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Quantifying thigh muscle co-activation during isometric knee extension contractions: Within- and between-session reliability

Dimitrios Katsavelis, A. Joseph Threlkeld *

Department of Physical Therapy, Creighton University, Omaha, NE 68178, United States

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ABSTRACT

Muscle co-activation around the knee is important during ambulation and balance. The wide range of methodological approaches for the quantification of co-activation index (CI) makes comparisons across studies and populations difficult. The present study determined within- and between-session reliability of different methodological approaches for the quantification of the CI of the knee extensor and flexor muscles during maximum voluntary isometric contractions (MVICs). Eight healthy volunteers participated in two repeated testing sessions. A series of knee extension MVICs of the dominant leg with concomitant torque and electromyographic (EMG) recordings were captured. CI was calculated utilizing different analytical approaches. Intraclass correlation coefficient (ICC) showed that within-session measures displayed higher reliability (ICC > 0.861) and lower variability (Coefficient of variation; CV < 21.8%) than between-session measures (ICC < 0.645; CV > 24.2%). A selection of a 500 ms or larger window of RMS EMG activity around the PT delivered more reliable and less variable results than other approaches. Our findings suggest that the CI can provide a reliable measure for comparisons among conditions and is best utilized for within-session experimental designs.

1. Introduction

Co-activation is the simultaneous activation of agonist and antagonist muscle groups around a joint which contributes to joint stability, homogeneous load distribution (Baratta et al., 1988), control of bone displacements (Solomonow et al., 1987) and movement efficiency (Levine and Kabat, 1952). Co-activation of knee joint muscles has been extensively studied over the past two decades due to its importance during ambulation and balance (Baratta et al., 1988; Seyedali et al., 2012). Opposing muscle groups such as the quadriceps and the hamstrings function as synergists to provide stability and stiffness to the knee joint (Ait-Haddou et al., 2000). Selected joint pathologies, central or peripheral nervous system disorders can induce abnormal levels of co-activation (Busse et al., 2005). Inappropriate co-activation levels produce movement dysfunction, which in turn can lead to joint injury (Baratta et al., 1988; Busse et al., 2005; Macaluso and De Vito, 2004). Reliable and meaningful measures are needed that accurately assess co-activation levels by calculation of the co-activation index (CI). Such a CI will permit comparisons between studies and serve as an outcome measure for rehabilitation interventions.

There are a number of parameters that may affect the reliability and validity of the CI calculation. Parameters that are related to the data collection include the number of muscles or muscle segments sampled, pennation angle, the inclusion of monoarticular or multiarticular muscles, type of contraction, joint position, and electrode placement. Parameters that are related to data analysis include the selection of the time unit (window) and the smoothing approach applied to the electromyographic (EMG) signal, as well as the equation/method for the quantification of the CI. While most data collection parameters have inherent and inevitable limitations that affect comparison among studies, parameters that are related to data analysis can be controlled and standardized.

There are four commonly utilized methods for the quantification of the CI. The first two rudimentary methods were the semi-quantitative estimates of EMG magnitude (Frost et al., 1997) and the agonist-to-antagonist ratio of EMG activity utilizing millivolts of electrical activity (Damiano et al., 2000; Fung and Barbeau, 1989). The limitations of these two methods led to the adoption of more robust techniques that normalized the EMG amplitude for each of the agonist and antagonist muscle groups to the respective maximum voluntary contraction values (MVC; Ervilha et al., 2012; Knutson et al., 1994). The last and more recent method for the calculation of the CI quantified the antagonist moment using mathematical modeling of the EMG/joint torque relationship, but

* Corresponding author. Tel.: +1 402 280 5676; fax: +1 402 280 5692.
E-mail address: JoeThrelkeld@creighton.edu (A. Joseph Threlkeld).

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with controversial applicability due to changes in the slope attributable to evolution of the firing frequency and recruitment across the range of muscle activation (Merletti and Parker, 2004).

Normalization methods have been widely adopted but there are many inconsistencies with respect to window size and smoothing techniques utilized to estimate muscle activation. These inconsistencies reduce the comparability of calculated CIs between studies. Researchers have used peak EMG amplitude (Yang and Winter, 1984), average EMG (Kellis et al., 2011), integrated EMG (Kubo et al., 2004), root mean square (Hortobágyi et al., 2005) and envelope EMG (Frost et al., 1997) of various window sizes among other filtering and smoothing techniques. Besides the peak amplitude technique, which estimates muscle activation from a single value, the other techniques calculate an average value over a selected segment of data (window). Signal processing using RMS requires fewer steps in the data reduction process and minimizes signal distortion (Cram et al., 1998). The second important issue is the selection of the optimum window size. Utilizing a small window or even choosing a single value (e.g., peak amplitude) can be affected by artifacts or outliers. A larger EMG window that is temporally associated with the highest joint torque produced during the MVC may be more representative of the muscle's activation. On the contrary, an excessively large window size may distort estimates by including segments of submaximal muscle activation. It still remains unanswered which data smoothing method and window size can generate the most reliable and meaningful CI.

Replication of electrode placement can be a limiting factor in between-day reproducibility. Electrode placement on the belly of an agonistic muscle during MVC has produced very reliable between-day estimates of maximal muscle EMG (Larsson et al., 2003; McKenzie et al., 2010). However, when assessing co-activation, the antagonist muscle group undergoes a submaximal contraction. During submaximal contractions, a slight shift in electrode placement between sessions could capture different EMG activity or increase the variability of the signal (Van Dijk et al., 2009) due to changes in spatial summation of the signals.

Therefore, the purpose of the present study was to assess thigh muscle CI during isometric contractions by comparing the results from commonly employed signal processing techniques and to determine within- and between-session CI reliability. It was hypothesized that RMS EMG of a window size around the peak torque during a maximum voluntary isometric contraction would produce more reliable estimates of CI. Additionally, we hypothesized that within-session reliability would be higher than between-session values.

2. Methods

2.1. Informed consent

The study was approved by the Creighton University Institutional Review Board and conducted in accordance with the Declaration of Helsinki. All subject volunteers read, understood and signed the informed consent document prior to participation.

2.2. Subjects

Ten healthy young adults (5 males, 5 females; 27.5 ± 4 years, 174.6 ± 12 cm; 77.8 ± 12 kg) volunteered from a convenience sample of young, healthy university students that were enrolled in health sciences graduate curricula. None of the volunteers were currently participating in formal collegiate sports teams. To minimize practice/learning effects, subjects were required to have prior experience with an isokinetic dynamometer. Subjects were free of musculoskeletal and/or neurological problems that may have affected their ability to generate maximal knee flexion and extension torque in the dominant (preferred kicking) leg.

2.3. Torque recordings

Subjects were positioned and restrained on a Biodex System 3 isokinetic dynamometer per manufacturer recommendations for knee assessment (Biodex Medical Systems Inc., Shirley, NY, USA) with joint angles of 60° at both the hip and knee using zero-neutral measurements. The lateral epicondyle was aligned with the dynamometer's power shaft and the inferior edge of the ankle cuff was placed 2 cm above the lateral malleolus. The subject's arms were kept folded in front of his/her chest during testing. The Biodex raw torque signal was digitally sampled at 1 kHz and stored on a PC (Windows XP) running DataPac 2K2 (Run Technologies, Mission Viejo, CA, USA). The raw torque data were low pass filtered at 10 Hz, converted to Newton-meters and corrected for gravity offset.

2.4. EMG recordings

The skin over the vastus lateralis, rectus femoris, vastus medialis, lateral and medial hamstrings was shaved and wiped with alcohol on the dominant side. Pairs of surface EMG electrodes (BIOPAC Systems, Inc., Goleta, CA, USA) were attached over each muscle following the SENIAM guidelines maintaining a 2 cm center-to-center interelectrode spacing (Hermens et al., 2000). A ground electrode was placed on the ipsilateral lateral malleolus. Electrodes were attached by short, shielded wires to on-site preamplifiers. The differential amplifiers had a gain of 1000–2000, an input impedance of 100 kΩ, and a common mode rejection ratio of 100 dB (Motion Lab Systems MA-300™). EMG signals and the Biodex torque signal were digitally sampled at 1 kHz and stored on a PC using DataPac 2K2. Using a custom-written Matlab program (Matlab 2012b; Mathworks Inc., Natick, MA, USA), EMG signals were band-pass filtered (10–450 Hz), notch filtered at 60 Hz, corrected for zero offset, full-wave rectified and stored for further analysis.

2.5. Experimental design

After measuring and recording stature and body mass, each subject warmed-up by walking on a treadmill for 5 min at 5–6 km/h. Prior to testing, each subject was allowed to become accustomed to the dynamometer by performing brief submaximal and maximal contractions for both knee extension and flexion. Three to four familiarization contractions lasting 2–3 s were allowed in each direction. A computer monitor provided feedback of their performance by displaying the torque curve in real time while a horizontal line demarcated the subject's highest torque.

In the first session, each subject performed one knee flexion maximum voluntary isometric contraction (MVIC), rested for two minutes then four successive maximum knee extension MVICs. They were instructed to flex or extend the knee as hard as possible for 2–3 s. One minute of rest was allowed between each extension contraction. Upon successful completion of the first session, all subjects were retested with a minimum of 3 days between sessions.

2.6. Data processing

EMG activity was used to quantify CI during quadriceps MVIC. The CI was calculated using 7 different approaches that were based on (a) a single value (the peak amplitude of the raw EMG signal), (b) an interval around the peak torque [20 ms (RMS_{20PT}), 50 ms (RMS_{50PT}) and 500 ms (RMS_{500PT}); Fig. 1], and (c) throughout the entire period of extensor torque production [for the entire