weight and achieve full knee extension (concentric mode), (2) hold the weight in the extended position for approximately 2 s (isometric mode), and (3) to lower the weight in slow and controlled manner (eccentric mode). One investigator continually provided verbal instruction and encouragement to all subjects, according to the specified criteria (McNair et al., 1996). The average number of attempts of 1RM determination was 2.6 (range = 1–4). Subjects then performed a series of two sub-maximal repetitions at loads equating to 20–90% 1RM (10% increments), in a random order. Additional loads were secured to the weight stack to approximate the calculated loads to the nearest 0.23 kg. The weight corresponding to each subjects' 10% 1RM was not used, as the lowest load on the machine was limited to 9.07 kg.

2.3. Measurement of QF muscle EMG

Electromyograms of the VM, VL, and RF muscles were sampled with pre-amplified bipolar circular surface electrodes (Ag/AgCl; 0.8 cm diameter) with a fixed inter-electrode distance (center to center) of 2 cm. Prior to electrode placement, the skin area was shaved, cleaned with isopropyl alcohol, and abraded with coarse gauze to reduce electrical impedance and ensure adhesion of the electrodes. Electrode placement for the VM was 20% of the distance from the medial joint line of the knee to the anterior superior iliac spine (ASIS), and was oriented at approximately 45° along its longitudinal axis (Rainoldi et al., 2004; Zipp, 1982). Electrode placement for VL and RF muscles was the midpoint between the head of the greater trochanter and the lateral femoral epicondyle, and 50% of the distance from the ASIS to the superior pole of the patella, respectively (Zipp, 1982). The reference electrode was placed over the medial shaft of the tibia 6–8 cm below the inferior pole of the patella. The EMG were sampled (1000 Hz, gain = 10,000) via differential amplifiers (common mode rejection ratio = 87 dB at 60 Hz, input impedance > 25 MΩ at dc; Therapeutics Unlimited, Iowa City, IA) for subsequent analysis (Acqknowledge, v.3.2.6 Biopac Systems Inc., Santa Barbara, CA). The raw EMG was bandpass filtered (20–500 Hz), full-wave rectified and integrated (IEMG) separately over the concentric, isometric and eccentric modes. Each mode (Fig. 1) was identified with an electrogoniometer (Therapeutics Unlimited, Iowa City, IA) secured to the lateral side of the subjects' leg. The IEMG over each mode was divided by its respective duration yielding a one second average, and subsequently averaged over the two repetitions at each sub-maximal lifting load. The processed IEMG at each load was normalized to the similarly processed IEMG during the established 1RM [(sub-maximal IEMG/1RM IEMG) × 100%], separately for each mode. Previous measures of normalized EMG of the superficial QF muscle, during concentric and eccentric contractions, have ranged from moderate to high (ICC = 0.51–0.91) (Finucane et al., 1998). The analysis of the EMG in the frequency domain was performed, via a fast Fourier transformation (FFT) of 1024 points (Hamming window processing), over the middle 1.023 s of the isometric mode. The f_{med} was determined for each muscle during the 1RM, and averaged over the two repetitions at each sub-maximal load. The average knee angular velocity was calculated as the total change in knee position divided by the concentric or eccentric mode duration (Pincivero et al., 2006).

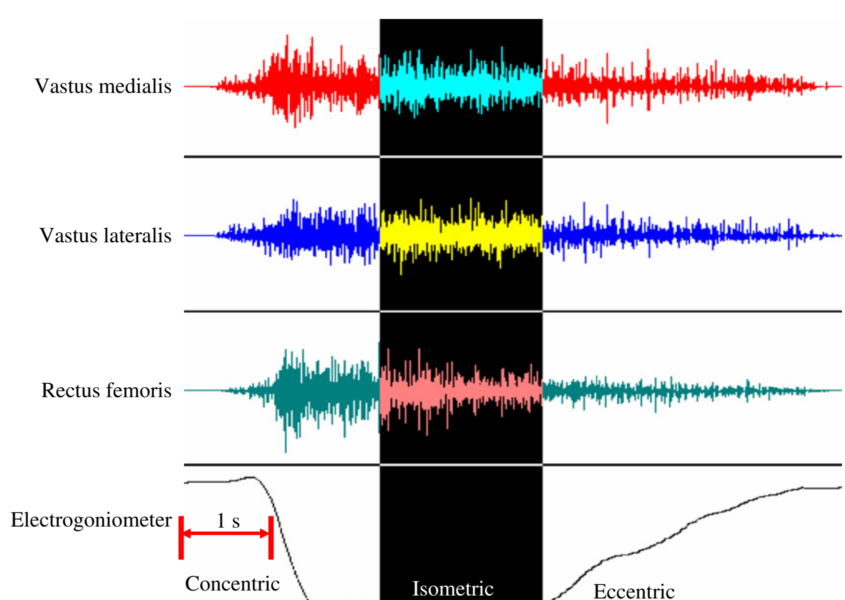

Fig. 1. Sample EMG activity of the vastus medialis, vastus lateralis, and rectus femoris muscles during the concentric, isometric, and eccentric modes of a dynamic knee extension, as identified by the electrogoniometer tracing.