Journal of Neuroscience Methods 181 (2009) 45–51

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

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

A new EMG frequency-based fatigue threshold test

C. Russell Hendrix*, Terry J. Housh, Glen O. Johnson, Michelle Mielke, Clayton L. Camic, Jorge M. Zuniga, Richard J. Schmidt

Department of Nutrition and Health Sciences, Human Performance Laboratory, University of Nebraska–Lincoln, Lincoln, NE 68583-0806, United States

ARTICLE INFO

Article history:
Received 1 April 2009
Received in revised form 13 April 2009
Accepted 15 April 2009

Keywords:
Electromyographic mean power frequency (EMG MPF)
EMG MPF fatigue threshold (EMG MPF_{FT})
Critical torque (CT)
Discrete Fourier transform (DFT)

ABSTRACT

Theoretically, the critical torque (CT) and electromyographic mean power frequency fatigue threshold (EMG MPF_{FT}) describe the maximal non-fatiguing isometric torque level.

Purpose: The purposes of this study were two-fold: (1) to determine if the mathematical model for estimating the EMG fatigue threshold (EMG_{FT}) from the amplitude of the EMG signal was applicable to the frequency domain of the EMG signal to estimate a new fatigue threshold called the EMG MPF_{FT}; and (2) to compare the torque level derived from the CT test to that of the EMG MPF_{FT} test for the vastus lateralis (VL) muscle during isometric muscle actions of the leg extensors.

Methods: Nine adults (4 men and 5 women; mean ± SD age = 21.6 ± 1.2 yr) performed three or four continuous, fatiguing, isometric muscle actions of the leg extensors at 30, 45, 60, and 75% of maximum voluntary isometric contraction (MVIC) to determine the time to exhaustion (T_{lim}) values. The slope coefficient of the linear relationship between total isometric "work" (W_{lim} in N m s = Torque × T_{lim}) and T_{lim} was defined as the CT. Surface EMG signals were recorded from the vastus lateralis (VL) muscle during each fatiguing isometric muscle action. The EMG MPF_{FT} was defined as the *y*-intercept of the isometric torque versus slope coefficient (EMG MPF versus time) plot.

Results: There were no significant differences between CT (19.7 ± 5.8%MVIC) and EMG MPF_{FT} (21.4 ± 8.7%MVIC).

Conclusion: These findings provided indirect validation of the EMG MPF_{FT} test.

1. Introduction

Theoretically, the critical torque (CT) and electromyographic fatigue threshold (EMG_{FT}) tests demarcate fatiguing from non-fatiguing isometric torque levels. These tests, however, utilize different methodologies (the EMG_{FT} test measures neuromuscular activity, while the CT test describes the torque versus duration relationship) and recent studies (Hendrix et al., 2009a,b) have reported that during isometric muscle actions, the CT was less than EMG_{FT} for the forearm flexors (6.6 ± 3.2 and 10.9 ± 4.7 N m, respectively) and leg extensors (CT = 25.9 ± 12.1 N m; EMG_{FT} of the rectus femoris muscle = 41.1 ± 20.7 N m). Thus, the torque level associated with the onset of fatigue is dependent upon which fatigue threshold is identified and the muscles involved.

The CT test for isometric muscle actions is an adaptation of the original critical force test of Monod and Scherrer (1965), and involves a series of fatiguing, isometric muscle actions (three or four) at different torque levels that are maintained continuously for as long as possible. The CT test utilizes an isometric analogue of mechanical work called the limit work (W_{lim}) and is calculated as the torque of the isometric muscle action multiplied by the time to exhaustion (or limit time, T_{lim}) that the torque can be maintained (Monod and Scherrer, 1965). That is,

$$W_{lim} = \text{torque} \times T_{lim} \quad (1)$$

where W_{lim} is the total amount of "isometric work" that can be accomplished at a specific level of torque and T_{lim} is the time to exhaustion at the specific torque. The W_{lim} is then calculated for each torque and plotted as a function of the T_{lim} values for the muscle actions (Fig. 1). The linear relationship between W_{lim} and T_{lim}

$$W_{lim} = \text{AWC} + \text{CT}(T_{lim}) \quad (2)$$

is then used to estimate the CT (slope coefficient of the W_{lim} versus T_{lim} relationship). The anaerobic work capacity (AWC) is defined as the total "isometric work" that can be performed utilizing only energy reserves within the muscle such as ATP (adenosine triphosphate), phosphocreatine, glycogen, and the oxygen bound to myoglobin (Bulbulian et al., 1996; Monod and Scherrer, 1965; Moritani et al., 1981).

* Corresponding author at: Department of Nutrition and Health Sciences, 110 Ruth Leverton Hall, University of Nebraska-Lincoln, Lincoln, NE 68583-0806, United States. Tel.: +1 402 472 2690; fax: +1 402 472 0522.
E-mail address: rhendri7@unlserve.unl.edu (C.R. Hendrix).

0165-0270/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.jneumeth.2009.04.011

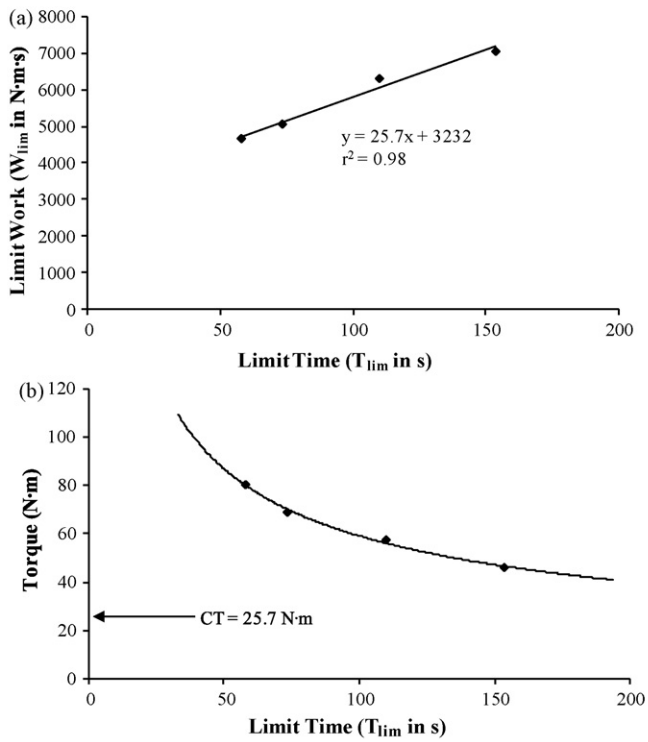

Fig. 1. Method for estimating the critical torque (CT) from data for subject 3. (a) The slope coefficient of the W_{lim} versus T_{lim} relationship is the CT (25.7 N m) which also represents the asymptote of the torque versus T_{lim} relationship (b).

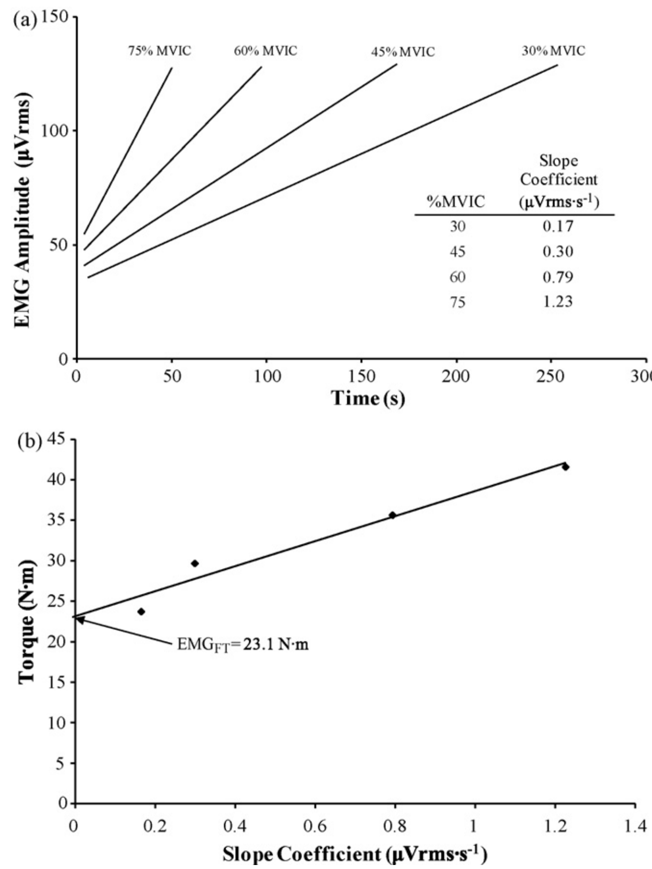

Fig. 2. Theoretical model for estimating the EMG_{FT} from isometric data. (a) The EMG amplitude (μVrms) data were plotted as a function of time (s) for the four continuous, fatiguing isometric workbouts at 30, 45, 60, and 75%MVIC. (b) The slope coefficients from (a) were plotted versus torque for each of the four percentages of MVIC and the EMG_{FT} was estimated as the *y*-intercept (slope coefficient of zero) value (23.1 N m).

The EMG_{FT} test for isometric muscle actions (Hendrix et al., 2009a,b) is an adaptation of the original EMG_{FT} test for cycle ergometry (deVries et al., 1982) and involves the determination of the rate of rise in EMG amplitude as a function of time (slope coefficient) at three or four fatiguing torque levels (Fig. 2a). The torque levels are then plotted as a function of their corresponding slope coefficients for the EMG amplitude versus time relationships and the EMG_{FT} is defined as the *y*-intercept (Fig. 2b) (deVries et al., 1982). Therefore, the EMG_{FT} test (deVries et al., 1982) estimates the highest level of isometric torque that can be sustained without neuromuscular evidence of fatigue (i.e., a slope coefficient for the EMG amplitude versus time relationship of zero) (Matsumoto et al., 1991; Moritani et al., 1993).

Previous studies (Hagberg, 1981a,b; Mannion et al., 1997; Petrofsky and Lind, 1975; Roy et al., 1997; Sparto et al., 1997) have reported that the EMG mean power frequency (MPF) decreases as a function of time during fatiguing, continuous, isometric muscle actions. Furthermore, the rate of decrease (negative slope coefficient) for the EMG MPF versus time relationship is inversely proportional to the torque level (Basmajian and DeLuca, 1985). Thus, the mathematical model that has previously been used to determine EMG_{FT} (deVries et al., 1982) may be applicable to EMG MPF responses. Therefore, the purposes of this study were twofold: (1) to determine if the mathematical model for estimating the EMG_{FT} from the amplitude of the EMG signal was applicable to the frequency domain of the EMG signal to estimate a new fatigue threshold called the electromyographic mean power frequency fatigue threshold (EMG MPF_{FT}); and (2) to compare the torque level derived from the CT test to that of the EMG MPF_{FT} test for the vastus lateralis (VL) muscle during isometric muscle actions of the leg extensors. On the basis of previous studies (Hagberg, 1981a,b; Hendrix et al., 2009a,b; Mannion et al., 1997; Petrofsky and Lind, 1975; Roy et al., 1997; Sparto et al., 1997), it was hypothesized that: (1) the mathematical model used for the determination of EMG_{FT} (deVries et al., 1982) would be applicable to EMG MPF responses to estimate the EMG MPF_{FT}; and (2) the torque level associated with the EMG MPF_{FT} would be significantly greater than that of the CT.

2. Methods

2.1. Subjects

Nine adults (4 men and 5 women, mean ± SD; age = 21.6 ± 1.2 yr; height = 169.3 ± 15.3 cm; weight = 67.9 ± 19.2 kg) volunteered for this study. The CT data from eight of these subjects were included in a previous study (Hendrix et al., 2009a) that compared the fatigue-related neuromuscular responses of the vastus lateralis, vastus medialis, and rectus femoris muscles. None of the subjects were competitive athletes, but they participated regularly in walking (n = 1), bicycling (n = 2), jogging or running (n = 8), weight training (n = 3), and/or various sports (n = 1: basketball or boxing). All procedures were approved by the University Institutional Review Board for human subjects, and each subject completed a health history questionnaire and gave their written informed consent to participate prior to testing. The subjects visited the laboratory on five occasions. The first visit served as an orientation to familiarize the subject with the testing protocols and equipment used during the study. During the second visit, maximum voluntary isometric contraction (MVIC) was determined and one continuous, fatiguing muscle action was performed to determine the T_{lim} at a randomly ordered percentage of MVIC (approximately 30%, 45%, 60%, or 75%). These %MVIC values were selected to be consistent with those