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The influence of electromyographic recording methods and the innervation zone on the mean power frequency–torque relationships

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ABSTRACT

This study examined the effects of electromyographic (EMG) recording methods and innervation zone (IZ) on the mean power frequency (MPF)–torque relationships. Nine subjects performed isometric ramp muscle actions of the leg extensors from 5% to 100% of maximal voluntary contraction with an eight channel linear electrode array over the IZ of the vastus lateralis. The slopes were calculated from the log-transformed monopolar and bipolar EMG MPF–torque relationships for each channel and subject and 95% confidence intervals (CI) were constructed around the slopes for each relationship and the composite of the slopes. Twenty-two to 55% of the subjects exhibited 95% CIs that did not include a slope of zero for the monopolar EMG MPF–torque relationships while 25–75% of the subjects exhibited 95% CIs that did not include a slope of zero for the bipolar EMG MPF–torque relationships. The composite of the slopes from the EMG MPF–torque relationships were not significantly different from zero for any method or channel, however, the method and IZ location slightly influenced the number of significant slopes on a subject-by-subject basis. The log-transform model indicated that EMG MPF–torque patterns were nonlinear regardless of recording method or distance from the IZ.

1. Introduction

Despite surface electromyography's (EMG) broad applications, surface EMG is commonly used to examine motor control strategies, monitor muscle fatigue, assess neuromuscular alterations with aging, and track neurological diseases (De Luca, 1984; Merletti et al., 1990, 2002; Farina et al., 2003). Surface EMG has been characterized with slight increases, no changes, or decreases in the center frequency parameters across the force (or torque) spectrum (Moritani and Muro, 1987; Gerdle et al., 1990; Rainoldi et al., 1999; Coburn et al., 2005; Ryan et al., 2008). Typically, it is reported that modest increases in EMG center frequency values with increasing force reflects increasing average action potential conduction velocities of the active motor units (MU) (Karlsson and Gerdle, 2001; Ryan et al., 2008). Thus, a positive linear relationship would indicate a progressive recruitment of larger and faster conducting MUs (Broman et al., 1985; Andreassen and Arendt-Nielsen, 1987; Sadoyama et al., 1988; Vila-Cha et al., 2010, 2012), however, this relationship would be nonlinear with a plateau at higher forces if there were no additional MUs to recruit and force was increased by other mechanisms (i.e., firing rates). Linear increases in EMG center frequency have been observed, however, these changes in EMG center frequency would be best classified as modest (Karlsson and Gerdle, 2001; Bilodeau et al., 2003). More appropriate statistics, such as the log-transform model, has yet to be applied to EMG center frequency–force relationships to correctly characterize the linearity of the EMG

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center frequency force relationships (Herda et al., 2009, 2011). Nonetheless, it has been observed that the linearity of these relationships is influenced fatigue as a result of alterations in MU conduction velocities (Bilodeau et al., 2003).

Variability in these patterns may be influenced by anatomical factors, such as muscle fiber type composition, skinfold thickness, and the locations of the active motor units within the muscle. In addition, technical factors, such as amplitude cancelation by methods of differential amplification can reduce the amount of valuable information from the EMG signal (Keenan et al., 2005; Tucker and Turker, 2005). Previous studies (De Vries, 1966; de Vries, 1968) have recorded surface EMG using monopolar electrode configurations, which requires one recording electrode and one reference electrode. More recently and now most common, bipolar electrode configurations are used, which involves two recording electrodes and one reference electrode. A difference signal between the two recording electrodes with respect to the reference electrode is designated as the representative EMG signal. The primary advantages of the bipolar recording technique are the reductions of electromagnetic noise that can contaminate the EMG signal (Tucker and Turker, 2005) and smaller pick-up areas that may reduce the risk of cross-talk from adjacent muscles (van Vugt and van Dijk, 2001). However, bipolar EMG suffers from common mode rejection and substantial signal cancelation (Keenan et al., 2005). For example, Keenan et al. (2005) reported that signal cancelation resulted in a loss of up to 60% in the amplitude of the signal and could confound potential interpretations of surface EMG. In contrast, monopolar EMG has a greater pick-up area and represents the true electrical voltage emitted from muscle (De Vries, 1966), but may be more susceptible to electromagnetic noise.

The innervation zone (IZ) has been defined as the location where nerve terminations and muscle fibers are connected (Rainoldi et al., 2004). Action potentials propagate in opposite direction away from the motor end plates with the potentials extinguishing at the tendinous regions. Recently, much emphasis has been placed on the importance of electrode placement in reference to the location of the IZ (Beck et al., 2007a–c, 2008a–c, 2009; Defreitas et al., 2008). Previous studies have reported lower amplitudes and higher frequency values of the EMG signal when the bipolar configuration is placed over the IZ in comparison to electrodes positioned away from the IZ (Rainoldi et al., 2004; Tucker and Turker, 2005). To our knowledge, there have been no studies that have compared the monopolar and bipolar EMG center frequency–force/torque relationships in reference to the location of the IZ. Beck et al. (2007a–c) reported higher mean power frequency (MPF) values across the force spectrum for the monopolar than bipolar method, however, Beck et al. (2007a–c) did not monitor these patterns in relation to the IZ.

The linear electrode array has simplified and expanded the applications of surface EMG signals (Merletti et al., 1999, 2003). A linear array simultaneously records monopolar surface EMG signals from multiple electrodes positioned along a straight line with equal interelectrode distances. An advantage of the linear array is the ease of identifying the IZ when examining the signals in bipolar mode (Merletti et al., 2003; Beck et al., 2007a–c). Subsequently, the bipolar EMG channel that demonstrates minimum amplitude and phase reversal is identified as the IZ.

To date, no studies have examined the monopolar or bipolar EMG center frequency–torque relationships as a function of the IZ nor have these patterns been analyzed with an appropriate statistical model to correctly characterize the linearity of the relationships (log-transform model). This information is critical for a better understanding of the potential physiological meaning of such relationships, which have previously been reported to be influenced by fatigue. Therefore, the purpose of the present study was to examine the log-transform monopolar and bipolar EMG MPF–torque relationships at different locations relative to the IZ during an isometric ramp contraction of the vastus lateralis (VL).

2. Methods

2.1. Participants

Seven men (mean ± SD; age = 23 ± 2 year; mass = 82 ± 10 kg) and two women (age = 21 ± 1 year; mass = 62 ± 8 kg) volunteered for this investigation. None of them reported any current or ongoing neuromuscular disease or musculoskeletal injuries that involved the ankle, knee, or hip joints. This study was approved by the Institutional Review Board. All participants read and signed an informed consent form and completed a health history questionnaire. There are no previous studies that examined the log-transform EMG MPF–torque relationships to assess sample size, however, this model has distinguished channel-related differences in the EMG amplitude–torque relationships recorded with an 8-channel linear electrode array with 9 subjects (Herda et al., 2013).

2.2. Research design

Isometric testing of the dominant leg extensors were performed on a calibrated Cybex II dynamometer with knee and hip angles of 120° and 90°, respectively. Participants performed five warm-up 6-s isometric muscle actions at 50% of their MVC. Following the warm-up, two 6-s isometric MVCs of the leg extensors were performed. Strong verbal encouragement was provided during the MVC and 2-m rest was given between each isometric contraction. The highest torque output between the two trials was selected as the representative MVC value. After the MVC trials, each subject performed two to four 6-s isometric ramp muscle actions separated by 2-m rest. During the ramp muscle actions, participants were required to track their torque production on a computer monitor placed in front of them that displayed their real-time, digitized torque signal overlaid onto a programmed ramp template. The ramp template consisted of a 5-s horizontal baseline at 5% MVC, a 6-s linearly increasing ramp line from 5% to 100% MVC. Of the three attempts, the ramp trial that best satisfied the following criteria was used for analysis: (a) force reaching at least 90% of the MVC and (b) a tracking error less than 3% around the ramp template as visually inspected by an experienced investigator. The isometric ramp muscle action templates and real-time torque signal overlay was programmed using LabVIEW 8.5 software (National Instruments, Austin, TX).

2.3. Electromyography

Prior to the experimental session, participants were required to visit the laboratory to determine the location of the IZ and the pennation angle of the muscle fibers for the vastus lateralis (VL) muscle. Before electrode placement, the skin was shaved, carefully abraded, and cleaned with isopropyl alcohol. For the determination of the IZ and pennation angle, a probe of 16 silver bar electrodes (5 mm × 1 mm, 10 mm interelectrode distance [Ottino Bioelectronica, Torino, Italy]) was placed over the belly of the VL and oriented at a 20° angle (relative to the reference line between the anterior superior iliac spine and superior border of the patella) to approximate the muscle fiber pennation angle with the reference electrodes located around the participant's wrist (Abe et al., 2000). The participants were then asked to contract the right leg extensors at approximately 50% of their MVC, while the EMG signal from the probe was differentially amplified (gain × 2000), analog filtered (fourth-order Bessel, bandwidth = 10–500 Hz), and displayed on a computer screen. The location of the IZ for the VL was identified