Journal of Neuroscience Methods 184 (2009) 256–262

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

The effects of electrode orientation on electromyographic amplitude and mean power frequency during cycle ergometry

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ARTICLE INFO

Article history:
Received 28 July 2009
Accepted 13 August 2009

Keywords:
Parallel
Perpendicular
Pedaling exercise
Electromyography (EMG)
Vastus lateralis
SENIAM

ABSTRACT

The purposes of this study were threefold: (1) to compare the power output related patterns of absolute and normalized EMG amplitude and MPF responses for electrode orientations that were approximately parallel and perpendicular to the muscle fibers of the vastus lateralis muscle (VL); (2) to examine the influence of electrode orientation on mean absolute EMG amplitude and MPF values; and (3) to determine the effects of normalization on mean EMG amplitude and MPF values from parallel and perpendicular electrode orientations. Twenty adults (10 men and 10 women mean ± SD age = 23.4 ± 3.6 years) performed incremental cycle ergometry tests to exhaustion. Two sets of bipolar surface EMG electrodes were placed approximately parallel and perpendicular to the muscle fibers over the VL. Paired *t*-tests indicated that absolute EMG amplitude values for the parallel electrode orientation were greater ($p < 0.05$) at 50, 75, and 100 W. The normalized EMG amplitude also had greater values for the parallel electrode orientation at 75 and 100 W. For absolute EMG MPF, the parallel electrode orientation had greater values for all six power outputs, but after normalization, the perpendicular electrode orientation had a greater value at 75 W. Ten percent of the subjects exhibited different power output related patterns of responses between electrode orientations for EMG amplitude and 35% exhibited different patterns for MPF. These findings indicated that normalization reduced, but did not eliminate the influence of electrode orientation and highlighted the importance of standardizing electrode orientation to compare EMG values during cycle ergometry.

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1. Introduction

The amplitude and frequency contents of the surface electromyographic (EMG) signal have been used to examine various aspects of muscle function in laboratory and clinical settings. For example, the EMG signal has been used to provide information regarding the motor unit activation strategies of various muscles, as well as to identify central and peripheral aspects of fatigue (Beck et al., 2005; David et al., 2008; DeVries, 1968; Lawrence and De Luca, 1983). Furthermore, during cycle ergometry, the EMG signal has been used to quantify muscle fiber recruitment and describe the bilateral coordination of stroke patients with severe hemiparesis (Fujiwara et al., 2003; Kautz et al., 2006), evaluate muscle activation during rehabilitation in stroke patients (Brown and Kautz, 1998), and assess the effectiveness of a rehabilitation program to increase aerobic capacity in cardiac transplant patients (Lucia et al., 1997).

The surface EMG signal is a linear summation of the motor unit action potentials that activate skeletal muscle fibers (Basmajian and De Luca, 1985) and its amplitude and frequency contents can be affected by electrode placement (Beck et al., 2005; De Luca, 1997; Farina et al., 2004; Mercer et al., 2006; Rainoldi et al., 2004). Mercer et al. (2006) stated that there is great variability in the location for the placement of bipolar EMG electrodes and that this variability could be due to the determination of the location of the innervation zone, interelectrode distance, subject morphology, and/or experience of the person determining landmarks for placement of the electrodes. Furthermore, Farina et al. (2004) described a number of non-physiological factors (crosstalk, thickness of the skin, interelectrode distance, innervation zone, orientation of the recording electrodes, electrode size, and electrode shape) that can affect the surface EMG signal. Recently, Malek et al. (2006a,b) examined the effects of two of these non-physiological factors (interelectrode distance and innervation zone) on the absolute and normalized EMG amplitude and (mean power frequency) MPF versus power output relationships. These studies (Malek et

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doi:10.1016/j.jneumeth.2009.08.008

al., 2006a,b) indicated that interelectrode distance and placement of the bipolar EMG electrodes over the innervation zone affected absolute mean EMG amplitude and MPF values, as well as the slope coefficients and/or individual patterns for the EMG amplitude and MPF versus power output relationships. Normalization, however, eliminated the mean differences in absolute EMG amplitude and MPF responses due to interelectrode distance and the innervation zone.

To measure the action potentials from the same group of muscle fibers, the active bipolar surface EMG electrodes are oriented parallel to the muscle fiber pennation angle (Hermens et al., 2000). If the orientation is not parallel, the electrodes record action potentials from different groups of muscle fibers (Hermens et al., 2000) which can affect the absolute amplitude and MPF of the EMG signal. For example, it has been reported that for isometric muscle actions (Andreassen and Rosenfalck, 1978; Vigreux et al., 1979; Zedka et al., 1997), EMG amplitude and frequency values recorded using bipolar electrodes oriented parallel to the muscle fibers were greater than those for electrodes placed perpendicular to the muscle fibers. It may be possible, however, to reduce the influence of electrode orientation on time and frequency domain parameters of the EMG signal through normalization (Knutson et al., 1994; Soderberg and Knutson, 2000). Therefore, the purposes of this study were threefold: (1) to compare the power output related patterns of absolute and normalized EMG amplitude and MPF responses for electrode orientations that were approximately parallel and perpendicular to the muscle fibers of the vastus lateralis muscle (VL); (2) to examine the influence of electrode orientation on mean absolute EMG amplitude and MPF values; and (3) to determine the effects of normalization on mean EMG amplitude and MPF values from parallel and perpendicular electrode orientations. Based on the result of previous studies (Andreassen and Rosenfalck, 1978; Beck et al., 2005; Vigreux et al., 1979; Zedka et al., 1997; Zuniga et al., in press.), we hypothesized that: (1) there would be differences between the parallel and perpendicular electrode orientations for the power output related patterns of absolute and normalized EMG amplitude and MPF; (2) the parallel electrode orientation would result in greater mean absolute EMG amplitude and MPF values than the perpendicular orientation; and (3) normalization would eliminate differences between the parallel and perpendicular electrode orientations for the mean EMG amplitude and MPF values.

2. Methods

2.1. Subjects

Twenty adults [ten men (mean ± SD age = 24.7 ± 3.4 years) and ten women (mean ± SD age = 22.1 ± 3.4 years)] volunteered to participate in the investigation. The study was approved by the University Institutional Review Board for Human Subjects and all the subjects completed a health history questionnaire and signed an informed consent document before testing.

2.2. Maximal cycle ergometer test

Following an orientation session and familiarization with the protocol each subject performed an incremental test to exhaustion on a Calibrated Quinton (Corval 400) electronically braked cycle ergometer at a pedal cadence of 70 rev min^{-1}. The seat was adjusted so that the subject's legs were at near full extension during each pedal revolution. The subject was fitted with a nose clip and breathed through a one-way valve (2700; Hans Rudolph, Kansas City, MO). Expired gas samples were collected and analyzed (8-breath rolling averages) using a calibrated TrueMax 2400 metabolic measurement system (Parvo Medics, Sandy, UT). Heart rate was monitored with a Polar Heart Watch system (Polar Electro Inc., Lake Success, NY). After a period of stabilization at rest, the subjects began pedaling at 50 W for 2 min. The power output was then increased by 25 W every 2 min throughout the test. $\dot{V}O_{2\ peak}$ was defined as the highest $\dot{V}O_2$ value in the last 30 s of the test if the subject met at least two of the following three criteria (Day et al., 2003): (a) 90% of age-predicted maximum heart rate (220-age), (b) respiratory exchange ratio > 1.20, and (c) a plateau of oxygen uptake ($\leq$150 ml min^{-1} in $\dot{V}O_2$ over the last 30 s of the test). At the completion of the test, the subjects were allowed to cool-down for as long as they liked.

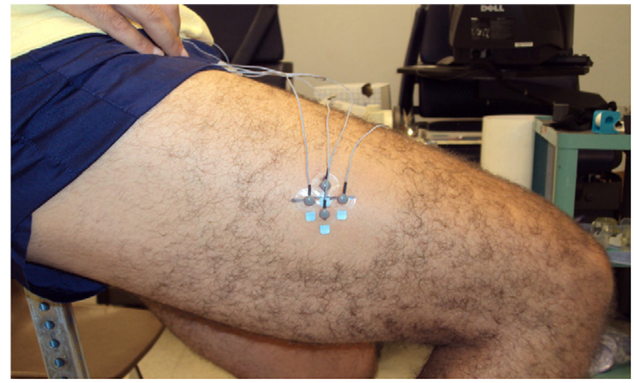

Fig. 1. Example of the bipolar EMG electrode placements for the parallel and perpendicular orientations.

2.3. EMG measurement

Two separate bipolar surface EMG electrode (circular 4 mm diameter, silver/silver chloride, Biopac Systems, Inc., Santa Barbara, CA) orientations (20 mm interelectrode distances) were placed on the VL of the right leg. The electrodes were oriented approximately parallel and perpendicular to the muscle fibers of the VL (Fig. 1). The parallel electrode configuration was placed in accordance with the recommendations from the SENIAM Project (Hermens et al., 1999). Specifically, a reference line was drawn from the lateral border of the patella and the anterior superior iliac crest. The active electrodes were placed approximately 5 cm lateral from one-third of the distance of the reference line from the lateral border of the patella. A standard goniometer (Smith & Nephew Rolyan, Inc., Menomonee Falls, WI) was used to orient the electrodes at a 20° angle to the reference line to approximate the pennation angle of the VL (Abe et al., 2000; Fukunaga et al., 1997; Lieber and Friden, 2000). The active electrodes for the perpendicular orientation were placed at 90° to the parallel electrodes (Fig. 1). The reference electrodes were placed over the iliac crest. The shaved skin at each electrode site was carefully abraded and cleaned with alcohol, and the impedance was less than 2000 Ω. The EMG signal from each electrode orientation was amplified (gain: ×1000) using differential amplifiers (EMG 100, Biopac Systems, Inc., Santa Barbara, CA, bandwidth 1.0–500 Hz).

2.4. Signal processing

The raw EMG signals were digitized at 1000 Hz and stored in a personal computer for subsequent analysis. All signals processing was performed using a custom program written with LabVIEW programming software (version 7.1, National Instruments, Austin, TX). The EMG signals were bandpass filtered (fourth-order Butterworth) at 10–500 Hz, and the amplitude (microvolts root mean square, μVrms) and MPF (in Hz) values were calculated for each power

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