2016

THE EFFECT OF CARDIORESPIRATORY FITNESS ON THE ASSESSMENT OF THE PHYSICAL WORKING CAPACITY AT THE FATIGUE THRESHOLD

Brittney M. Mikkelsen
Creighton University

Jorge Zuniga
jmzuniga@unomaha.edu

William K. Herron
Creighton University

Frances E. Frauso
Creighton University

Anne N. Pulliam
Creighton University

Recommended Citation

Mikkelsen, Brittney M.; Zuniga, Jorge; Herron, William K.; Frauso, Frances E.; and Pulliam, Anne N., "THE EFFECT OF CARDIORESPIRATORY FITNESS ON THE ASSESSMENT OF THE PHYSICAL WORKING CAPACITY AT THE FATIGUE THRESHOLD" (2016). *Journal Articles*. 191.
https://digitalcommons.unomaha.edu/biomechanicsarticles/191

Mikkelsen et al. (2016) *Int J Res Ex Phys*. 11(2):16-24.

Sponsored by:
Exercise and Sport Science Program
Western State Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

THE EFFECT OF CARDIORESPIRATORY FITNESS ON THE ASSESSMENT OF THE PHYSICAL WORKING CAPACITY AT THE FATIGUE THRESHOLD

Brittney M. Mikkelsen[1], Jorge M. Zuniga[2], William K. Herron[1], Frances E. Frauso[1], Anne N. Pulliam[1]
[1] Department of Exercise Science and Pre-Health Professions, Creighton University, Omaha, NE, USA
[2]Department of Biomechanics, University of Nebraska Omaha, Omaha, NE, USA

Abstract

Purpose: The purpose of this study was to determine if different cardiorespiratory fitness levels (maximal oxygen uptake or VO_2max) affect neuromuscular fatigue as measured by the physical working capacity at the fatigue threshold (PWC_{FT}). **Methods:** Fourteen adults (14 men; mean ± SD; age = 20.79 ± 0.89 years; body weight = 80.7 ± 10.91 kg; height = 178.4 ± 5.29 cm) volunteered to participate in the investigation. Each participant performed an incremental cycle ergometry test to fatigue while electromyographic (EMG) signals were measured from the vastus lateralis (VL) muscle. Mean, standard deviation, and range values were calculated for the power outputs determined by the PWC_{FT}. The relationships for EMG amplitude and power output for each participant were examined using linear regression (SPSS software program, Chicago, IL). An alpha level of $p \leq 0.05$ was considered significant for all statistical analyses. **Results:** Participants were divided in a low and high fitness levels according to their VO_2max values. A paired dependent t-test was used to determine if there were significant mean differences in power outputs associated to the PWC_{FT} test for the low (Mean ± SD 162.5 ± 90.14 W) and high (173.21 ± 49.70 W) VO_2max groups. The results of the dependent t-test indicated that there were no significant mean differences ($p > 0.05$) between the high and low VO_2max groups. The zero-order correlation for the power outputs between groups were not significantly correlated ($r = 0.23$). **Conclusion:** The results of the present investigation indicated that the cardiorespiratory fitness level does not affect neuromuscular fatigue assessment during cycling.

Key Words: VO_2max, exercise, electromyography, cycling test, neuromuscular fatigue

Introduction

Electromyography (EMG) is a method used to examine the recruitment of muscle fibers throughout a movement and the electrical activity produced from the nerves in the muscle[1]. An EMG recognizes the signals and converts the data to numerical values that can be transferred to a graph. The signal provides the amplitude and frequency of the energy produced in the muscle. The amplitude is determined by the number of motor units recruited and the increased rate of which the action potentials propagate throughout the muscle. As the intensity of the exercise increases, the muscles respond by recruiting more muscle fibers, thus, resulting in a higher amplitude reading[1]. The amplitude of the EMG determines the physical working capacity at the fatigue threshold (PWC_{FT}). The PWC_{FT} represents the average value between the highest output without fatigue-related increases in EMG amplitude and the lowest power output at the point of fatigue-related increases in EMG amplitude[1-2]. The disproportional increase of the EMG amplitude has been used as an indicator of neuromuscular fatigue (NMF).

Fatigue can be understood as a decline in physical functioning or inability to maintain an exercise at the initial set intensity[3]. Fatigue exists in two forms: central fatigue and peripheral fatigue. Peripheral fatigue is the type which manifests itself in the muscles, affecting the peripheral nerves, neuromuscular junctions, and the muscle itself[3]. As an individual begins to fatigue, the decline in his or her performance is a result of several changes in the muscle's functioning. Changes occur in the maximum isometric force, shortening velocity, and relaxation time span[3]. Fatigue in the muscle can be identified when the EMG displays the recruitment of more motor units (seen as a disproportional increase in EMG amplitude) to maintain the same exercise intensity[2]. In a study conducted by Camic et al., at fatiguing exercise intensities, the EMG amplitude increased linearly. However, if the participants exercised at intensities that did not induce fatigue, no change was observed in the EMG amplitude[2]. By assessing the level of exercise at which an individual begins to fatigue, one can determine an exercise intensity that will delay the onset of exhaustion.

The cardiorespiratory system circulates oxygen throughout the body and provides muscles with the essential sources required to exercise. In order to measure the cardiorespiratory response during exercise, there are different methods that are used. Throughout the exercise, ergometer tests are used in which a tube is attached on a participant to calculate his or her VO_2[4]. According to the American College of Sports Medicine, cardiorespiratory fitness (CRF) is related to the ability to perform large muscle, dynamic, moderate-to-vigorous intensity exercise for a prolonged period of time[5]. The way the body responds to CRF is based on a person's physical fitness level. To assess CRF levels, the maximal oxygen uptake (VO_2max) may be measured by an ergometer test or by the Fick equation assuming values are provided to solve the mathematical problem. VO_2max is a product of the maximal cardiac output Q (L blood x min-1) and arterial-venous oxygen difference (mL O2 x L blood-1)[5]. The higher the CRF level on an individual, the higher VO_2max they will have. Graef et. al. used an EMG fatigue threshold test (EMG_{FT}) to examine the metabolic relationship between VO_2peak, ventilatory threshold (VT), and the EMG_{FT} in order to compare the power output at VO_2peak, VT, and EMG_{FT}. The main difference between VO_2max and VO_2 peak is when the participant decides to voluntarily withdraw from the test or not. In addition, the EMG_{FT} test is an adaptation to the PWC_{FT} test, using a bipolar supramaximal protocol[6]. Previous studies verified the use of the EMG_{FT} as a reliable and non-invasive method for identifying the onset of NMF[6]. However, there was no significant difference between metabolic values at EMG_{FT}, VO_2, and VT found[6]. Based on this information, it is unclear if CRF has an effect on the assessment of a measure of muscular fatigue, such as PWC_{FT}.

The purpose of this study was to determine if different cardiorespiratory fitness levels, measured by the EMG and ergometer procedure, affect the PWC_{FT}. From the EMG, the amplitude domain will provide electrical signals that represent the amount of muscle fibers recruited throughout the exercise[1]. As the intensity of exercise increases, the muscles recruit more muscle fibers and increase the amplitude reading. This increase in amplitude reading provides information about the development of fatigue[1]. Fatigue decreases the physical functioning of the muscles and the ability to maintain an exercise at a high intensity level[3]. CRF plays an important role in the delivery and utilization of oxygen to the exercising muscle with that said fatigue decreases the physical functioning of the muscles and the ability to maintain an exercise at high intensity level[3,5]. Based off the previous study concluded by Camic, there is a correlation between the ventilatory threshold (VT) and PWC_{FT}[2]. We hypothesize from the knowledge established in past studies that the higher an individual's VO_2max, the higher one's PWC_{FT}.

Methods

Participants

Fourteen adults (14 men; mean ± SD; age = 20.79 ± 0.89 years; body weight = 80.7 ± 10.91 kg; height = 178.4 ± 5.29 cm) volunteered to participate in the investigation. All participants regularly participated in physical activity. The study was approved by the University Institutional Review Board for Human Participants and all participants completed a health history questionnaire and signed an informed consent document before testing.

Instrumentation

Maximal Cycle Ergometer Protocol

Participants were instructed on the maximal cycle ergometer test that they were going to execute. Each participant performed an incremental test to exhaustion on a Calibrated Lode (Corival V3, Groningen, the Netherlands) electronically braked cycle ergometer at a pedal cadence of 70 rev·min-1. The seat was adjusted so that the participant's legs were near full extension during each pedal revolution. Heart rate was monitored with a Polar Heart Watch system (Polar Electro Inc., Lake Success, NY). Borg's rating of perceived exertion (RPE, 6-20) scale was explained to the participant and recorded for each stage of the test. The participants started pedaling at 50 W, and the power output was increased by 25 W after each 2-min stage until voluntary exhaustion. The test was terminated if the participant met at least two of the following three criteria: a) 90% of age-predicted heart rate (220-age), b) RPE of 18 or higher, and c) an inability to maintain the pedal cadence of 70 rev·min^{-1}. After the test was finished the participants were encouraged to cool-down.

EMG Measurements

According to the SENIAM Project recommendations, EMG electrode (circular 4 mm diameter, silver/silver chloride, BIOPAC Systems, Inc., Santa Barbara, CA) arrangements were placed on the vastus lateralis (VL) of both legs (7). Prior to placing the EMG electrodes, reference lines were drawn after one-third the distance from the lateral border of the patella to the anterior superior iliac crest and was measured with the tape measure (Gulick Tape II, Moberly, Missouri) (7). A goniometer (Smith and Nephew Rolyan, Inc., Menomonee Falls, WI) was used to orient the electrodes at a 20 degree angle to the reference line to approximate the pennation angle of the VL (8). The site was carefully shaved, abraded and cleaned with an alcohol wipe. Electrodes were then placed over the vastus lateralis with interelectrode distance of 20 mm center to center to prepare for EMG measurements (1). Interelectrode impedance was less than 2000 Ω. The EMG signal was amplified (gain: x1000) using differential amplifiers (EMG 100, Biopac Systems, Inc., Santa Barbara, CA, bandwidth= 10-500 Hz).

Procedures

Signal Processing

The raw EMG signals from the VL were digitized at 1000 Hz and stored in a personal computer for subsequent analysis (Inspiron 1520, Dell, Inc., Round Rock, TX). All signal 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.

Determination of the PWC$_{FT}$

The PWC$_{FT}$ was determined by utilizing the amplitude domain of the EMG signal recorded from the VL during each stage of the cycle ergometry test to exhaustion (9). Six, 10-s EMG samples were recorded and used to calculate the average of the EMG amplitude (microvolts root mean square, µV RMS) values (9). The 10-s epochs for each stage were plotted in a graph across time and the slope was determined (2). The PWC_{FT} was calculated by taking an average of the highest power output that resulted in a non-significant slope ($p > 0.05$) and the lowest power output with a significant positive slope ($p \leq 0.05$).

Statistical analyses

Mean, standard deviation, and range values were calculated for the power outputs determined by the PWC_{FT} and VO_2 methods. The relationships for EMG amplitude and power output for each participant were examined using linear regression (SPSS software program, Chicago, IL). A paired dependent t-test was used to determine if there were significant mean differences in power outputs between the PWC_{FT} and the VO_2 methods. A zero-order correlation was used to determine the relationships between the power output of the PWC_{FT} and the VO_2. An alpha level of $p \leq 0.05$ was considered significant for all statistical analyses.

Results

Table 1 provides the mean, standard deviation and range values for all fourteen participants' demographic data. Table 2 provides the PWC_{FT} and VO_2 values for each participant based on the EMG amplitude. The results of the dependent t-test indicated that there were not significant mean differences ($p > 0.05$) between the PWC_{FT} high VO_2 and PWC_{FT} low VO_2 values. The zero-order correlation for the power outputs determined by the PWC_{FT} high VO_2 and PWC_{FT} low VO_2 values showed that the two methods were not significantly correlated ($r = 0.23$).

Table 1. Physical characteristics and means for fatigue thresholds (n=14).

Variable	Mean ± SD (range)
Age (years)	20.79 ± 0.89 (19-22)
Body Weight (kg)	80.7 ± 10.91 (65.9-100.0)
Height (cm)	178.4 ± 5.29 (170.2-187.9)
PWC_{FT}* (W)	167.9 ± 70.15 (87.5-312.5)
VO_2**(mL/kg/min)	48.24 ± 8.75 (37.2- 65.3)

* PWC_{FT} = EMG physical working capacity at fatigue threshold
**VO_2 = Measure of maximal oxygen consumption

Table 2. Individual, mean, and standard deviation values for fatigue thresholds (n=14).

Participants (Men)	PWCft (W)*	VO_2 (mL/kg/min)**
1	237.5	50.86497498
2	212.5	52.65382385
3	187.5	48.55102921
4	112.5	38.6912384
5	87.5	45.13445663
6	112.5	44.34153748
7	87.5	50.08744049
8	137.5	65.30821991
9	262.5	48.29754257
10	162.5	50.03303146
11	162.5	37.18058014
12	87.5	37.18058014
13	187.5	64.80393219
14	312.5	42.17188644
Mean	167.85714	48.23573
SD	70.14996	8.75413

PWC_{FT} = EMG physical working capacity at fatigue threshold
VO_2 = Measure of maximal oxygen consumption

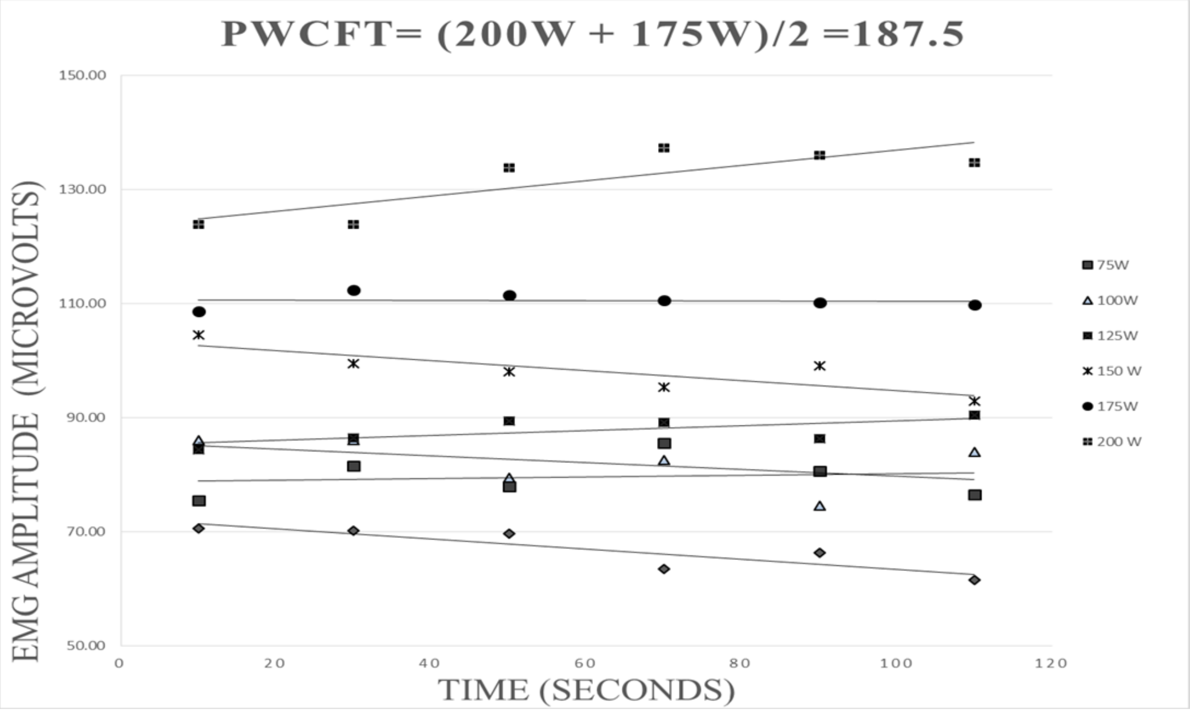

Figure 1. Example of method used for estimating the physical working capacity at the fatigue threshold (PWC_{FT}). The PWC_{FT} in the current example (187.5 W) was determined by averaging the highest power output (175 W) that resulted in non-significant ($p > 0.05$) slope coefficient for the EMG amplitude vs. time relationship, with the lowest power output (200 W) that resulted in a significant ($p \leq 0.05$) positive slope coefficient. Slope coefficient significantly greater than zero at $p \leq 0.05$.

Discussion

The purpose of this study was to examine the effect of the cardiorespiratory fitness on the assessment of the PWC_{FT}. It was hypothesized that the higher an individual's VO_2max, the higher the one's PWC_{FT} would be. The main findings of the present investigation disagreed with our hypothesis, as the analysis demonstrated that there were no significant mean differences ($p > 0.05$) between the PWC_{FT} of the low (Mean SD 162.5 ± 90.14 W) and high (173.21 ± 49.70 W) VO_2max groups and that the power outputs between groups were not significantly correlated ($r = 0.23$) to the PWC_{FT} method when assessing NMF during cycling. These findings suggest that the power outputs between groups could not be considered an accurate method of assessment for NMF using the amplitude domain of the EMG signal, therefore, in determining the PWC_{FT}. It has been found that the PWC_{FT} test is determined by EMG amplitude fatigue curves during a single continuous, incremental test on a cycle ergometer[2,10]. Therefore, it seems conceivable to suggest to researchers that utilizing VO_2 levels as an indication of PWC_{FT} will not yield accurate measurements.

In the present investigation, the PWC_{FT} from the amplitude domain of the EMG signal was compared to the high and low VO_2 levels using the correlation test and dependent t-test. VO_2max is a product of the maximal cardiac output Q (L blood x min-1) and arterial-venous oxygen difference (mL O2 x L blood-1) and seems to affect the CRF, but it has not been shown to affect the PWC_{FT}[5]. In previous investigations, the fatigue threshold determined by the EMG amplitude have different factors between cardiac and neuromuscular factors for fatigue[11]. Previous studies[2,10] reported that fatigue induced signals from the EMG occurred at a lower power output for the amplitude than the frequency. The reasoning for this is unclear but several studies have suggested that the accumulation of metabolic byproducts of muscular contraction as an individual starts to become fatigued. Previous studies conclude that the intracellular pH level declines as lactate increases resulting in an indication for more motor units to be recruited to maintain the power output and, therefore, causing the muscle fiber conduction velocity to decline[12]. The decrease in muscle contractility could result in the PWC_{FT} occurring at a lower power output. With tests, the current findings supports VO_2 levels could not be used to assess NMF when performing a cycle ergometer test.

In a more recent study, the EMG frequency-based test that was used to assess NMF during an incremental cycle ergometry was seen if it could be applied to a single workout on a treadmill to derive a new fatigue threshold for running. They found that the application of the PWC_{FT} model used during a cycle ergometer can be used to identify the onset of fatigue during treadmill running. Their findings were consistent with an earlier study that they were able to identify a demarcation between fatiguing and non-fatiguing exercise by statistically examining the slope coefficients for the EMG amplitude versus time relationship at each running velocity during the incremental treadmill test[2]. It is likely that increases in EMG amplitude that occur during constant-velocity treadmill running reflect fatigue-induced increases in muscle activation that are necessary to maintain the required pace[2]. Zuniga et al. suggests that in addition to VO_2 increasing to VO_2max and blood lactate increasing throughout the work bout, the severe exercise intensity domain is also characterized by a decrease in EMG MPF that results from declines in conduction velocity and changes in shape of the action potential waveform of active muscle fibers[13]. These findings do not support the current investigation, and it could be the cause of different physiological mechanisms that was not taken into account for.

A potential limitation of this study was the variability among the test subjects. Subjects were selected based on availability to participate, with no preference for fitness level, cycling experience, or body composition, all of which could have been sources of error in the present investigation. Similarly, the small sample of subjects may have caused irregularities in the statistical analysis of the mean values. Future studies should examine larger populations with high levels of cycling experience to produce more accurate results.

Future studies should examine the correlation between PWC_{FT} and VO_2 levels using a larger sample with consistent fitness and cycling abilities. It could also examine the effects of different intensities or modes of incremental exercise on different muscle groups. Although the methodology used in this study was practical, it could be made effective in a future investigation. Certainly, multiple visits from the subjects could help assess retest reliability.

Interestingly, in the present study standard deviation of VO_2 level were lower than PWC_{FT} indicating that it has less variability. Collecting VO_2max levels seems to be a more practical way to assess cardiorespiratory fitness instead of PWC_{FT} because the current findings show they are not correlated.

Conclusions

In conclusion, the present study found that were no significant mean differences in the high and low VO_2 levels and the PWC_{FT} values. There were also no significantly correlated value when assessing the NMF. Our study and previous studies suggest that PWC_{FT} cannot be related to cardiorespiratory fitness. These findings are important for exercise scientists, coaches, or athletes trying to assess NMF during incremental exercise testing. It can be beneficial to exercise scientists in suggesting that neuromuscular fatigue have separate physiological mechanisms than cardiorespiratory fitness. The findings also suggest that future studies should examine the physiological mechanisms that regulate neuromuscular fatigue and cardiorespiratory fitness assessed by VO_2max.

Acknowledgements

The authors would like to thank all of the subjects who donated their time for the study and students in EXS 407: Basic Statistics and Research Design (Spring 2016) who helped with subject recruitment and data collection.

Address for Correspondence

Jorge M. Zuniga, Ph.D., Department of Biomechanics, University of Nebraska Omaha, Omaha, NE, USA 68182. PHONE: (402) 554-3228; EMAIL: jmzuniga@unomaha.edu.

References

1. Galen SS, Guffey DR, Coburn JW, Malek MH. (2015). Determining the electromyographic fatigue threshold following a single visit exercise test. *J Vis Exp*, 101, e52729.
2. Camic CL, Kovacs AJ, Enquist EA, VanDusseldorp TA, Hill EC, Calantoni AM, Yemm AJ. (2014). An electromyographic-based test for estimating neuromuscular fatigue during incremental treadmill running. *Physiol Meas*, 35, 2401-2413.
3. Allen DG, Lamb GD, Westerblad H. (2008). Skeletal muscle fatigue: Cellular mechanisms. *Physiol Rev*, 88, 287-332.
4. Aminoff T, Smolander J, Korhonen O, Louhevaara V. (1997). Cardiorespiratory and subjective responses to prolonged arm and leg exercise in healthy young and older men. *Eur J Appl Physiol Occup* Physiol, 75, 363-368.
5. Medicine ACS. (2013). ACSM's guidelines for exercise testing and prescription. Wolters Kluwer Health.
6. Graef JL, Smith AE, Kendall KL, Walter AA, Moon JR, Lockwood CM, Beck TW, Cramer JT, Stout JR. (2008). The relationships among endurance performance measures as estimated from VO(2PEAK), ventilatory threshold, and electromyographic fatigue threshold: A relationship design. *Dyn* Med, 7:15.
7. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr* Kinesiol, 10, 361-374.
8. Fukunaga T, Ichinose Y, Ito M, Kawakami Y, Fukashiro S. (1997). Determination of fascicle length and pennation in a contracting human muscle in vivo. *J Appl Physiol (1985)*, 82, 354-358.
9. Bracciano EM, Zuniga JM, Mita AN, King KM, Lawson TA, King KJ. (2014). The effects of precooling on the assessment of the physical working capacity at the fatigue threshold. *J Ath Med*, 2, 20-28.
10. Camic CL, Housh TJ, Johnson GO, Hendrix CR, Zuniga JM, Mielke M, Schmidt RJ. (2010). An EMG frequency-based test for estimating the neuromuscular fatigue threshold during cycle ergometry. *Eur J Appl* Physiol, 108, 337-345.
11. Guffey DR, Gervasi BJ, Maes AA, Malek MH. (2012). Estimating electromyographic and heart rate fatigue thresholds from a single treadmill test. *Muscle* Nerve, 46, 577-581.
12. Lindstrom L, Magnusson R, Petersen I. (1970). Muscular fatigue and action potential conduction velocity changes studied with frequency analysis of EMG signals. Electromyography, 10, 341-356.
13. Zuniga JM, Housh TJ, Camic CL, Hendrix CR, Schmidt RJ, Mielke M, Johnson GO. (2010). A mechanomyographic fatigue threshold test for cycling. *Int J Sports* Med, 31, 636-643.