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ELECTROMYOGRAPHIC CHARACTERISTICS OF THE QUADRICEPS FEMORIS DURING PERFORMANCE OF THE WINGATE TEST

ELEKTROMIOGRAFSKE ZNAČILNOSTI MIŠICE QUADRICEPS FEMORIS MED IZVAJANJEM TESTA WİNGATE

ABSTRACT

The purpose of this study was to investigate the relationship between the Wingate Anaerobic Test (WAT) outputs and the Electromyography (EMG) parameters.
Seventeen sedentary college males participated in the study (mean ± SD, age 20. 5 ± 2. 4 y; height 174.2 ± 4.3 cm; body mass 66. 2 ± 7. 6 kg). Surface electromyographic signals of vastus medialis, vastus lateralis and rektus femoris were recorded during WAT. Power, normalized power, cadence, Mean power frequency (MPF) of each muscle and Root Mean Square (RMS)EMG were calculated as 5 s averages. Mean differences in power and cadence, mean EMG frequency and RMS EMG were analyzed by repeated measures one way ANOVA with Bonferroni post hoc adjustment for multiple pairwise comparisons. Pearson's correlation coefficient was used to evaluate the relationship between the WAT performance variables and muscle EMG outputs All data are presented as mean ± SD.
The peak power and cadence decreased significantly ($p<0.01$). Mean power frequency of all muscles decreased significantly ($p<0.01$) but REMG did not change during the test duration($p>0.01$). There was a correlation between peak power, normalized power, cadence and MPF of the quadriceps muscles also.
The results suggest that there was a correlation between mean power frequencies of vastus medialis, vastus lateralis, rectus femoris and WAT performance. The decreases of the peak power and cadence should be related to the decreases of the mean frequencies of the quadriceps muscles.

Keywords: Wingate Anaerobic Test, Mean Power Frequencies, EMG

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IZVLEČEK

Namen te raziskave je bil preučiti odnos med rezultati anaerobnega testa Wingate (WAT) in parametri elektromiografije (EMG).
V raziskavi je sodelovalo 17 študentov moškega spola, ki veliko časa preživijo sede (srednja vrednost ± SD; starost 20,5 ± 2,4 leta; višina 174,2 ± 4,3 cm; telesna masa 66,2 ± 7,6 kg). Med izvajanjem WAT so bili posneti površinski elektromiografski signali mišic vastus medialis, vastus lateralis in rectus femoris. Moč, normalizirana moč, kadenca, srednja močnostna frekvenca (MPF) vsake mišice in srednja kvadratna vrednost (RMS) EMG so bile izračunane kot 5-sekundna povprečja. Srednje razlike v moči in kadenci, srednjo EMG frekvenco in RMS EMG smo analizirali z enosmerno ANOVA s ponovljenimi meritvami, s prilagoditvijo Bonferronijevega post hoc testa za večkratno ugotavljanje razlik med pari. S Pearsonovim korelacijskim koeficientom smo ocenili odnos med spremenljivkami uspešnosti testa WAT in rezultati EMG mišic. Vsi podatki so predstavljeni kot srednje vrednosti ± SD.
Najvišja moč in kadenca sta se značilno znižali ($p < 0,01$). Srednja frekvenca močnostnega spektra pri vseh mišicah se je značilno znižala ($p < 0,01$), vendar se med trajanjem testa REMG ni spremenila ($p > 0,01$). Med najvišjo močjo, normalizirano močjo, kadenco in MPF mišic quadriceps je bila ugotovljena korelacija.
Rezultati so pokazali korelacijo med srednjo frekvenco močnostnega spektra pri mišicah vastus medialis, vastus lateralis in rectus femoris ter uspešnostjo testa WAT. Znižanje najvišje moči in kadence bi morali povezovati z znižanjem srednjih frekvenc mišic quadriceps.

Ključne besede: anaerobni test Wingate, srednje močnostne frekvence, EMG

INTRODUCTION

The Wingate anaerobic test (WAT) is widely used for evaluating anaerobic capacity (Bernardi, Solomonow, & Baratta 1997). Generally, subjects cycle all out during 30 sec duration. Maximal power is recorded in initial seconds, then the power and cadence decrease. An increase in lactate levels and a decrease in pH at intramuscular level after WAT are reported (Hussian, Smith, Medbak, Wood, & Whipp, 1996). Increased H^+ may interfere with the excitation-contraction coupling process of skeletal muscle, which in turn may lead to a decrease in power output and fatigue (Chin & Allen, 1998; Smith et al., 2007).

Muscle fatigue is commonly defined as the fall of force or power producing capacity (Kent-Braun, Fitts, & Christie, 2012). There has been an interest in determining the contribution of central or peripheral factors that lead to fatigue (Ayalon, Inbar &Bar-Or, 1974). Factors proximal and distal neuro-muscular junction are classified as central and peripheral fatigue respectively. Surface electromyography (EMG) has been shown to be an acceptable method for non-invasive assessment of neuromuscular fatigue (Hug, Laplaud, Savin& Grelot, 2003; Lucia, Sanchez, Carvajal & Chicharro, 1999).

The EMG signals include details about the neural drive of the muscle and muscle fibers' electrical characteristics (Farina, Merletti, &Enoka, 2014). Frequencies and amplitude estimation are performed generally for evaluation of the neuromuscular changes during fatigue. At frequency analyses, mean or median frequency of each muscle is calculated. For consideration of the EMG signal amplitude, Root Mean Square (RMS) assessing is generally used (Millet & Lepers, 2004). EMG is a result of the summation of several separate motor unit action potentials in muscles. It depends on numerous factors such as the rate of stimulation of the muscle, the size of motor unit recruited, morphology of the motor units and the presence of any synchronization of the activity of different motor units (Singh, Kumar, Polus, & Fraser, 2007). During fatiguing contraction, it has been established that conduction velocity and mean or median frequency are correlated (Arendt-Nielsen& Mills, 1985). An increase in EMG activity has been reported to be reflecting the recruitment of the additional motor unit and an increase in the motor unit rate coding to compensate for the deficit in contractility that results from impairment of fatigued motor units (Enoka & Stuart, 1992).

There are limited studies about EMG measurements during WAT. These studies have investigated decreases (Hunter, Gibson, Lambert, Nobbs, & Noakes, 2003) on mean power frequency (MPF) and decreases (Vandewalle, Maton, Bozec, & Guerenbourg, 1991) or no-changes (Hunter et al., 2003) on EMG amplitude. To our knowledge, there is not any study that focuses on any correlation between WAT performance and EMG parameters. The purpose of this study was to investigate the relationship between the WAT outputs and the EMG parameters.

METHODS

Participants

Seventeen sedentary, male university students (age 20. 5 ± 2. 4 years; height 174.2 ± 4.3 cm; body mass 66. 2 ± 7. 6 kg; mean ± SD), with no history of muscle or joint injury, voluntarily participated in the study. The study was approved by the local Ethics committee and all volunteers were informed before the experiment. None of them was taking drugs, medications or supplements with potential effects on physical performance.

Wingate Anaerobic Test

All participants warmed-up on the cycle ergometer, at a power output 60 W, 60 rpm, for 5 min. The WAT was performed on a Peak Bike Ergometric 894E (Monark Exercise, Sweden). The power parameters and pedal rate were recorded through an interface between the cycle ergometer and computer. The basket on the cycle ergometer was loaded with a resistance equal to 7.5% of the subject's body mass. The subject pedaled the unloaded flywheel up to a maximal rate at that time the resistance was dropped by movement of the handle by the investigator and the computer automatically started the 30-second countdown at that instant, as well as beginning the calculation of the power (W) during the test. The subjects were encouraged to cycle at their maximal attainable pedaling frequency throughout the test and with the completion of the 30-second, the resistance was lifted by the investigator.

Surface EMG

Surface EMG activity during WAT was measured simultaneously by using an 8-channel Musle Tester ME3000P8 (Mega Electronics, Finland). Three of the eight channels were used in the test. Surface EMG was obtained from right (dominant in all cases) vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) muscles by using bipolar surface electrodes (Mega Electronics Ltd., Finland). Electrode placement was applied according to Seniam guidelines (Hermens, Freriks, Disselhorst- Klug, & Rau, 2000). Before placement of the electrodes, the site was shaved, abraded with sandpaper and cleaned with ethanol. In order to secure electrodes in place and minimize artifact during cycling, elastic bandages were wrapped around the subject's leg.

The EMG signal was recorded which sampled at 1000 Hz, bandpass filtered between 8 and 500 Hz, amplified (analogue differential amplifier, common mode rejection ratio > 110 dB, total gain 412, noise < 1.6 μV), analogue-to-digital converted (12-bit) and stored in a personal computer for later analysis. The impedance between the electrodes was about 2 MΩ.

The raw signal was amplified, filtered (high pass,20; low pass, 500 Hz) and digitized (sampling rate 1 KHz). Fourier transform was obtained by applying recursively (over 1 sec time-windowed signal) a 1024- point FFT (Fast Fourier Transform) with rectangular processing window algorithm, available at MatLab v.7 (Costa et al., 2010). Due to our purpose of figuring out EMG signal changes during WAT, we did not use any biomechanical data of pedal or crank angels.

In the final analysis, all WAT and EMG data were averaged over 5-second segment (0-5 seconds, 5-10 seconds, 10-15 seconds, 15-20 seconds, 20-25 seconds, 25-30 seconds) (Hunter et al., 2003). RMS EMG data was normalized by expressing as a percent of the initial maximal value (first 5 s).

Statistical Analyses

Mean differences in power, cadence, mean EMG frequency and relative RMS EMG were analyzed by repeated measures one way ANOVA with Bonferroni post hoc adjustment for multiple pair wise comparisons. Pearson's correlation coefficient was used to evaluate the relationship between the WAT performance variables and muscle EMG outputs. All data are presented as mean ± SD. Significance was accepted at $p<0.01$.

RESULTS

Power (F=113,38), normalized power (F= 134,86) and pedal cadence (F=354,67) displayed a significant decline (p<0.01). The peak power and cadence decreased from peak values to the end of the test by 44.7 ± 10.3%, 56.4± 7.7%, respectively (figure 1).

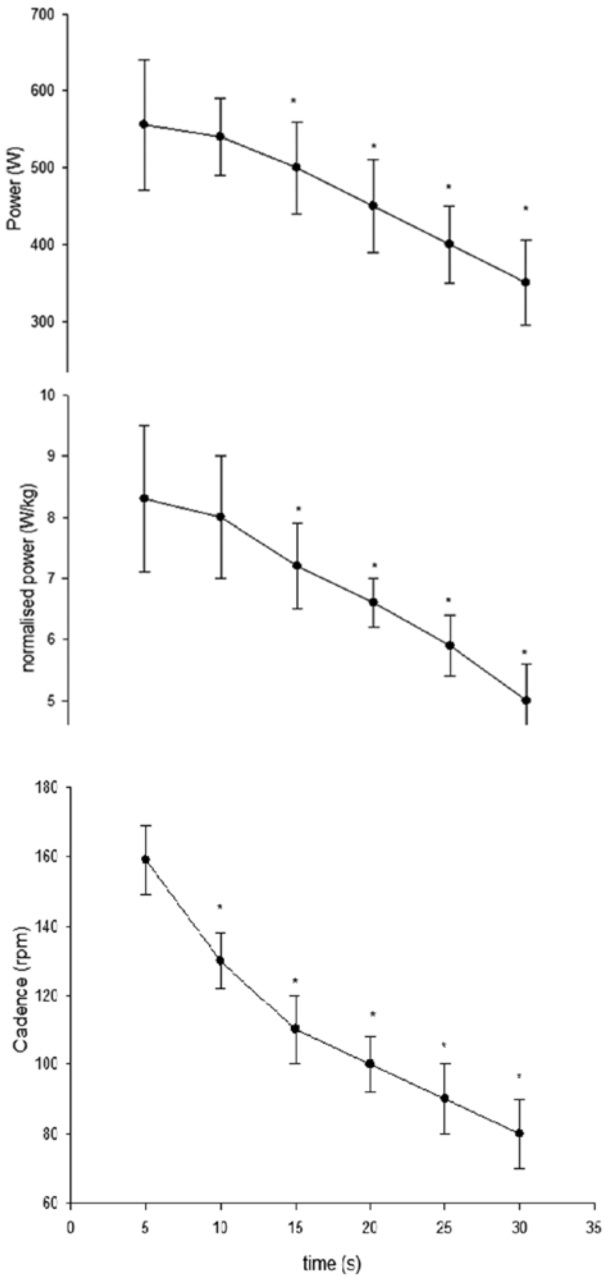

Figure 1

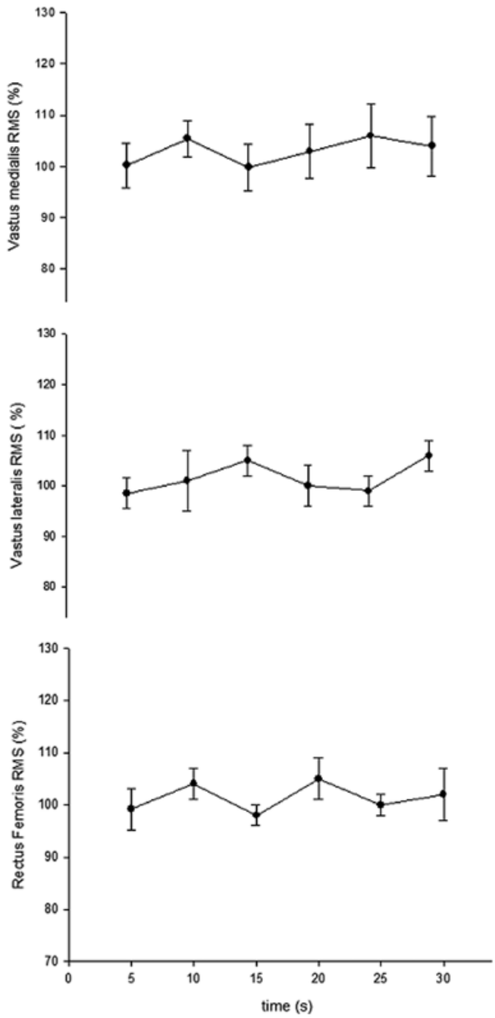

Figure 2

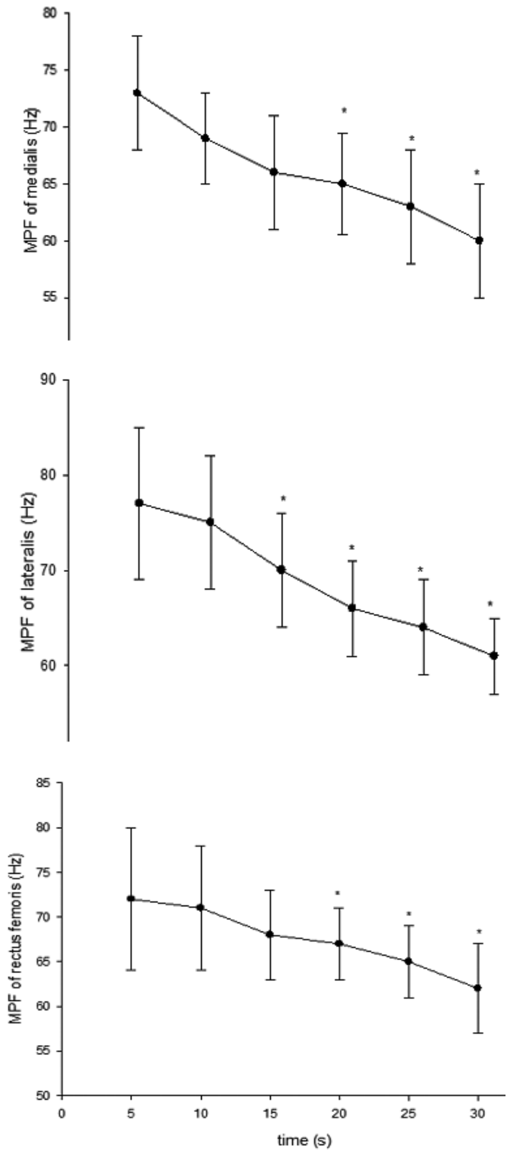

Figure 2

The effect of time in MPF of vastus medialis was significant (F=50,29; $p<0.01$) and MPF of vastus medialis decreased during the test. Mean frequency changes in the first three time periods (5s, 10s and 15s) were not significant ($p>0.01$), while the differences in the last three time periods (20s, 25s and 30s) were significant ($p<0.01$). The mean frequencies in the 20s,25s and 30s time periods were significantly lower compared to 5s, 10s and15s time periods. MPF of vastus lateralis in the 15s, 20s, 25s and 30s time periods were significantly lower compared to 5s and 10s periods (F=46,57; $p<0.01$). MPF of rectus femoris after the first three time periods (5s, 10s and 15s) significantly decreased (F= 12,25; $p<0.01$).

There was a correlation between power, normalized power, cadence and mean power frequencies of three muscles (table 1).

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RMS EMG normalized to first 5 s in three muscles did not change during the test duration significantly ($p>0.01$).

Table 1: Correlations confidence matrix between of the MPF and WAT performance.

	Caddence (rpm)	Peak power (W)	Normalised power (W/kg)
MPF of medialis	0,67*	0,50*	0,60*
MPF of lateralis	0,56*	0,38*	0,47*
MPF of rectus	0,28*	0,31*	0,32*
Cadence (rpm)		0,74*	0,88*
Peak power (W)			0,83*

*$p<0.05$ significant correlation between the variables.

DISCUSSION

The main finding of this study was the positive correlations between the WAT performances and the MPF of the muscles. In addition, as expected, during the test the power outputs and cadence decreased. Muscle fatigue affects the speed of cycling which results in a reduction of power output (Singh et al., 2007). The decrease in power and cadence conforms to previous studies (Hunter et al., 2003; Rana, 2006; Reiser, Maines, Eisenmann & Wilkinson 2002; Singh et al., 2007; Stewart, Farino, Shen, & Macaluso, 2011).

Decreased muscle frequency and unchanged amplitude during WAT were suggested (Hunter et al. 2003). To our knowledge, this is the first study related to the correlation between the test output and muscles' EMG data. During fatiguing contractions, there is a shift in frequency toward lower frequencies (Singh et al., 2007). In this study, mean power frequency of all muscles decreased throughout the test and there is a correlation between all muscles' mean frequency and power outputs. We did not measure any metabolites but some investigations have indicated that a decline in mean frequency of the active muscles may be caused by an accumulation of metabolites, resulting in the slowing down of the muscle fiber conduction velocity (Stewart et al.,2011). Nicolò, Bazzucchi, Felici, Patrizio and Sacchetti (2015) have demonstrated a high correlation between power and muscle fiber conduction velocity during maximal cycling test.

High threshold motor units, consisting mainly of type II muscle fibers, would be recruited early stage during the WAT and fatigued quickly due to the high work rate and mean frequency decreased consequently (Stewart et al., 2011). In maximal and supra-maximal loads, such as WAT, participants slog away and experience fatigue before the test is completed. Moreover, the peripheral changes such as the decreasing of the pH, effect the sarcolemmal excitability and consequently cause a decrease in the velocity of conduction as well as in the frequency (Hunter et al.,2003). The reduction of muscle fiber conduction velocity is one of the causes of the decrease in the mean frequencies (De Luca, 1984).

EMG amplitude is known to be a function of the neural drive to the muscle and indicates the overall stimulation of fibers during contraction, which is derived from several variables including discharge rate and motor unit recruitment. RMS EMG displayed no significant change for any muscle tested (vastus medialis, vastus lateralis and rectus femoris) throughout the test, which is consistent with the findings of Hunter et al. (2003). They reported an unaltered amplitude and concluded that this was due to an unchanged neural drive to the active muscles during the WAT. Nevertheless, Stewart et al. (2011) concluded longer action potential duration due to the decreasing of the conduction velocity because of the metabolic end products. They did not report any significant amplitude change but interpreted that this could be due to a decrease in discharge rate, which would have the greater action potential duration or de-recruitment of the fatigued motor units. EMG amplitude changes are related to contraction intensity (submaximal or maximal), contraction duration and individual properties like muscle composition (Wretling, Henriksson-Larsen& Gerdle, 1997). For example, incremental loads elicit the amplitude increase. Fatigue is often based upon a failure of neural excitation in case of the decline in the EMG amplitude in parallel with a power decline, but it is based upon the contractile processes when the EMG amplitude remains the same (DeLuca 1984). In this study, despite a significant decrease in power, the WAT did not exert any effect on the RMS of all muscles. In many studies that included dynamic contractions, RMS displayed no change (Hunter et al., 2003; Rana, 2006; Singh et al., 2007). Insignificant change in RMS may indicate an unchanging central drive during the test. An increased EMG/ force ratio is classified as “peripheral” fatigue in literature (Houtier et al.,2000). The unchanged EMG amplitude in this study may indicate that peripheral fatigue occurs during the 30-second WAT. Interestingly, Vandewalle et al. (1991) found out that IEMG decreased during WAT. However, they applied the test for 45 s. The longer duration may be the result of a decline in the central drive. Otherwise, this difference may be due to the variety of subjects.

This study contains some limitations. Neural information recorded by EMG is affected by thickness of the subcutaneous tissues, muscle fiber distribution, electrode locations and muscle fiber conduction velocities. These factors cannot be controlled or predict during the experimental conditionals used by surface EMG. Moreover, the metabolic changes such as lactate, pH are not measured in this study. Because these factors affect the muscle fiber conduction velocity, there is a need for observing these metabolic changes during the test. Additionally, the power output results from the different muscle recruitment and contraction characteristics. For this reason, knee flexor and calf muscles’ EMG alterations should be measured during the test.

In conclusion, during the WAT, mean power frequencies of all muscles decreased due to the fatigue in proportion to the power decline. It can be said that the positive correlations between MPF and anaerobic performance show that the power decrease of the active muscles during exhaustive exercise result from the decrease in frequencies. The frequency analyses of the active muscles during the exercise can be used for supplying objective and/or noninvasive measurements of localized muscle fatigue. Further investigations which would include different test durations, test loads, metabolic and neural measures are required.

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REFERENCES

Arendt-Nielsen, L. & Mills, K.R. (1985). The relationship between mean power frequency of the EMG spectrum and muscle fibre conduction velocity. *Electroencephalograph Clinical Neurophysiology 60* (2): 130–134.

Ayalon, A., Inbar, O., & Bar-Or, O. (1974). Relationships among measurements of explosive strength and anaerobic power. In: Nelson RC, & Morehouse CA (eds) International Series on Sport Science Volume I, Biomechanics IV, 572-577, University Press, Baltimore.

Bernardi, M., Solomonow, M.,& Baratta, R.V. (1997). Motor unit recruitment strategy of antagonist muscle pair during linearly increasing contraction. *Electromyography and Clinical Neurophysiology, 37*(1), 3-12.

Chin, E.R., & Allen, D.G. (1998). The contribution of pH-dependent mechanisms to fatigue at different intensities in mammalian single muscle fibres. *Journal of Physiology, 512*(3), 831- 840.

Costa, M.V., Pereia, L.A., Oliveira, R.S., Pedro, R.E., Camata, T.V., Abrao, T. et al. (2010). Fourier and Wavelet Spectral Analysis of EMG Signals in maximal constant load dynamic exercise, 32nd Annual International Conference of the IEEE, in Engineering in Medicine and Biology Society (EMBC), 4622-4625, Buenos Aires, Argentina.

DeLuca, C.J. (1984). Myoelectrical manifestations of localized muscular fatigue in humans. *Critical Reviews in Biomedical Engineering, 11*(4), 251–279.

Enoka, R., & Stuart, D. (1992). Neurobiology of muscle fatigue. *Journal of Applied Physiology, 72*(5), 1631-1648.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology, 10*(5), 361–374

Houtier, C.A., Arsac, L.M., Deghdegh, K., Souquet, J., Belli, A., &, Lacour, J.R. (2000). Influence of fatigue on EMG/force ratio and cocontraction in cycling. *Medicine& Science in Sports and Exercise, 32*(4), 839-843.

Hug, F., Laplaud, D., Savin, B., & Grelot, L. (2003). Occurrence of electromyographic and ventilatory thresholds in professional road cyclists. *European Journal of Applied Physiology, 90*(5), 643-646.

Hunter, A.M., Gibson, C.A., Lambert, M.I., Nobbs, L., & Noakes, T.D. (2003). Effects of supramaximal exercise on the electromyographic signal, *British Journal of Sports Medicine, 37*(4), 296-299.

Hussian, S.T., Smith, R.E., Medbak, S., Wood, R.F., & Whipp, B.J. (1996). Hemodynamic and metabolic responses of the lower limb after high intensity exercise in humans, *Experimental Physiology, 81*(2), 173-187.

Kent-Braun, J.A., Fitts, R.H., &Christie, A. (2012) Skeletal muscle fatigue. *Comprehensive Physiology, 2*(2), 997–1044.

Lucia, A., Sanchez, O., Carvajal, A., & Chicharro, J.L. (1999). Analysis of the aerobic-anaerobic transition in elite cyclists during incremental exercise with the use of electromyography. *British Journal of Sports Medicine, 33* (3), 178-185.

Millet, G.Y.& Lepers, R. (2004). Alterations of neuromuscular function after prolonged running, cycling and skiing exercises, *Sports Medicine, 34* (2), 105-116.

Nicolò, A., Bazzucchi, I., Felici, F., Patrizio, F., & Sacchetti, M. (2015). Mechanical and electromyographic responses during the 3-min all-out test in competitive cyclists. *Journal of Electromyography and Kinesiology, 25*(6), 907-913.

Rana, S.R. (2006). Effect of the wingate test on mechanomyography and electromyography. *Journal of Strength &Conditioning. Research, 20* (2), 292-297.

Reiser, R.F., Maines, J.M., Eisenmann, J.C., & Wilkinson, J.G. (2002). Standing and seated Wingate protocols in human cycling. A comparison of standard parameters. *European Journal of Applied Physiology, 88* (1), 152-157.

Singh, V.P., Kumar, D.K., Polus, B., & Fraser, S. (2007). Strategies to identify changes in SEMG due to muscle fatigue during cycling. *Journal of Medical Engineering & Technology, 31* (2), 144-151.

Smith, A.E., Walter, A.A., Herda, T.J, Ryan, E.D., Moon, J.R., Cramer, J.T. et al. (2007). Effects of creatine loading on electromyographic fatigue threshold during cycle ergometry in collage-aged women. *International Society of Sports Nutrition, 26* (4), 1-6.

Stewart, D., Farina, D., Shen, C., & Macaluso, A. (2011). Muscle fibre conduction velocity during a 30-s Wingate anaerobic test. *Journal of Electromyography and Kinesiology, 21*(3), 418-422.

Vandewalle, H., Maton, B., Le Bozec, S., & Guerenbourg, G. (1991). An electromyographic study of an all-out exercise on a cycle ergometer. *Archives Internationales de Physiologie, de Biochimie et de Biophysique, 99*(1), 89-93.

Wretling, M.L., Henriksson-Larsen, K., & Gerdle, B. (1997). Inter-relationship between muscle morhology, mechanical output and electromyographic activity during fatiguing dynamic knee-extention in untrained females. *European Journal of Applied Physiology, 76* (6), 483-490.