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The effects of interelectrode distance on electromyographic amplitude and mean power frequency during incremental cycle ergometry

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Abstract

The purpose of this study was to examine the effects of interelectrode distance (IED) on the relationships of absolute and normalized EMG amplitude and mean power frequency (MPF) versus power output during incremental cycle ergometry. Eleven adults (mean ± S.D. age = 24.2 ± 2.6 y; $\dot{V}_{O_2\,max}$ = 49.4 ± 8.3 ml kg^{-1} min^{-1}) performed incremental cycle ergometry tests. Surface EMG signals were recorded simultaneously from bipolar electrode arrangements placed over the VL muscle with IEDs of 20, 40, and 60 mm. Polynomial regression analyses were used to describe the relationships for absolute and normalized EMG amplitude (μV_{rms} and %max) and MPF (Hz and %max) versus power output (%max) for each subject at the three IEDs. In addition, separate one-way repeated measures ANOVAs were used to examine mean differences between the three IEDs for absolute and normalized EMG amplitude and MPF at power outputs of 80, 110, 140, and 170 W. The results of the polynomial regression revealed that the best fit model for each IED for the absolute and normalized EMG amplitude was linear for six of the 11 subjects and quadratic for five of the subjects. For EMG MPF, four of the 11 subjects exhibited significant relationships (linear or quadratic) across power outputs for at least one IED. The one-way repeated measures ANOVAs revealed significant mean differences between the IEDs for absolute EMG amplitude and MPF at 80, 110, 140, and 170 W. There were no significant mean differences, however, between the IEDs for normalized EMG amplitude or MPF at 80, 110, 140, and 170 W. The results of the study indicated that there were no consistent patterns of responses between individual subjects for EMG amplitude or MPF versus power output relationships for IEDs of 20, 40, and 60 mm during incremental cycle ergometry. The current findings supported the process of normalization for EMG amplitude and MPF data obtained during cycle ergometry when comparisons are made for different IEDs.

Keywords: Aerobic fitness; Electrode arrangement; EMG signal; Fatigue; Motor unit recruitment; Neuromuscular response; SENIAM

1. Introduction

Surface electromyography (EMG) is often used to study muscle function during isometric and dynamic muscle actions, as well as cycle ergometry (Basmajian and De Luca, 1985; Beck et al., 2004a,b; Perry et al., 2001c). For example, the time and/or frequency domains of the surface EMG signal have been used to examine central and peripheral aspects of neuromuscular fatigue, as well as the motor unit activation strategies that modulate torque (or force) production and power output in various muscles under a variety of conditions (Beck et al., 2004a,b; Cramer et al., 2002a,b; Ebersole et al., 1999; Evetovich et al., 2000; Perry et al., 2001a,b,c; Petrofsky, 1979). The amplitude of the EMG signal reflects muscle activation including both motor unit recruitment and firing rate, whereas during isometric muscle actions, the frequency content of the signal is associated with muscle fiber action potential conduction velocity (Basmajian and De Luca, 1985).

Surface EMG has been used during cycle ergometry to develop tests for identifying the power output associated with

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the onset of fatigue for the superficial muscles of the quadriceps femoris (deVries et al., 1982, 1987, 1990; Evetovich et al., 1996; Housh et al., 1996), examine the physiological mechanisms underlying neuromuscular fatigue (Housh et al., 1990, 1991), quantify the effects of endurance training in the elderly (deVries et al., 1989), describe muscle activation patterns during submaximal (Bull et al., 2000; Housh et al., 2000) and supramaximal (Hunter et al., 2003; Vandewalle et al., 1991) workbouts, and examine the relationship between the "iEMG threshold" and the "aerobic-anaerobic transition" in elite cyclists (Lucia et al., 1999) and cardiac transplant patients (Lucia et al., 1997). In addition, recent studies have examined the relationship between muscle activation patterns and the slow component of oxygen uptake kinetics during constant power output exercise for the moderate, heavy, and severe exercise domains (Jones and Poole, 2004; Lucia et al., 2000; Scheuermann et al., 2001; Shinohara and Moritani, 1992).

Although surface EMG is commonly used in clinical, laboratory, and applied settings (Basmajian and De Luca, 1985; Moritani et al., 2005), there is ongoing debate concerning the most appropriate procedures for signal acquisition and processing (Hermens et al., 2000). Recently, the SENIAM project (Hermens et al., 1999, 2000) has made recommendations regarding the recording of surface EMG including: (1) the shape and size of electrodes to be used, (2) skin preparation, (3) the location and orientation of the sensors on the muscle(s), and (4) processing of the EMG signal. One specific issue addressed by the SENIAM project (Hermens et al., 1999, 2000) was the selection of interelectrode distance (IED). In this regard, Hermens et al. (2000) stated "the effect of the inter-electrode distance (IED) on SEMG signal characteristics is regarded as one of the most relevant property of the SEMG senor" (p. 364). The SENIAM (Hermens et al., 1999) recommendation for IED for large muscles of the extremities such as the quadriceps femoris is 20 mm. However, a recent survey (Hermens et al., 2000) of 144 peer-reviewed papers on surface EMG indicated that while 20 mm was the most commonly used IED, "A high variability and a wide range of values of IEDs were found" (p. 364). The degree to which IED affects the amplitude and frequency domains of the surface EMG signal (Hermens et al., 1999) may have implications for the interpretation of studies related to muscle function, as well as comparisons of the results of studies that have utilized different IEDs. Furthermore, it has been suggested that IED can affect the amount of recorded cross-talk from adjacent muscles, as well as the contributions of superficial versus deep motor units to the surface EMG signal (Basmajian and De Luca, 1985; Fuglevand et al., 1992). A recent study by Beck et al. (2005), however, indicated that IED (20, 40, and 60 mm IEDs) had no effect on the patterns of the absolute and normalized EMG amplitude or MPF versus torque relationships during isometric or isokinetic muscle actions. No previous studies have examined the effects of IED on time and frequency domain parameters of the EMG signal during cycle ergometry. Therefore, the purpose of this study was to examine the effects of interelectrode distance (IED) on the relationships for absolute and normalized EMG amplitude and MPF versus power output during incremental cycle ergometry. Based on the findings of Beck et al. (2005) for isometric and isokinetic muscle actions, we hypothesized that IED would not affect the patterns of responses for the absolute and normalized EMG amplitude and MPF versus power output relationships during incremental cycle ergometry.

2. Methods

2.1. Subjects

Eleven adults (mean ± S.D. age = 24.2 ± 2.6 y; $\dot{V}_{O_2\,max}$ = 49.4 ± 8.3 ml kg^{-1} min^{-1}) volunteered as subjects for this investigation. All procedures were approved by the University Institutional Review Board for Human Subjects and each subject signed an informed consent prior to any testing.

2.2. Maximal cycle ergometer test

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}. Seat height was adjusted so that the subject's legs were at near full extension during each pedal revolution. The subjects wore a nose clip and breathed through a one-way valve (2700; Hans Rudolph, Kansas City, MO). Expired gas samples were collected and analyzed (eight-breath rolling averages) using a calibrated TrueMax 2400 metabolic measurement system (Parvo Medics, Sandy, UT). The subjects were also fitted with a Polar Heart Watch system (Polar Electro Inc., Lake Success, NY) to monitor heart rate throughout the test. Following a 5 min warm-up at 50 W, the power output was increased 30 W every 2 min until voluntary exhaustion. The durations for the exercise tests were between 8 and 12 min as suggested by Buchfuhrer et al. (1983). $\dot{V}_{O_2\,max}$ was defined as the highest $\dot{V}_{O_2\,max}$ value in the last 30 s of the test if the subject met two of the following three criteria test (ATS/ACCP, 2003; Baumgartner and Jackson, 2003; Day et al., 2003): (a) 90% of age-predicted heart rate (220 age), (b) respiratory exchange ratio >1.20, and (c) plateauing of oxygen uptake (≤150 ml min^{-1} in $\dot{V}_{O_2\,max}$ over the last 30 s of the test).

2.3. EMG measurement

Three separate bipolar (20, 40, and 60 mm center-to-center) surface electrode (circular 4 mm diameter silver/silver chloride; Biopac Systems Inc., Santa Barabara, CA) arrangements were placed on the dominant leg (based on kicking preference) over the vastus lateralis (VL) muscle (Fig. 1). The 20 mm IED electrodes were placed on the VL midway between the greater trochanter and the lateral condyle of the femur (Perry et al., 2001b,c). For the 40 mm IED placement, one of the active electrodes was then placed proximal and the