

Original Research

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## The Effect of Skinfold on the Assessment of the Mean Power Frequency at the Fatigue Threshold

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### ABSTRACT

*International Journal of Exercise Science 9(4): 376-383, 2016.* The purpose of this study was to determine if the amount of subcutaneous tissue over the quadriceps affects the assessment of mean power frequency at the fatigue threshold (MPF<sub>FT</sub>). It was hypothesized that greater skinfold values will result in lower power outputs associated to the MPF<sub>FT</sub>. Fourteen adults (Mean  $\pm$  SD age = 20.7  $\pm$  0.99; body weight = 72.8  $\pm$  12.6 kg) performed an incremental cycle ergometry test to exhaustion while surface electromyographic (EMG) signals were measured from the vastus lateralis. The skinfold thickness of each leg was taken prior to the test, and skinfold thicknesses were separated into a larger and a smaller groups. The independent t-test showed a significant difference ( $p = 0.01$ ) between the power outputs associated to the MPF<sub>FT</sub> of groups with high (Mean  $\pm$  SD 130.4  $\pm$  34.5 W) versus low skinfold (212.5  $\pm$  61.2 W) values. The results suggested that higher subcutaneous fat may have affected the assessment of MPF<sub>FT</sub> during cycle ergometry.

**KEY WORDS:** Cycle ergometry, EMG, frequency, subcutaneous tissue, body composition, quadriceps, electrode

### INTRODUCTION

Surface electromyography (EMG) is a method used to quantify the activity level of muscles and the nerves that control them (1) by placing electrodes on the surface of the skin to detect muscle contractions. The amplitude of the surface EMG signal reflects muscle activation (both motor unit recruitment and firing rate), while the frequency content is determined, in part, by the average muscle fiber action potential conduction velocity. The amplitude of the motor unit potential is dependent on the

density of the muscle fibers attached to one motor neuron. As the strength of contraction is slowly increased, motor units are recruited in an orderly sequence. Delayed recruitment is a reflection of loss of motor units within the muscle. The surface EMG mean power frequency (MPF) is in part represented by the firing rate frequency (Hz) (2). During dynamic muscle actions, the frequency of the conduction velocity of the muscle fiber will increase as the workload increases. At the onset of neuromuscular fatigue, however, there is a decline in the frequency content of the

surface EMG signal as a result to slow conduction velocity and accumulation of metabolic byproducts (2, 16).

Skinfold assessment is a method used to measure subcutaneous adipose tissue. The procedure is done with a skinfold caliper device used in specific regions of the body. This measurement has a direct correlation to the amount of tissue lying between the subject's muscle and skin. The skinfold method has a 3-5% error when using proper technique and equations (4).

In previous studies, the surface EMG has been used to measure the fatigue threshold during different types of muscle contractions. Moritani et al. (12) applied the EMG mean power frequency measurement at the fatigue threshold ( $MPF_{FT}$ ) during sustained maximal voluntary contraction of the adductor pollicis and triceps surae. Zaheer et al. (15) determined the preferred electrode placement for surface EMG decomposition based on the amount of subcutaneous adipose tissue between the electrode and underlying muscle. Results showed that muscles located in areas containing lower skinfold values (i.e. vastus lateralis, rectus femoris, and tibialis anterior), generated increased motor unit yields and decreased signal-to-noise ratios (15).

Previous studies have also shown that subcutaneous adipose tissue thickness on the quadriceps is in direct correlation with a decreased surface EMG amplitude and frequency (12). It is unknown if greater quadriceps adipose tissue would affect the  $MPF_{FT}$ . Thus, the purpose of this study was to determine if the amount of the quadriceps subcutaneous tissue, measured by a skinfold procedure, will affect the

assessment of  $MPF_{FT}$ . In the frequency domain, fatigue is represented by a decrease in frequency, representing a decrease in conduction velocity. The amount of subcutaneous tissue between the skin and the muscle tissue increases the distance that the EMG signal must travel (6). Based off of previous studies (6, 12-14) we hypothesize that greater skinfold values will result in lower power outputs associated to the  $MPF_{FT}$ .

## METHODS

### *Participants*

Fourteen adults (9 men; mean  $\pm$  SD age =  $20.7 \pm 1.1$  years; body weight =  $78.4 \pm 9.6$  kg and 5 females; mean  $\pm$  SD age =  $20.6 \pm 1.0$  years; body weight =  $60.3 \pm 10.9$  kg) volunteered to participate in the investigation. The subjects were not competitive athletes, but were all healthy individuals who exercise regularly. The study was approved by the University Institutional Review Board for Human Subjects and all subjects completed a health history questionnaire and signed an informed consent document before testing.

### *Protocol*

Skinfold Calipers (Creative Health Process Products Inc., Ann Arbor, Michigan) were used to assess anterior mid-thigh skinfold thickness. Skinfolds were taken on each leg. Determination of the location of the skinfold measurement was taken midway between the iliac crest and the patella using a gulick tape measure. Each subject was instructed to relax each leg as skinfold measurements were taken. The investigator pinched the skin to separate the skin and underlying adipose tissue from the muscle. The calipers were then placed approximately 1 cm below the pinch and a

reading in millimeters was taken shortly after. The measurements of each skinfold site was taken three times rotating through the sites to allow the skin to return to normal tension. If the two measurements had a difference that is greater than 2 mm, a third measurement was taken, and an average of the two closest skinfold measurements were calculated.

Each subject 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<sup>-1</sup>. The seat was adjusted so that the subjects' 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). Rating of perceived exertion (RPE) scale (6, easy-20, vigorous) with standard instructions was recorded for every workload. The subjects began pedaling at 50 W, and the resistance was increased by 25 W every 2 min throughout the test until voluntary exhaustion or until the subject could no longer maintain a pedal cadence of 70 rev·min<sup>-1</sup> despite strong verbal encouragement. Termination of the test was determined if the subject met at least two of the following three criteria: a) 90% of age-predicted maximal heart rate (220-age), b) RPE of 18 or higher, and c) inability to maintain the pedal cadence of 70 rev·min<sup>-1</sup> despite strong verbal encouragement. At the completion of the test, the subjects were allowed to cool-down at their own discretion.

A bipolar surface EMG electrode (circular 4 mm diameter, silver/silver chloride, Biopac Systems, Inc., Santa Barbara, CA) arrangement was placed on the vastus lateralis (VL) of the right leg border of the

patella to 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 (10). A 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 (1,5). The reference electrode was placed over the tibial tuberosity. Prior to electrode placement, the skin at each electrode site was shaved, carefully abraded, and cleaned with alcohol. Interelectrode impedance was less than 2000  $\Omega$ . The EMG signal was amplified (gain:  $\times 1000$ ) using differential amplifiers (EMG 100, Biopac Systems, Inc., Santa Barbara, CA, bandwidth= 10-500 Hz).

The raw surface EMG signals 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 Lab VIEW programming software (version 7.1, National Instruments, Austin, TX). The EMG signals were bandpass filtered (fourth-order Butterworth) at 10-500 Hz. For the MPF analysis, each data segment was processed with a hamming window and the discrete Fourier transform (DFT) algorithm in accordance with the recommendations of Hermens et al. (7) The MPF values were calculated as described by Kwanty et al. (9) using the following equation:

$$MPF = \frac{\sum_{f_0=f}^{f_c} f P(f)}{\sum_{f_0=f}^{f_c} P(f)}$$

where  $f$  is frequency,  $f_0$  is 0 Hz,  $f_c$  is the cutoff frequency (i.e., the last frequency in

the discrete summation), and  $P(f)$  is the power density ( $V^2/Hz$ ) of the EMG signal.

The  $MPF_{FT}$  values were determined by applying the model of Camic et al. (2) for the frequency domain of the EMG signal. During each 2 min stage of the incremental cycle ergometer test to exhaustion, six, 10-s EMG samples were recorded from the VL muscle. The EMG mean power frequency (Hz) values were calculated for each of the 10-s epochs (MP100, Biopac Systems) and plotted across time for each power output of the test. The  $MPF_{FT}$  was determined by averaging the highest power output that resulted in a non-significant ( $p > 0.05$ ; single-tailed  $t$ -test) slope coefficient for the EMG MPF vs. time relationship, with the lowest power output that resulted in a significant ( $p < 0.05$ ) negative slope coefficient.

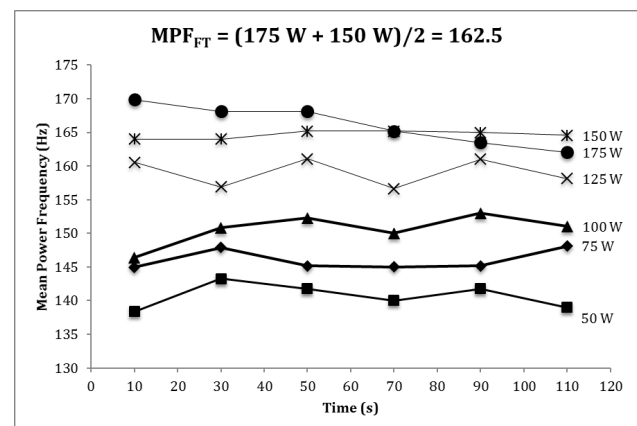
#### Statistical Analysis

Mean, standard deviation, and range values were calculated for  $MPF_{FT}$ . The relationships for EMG MPF and power output for each subject were examined using linear regression (IBM SPSS statistics version 22 software program, Chicago, IL; Figure 1). An independent  $t$ -test was used to determine if there were significant mean differences in power outputs among the  $MPF_{FT}$  for high and low skinfold measurements. An alpha level of  $p \leq 0.05$  was considered significant for all statistical analyses.

## RESULTS

Table 1 provides mean, standard deviations, and range values for the physical characteristics of the subjects as well as the  $MPF_{FT}$  and skinfold thickness (categorized as high and low). In order to

compare skinfold thickness, the subjects were divided (at the median skinfold thickness value of 20 mm) into two groups of low ( $n = 7$ ) and high ( $n = 7$ ) skinfold thickness values. The results of the independent  $t$ -test indicated significant mean differences ( $p=0.01279$ ) in power output for:  $MPF_{FT}$  with low skinfold thickness (mean  $\pm$  SD =  $212.5 \pm 61.2$  W) vs.  $MPF_{FT}$  with high skinfold thickness (mean  $\pm$  SD =  $130.4 \pm 34.5$  W). Table 2 provides individual mean (SD) values (W) for the  $MPF_{FT}$  of high and low skinfold as well as the slope coefficient values for the significant linear regression analysis described in Figure 1.



**Figure 1.** Illustration of the method used to estimate the EMG mean power frequency threshold ( $MPF_{FT}$ ). The  $MPF_{FT}$  in the current example (162.5 W) was determined by averaging the highest power output (150 W) that resulted in non-significant ( $p > 0.05$ ) slope coefficient for the EMG MPF vs. time relationship, with the lowest power output (175 W) that resulted in a significant ( $p < 0.05$ ) negative slope coefficient. \*Slope coefficient significantly less than zero at  $p < 0.05$ .

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

Variable	Mean ± SD (range)
Age (yrs)	20.7 ± 0.99 (19-22)
Body Weight (kg)	72.8 ± 12.6 (52.2-99.8)
Height (cm)	174.3 ± 14.1 (152.56-198.12)
High Skinfold (mm)	27.5 ± 3.8 (24-32.5)
Low Skinfold (mm)	15.7 ± 2.3 (12.5-19)
MPF <sub>FT</sub> with High Skinfold (W)	130.4 ± 34.5 (87.5-187.5)
MPF <sub>FT</sub> with Low Skinfold (W)	*212.5 ± 61.2 (137.5-312.5)

\*Significantly (p <0.05) different; MPF<sub>FT</sub> = Mean Power Frequency at the Fatigue Threshold

**Table 2.** Individual Mean (SD) Values for Subjects with High Skinfold (n=7) and Low Skinfold (n=7).

Subject	MPF <sub>FT</sub> High SKF (W)	Slope Coefficient	MPF <sub>FT</sub> Low SKF (W)	Slope Coefficient
1	187.5	-0.111	237.5	-0.057
2	137.5	-0.022	162.5	-0.108
3	87.5	-0.054	237.5	-0.097
4	137.5	-0.056	137.5	-0.048
5	137.5	-0.040	162.5	-0.084
6	137.5	-0.021	237.5	-0.033
7	87.5	-0.071	312.5	-0.047
Mean	*130.4	-0.053	*212.5	-0.0675
SD	34.5	-0.029	61.2	-0.0263

\*Significantly (p < 0.05) different. MPF<sub>FT</sub> = Mean Power Frequency at the Fatigue Threshold.

**DISCUSSION**

The purpose of this study was to examine the effects of skinfold thickness on the assessment of the MPF<sub>FT</sub>. It was hypothesized that an increase in skinfold thickness would produce a decrease in mean power frequency at the fatigue threshold (MPF<sub>FT</sub>). In agreement with our hypothesis, the results of the present investigation showed significant difference (p < 0.05, Table 2) between the MPF<sub>FT</sub> of the higher (130.4 ± 34.5 W) and lower (212.5 ± 61.2 W) skinfold groups (p = 0.01279).

The results found in this study suggest that skinfold thickness may have an inverse relationship with MPF<sub>FT</sub> readings at fatigue during an surface electromyographic (EMG) assessment. This relationship could be attributed to two main factors. The first reason being that the greater amount of subcutaneous tissue may disrupt the signal being transmitted from the muscle to the electrode. The greater distance the signal must travel may dampen the signal, therefore, affecting the MPF<sub>FT</sub> assessment (13). Second, the physiological mechanisms of participants with higher skinfolds may have led to fatigue at an earlier stage of the test compared to participants with low skinfolds. It has been shown (14), that individuals with a greater amount of subcutaneous tissue tend to fatigue easier, which may account for the lower MPF<sub>FT</sub> signal during the surface EMG test (14). Wilmore et al. (14) demonstrated that subjects who underwent a 20-week endurance program saw significant decreases in body fat percentages, suggesting that those who are more fit have lower body compositions (14).

In contrast to the present investigation, Zuniga et al. found no significant differences between high and low skinfold groups using mechanomyographic (MMG) measurements (16). Furthermore, Jaskolska et al. examined skinfold thickness effects on the median and peak frequencies of MMG. Jaskolska et al. found that in certain circumstances, subcutaneous tissue as a low-pass filter is negligible and has no effect on frequency in MMG measurements (8). The evidence presented by these studies suggested that the effect of skinfold thickness may be dependent on the type of signal used to assess neuromuscular fatigue (EMG vs. MMG). The MMG signal

measures the pressure waves developed by the lateral oscillations of the active muscle fibers (16). The surface EMG signal, however, measures voltage generation. Thus, it is conceivable that the low-pass filtering effect from subcutaneous tissue may affect the voltage and frequency generated by the contracting muscle with no major effect on the pressure waves.

To our knowledge, there have been no previous studies done evaluating the effect of skinfold thickness on mean power frequency at the fatigue threshold ( $MPF_{FT}$ ) of the quadriceps. Previous studies have investigated the relationship between skinfold thickness and the surface EMG signal. In a study done by Zaheer et al. (15), it was recommended to place the electrodes in muscles of low subcutaneous fat (ie. vastus lateralis), suggesting that skinfold thickness may affect the amplitude and frequency content of the EMG signal (14). Hemingway et al. (6) found that the distance of subcutaneous tissue between the skin and muscle tissue increases the distance that the EMG signal must travel. Their results showed that this increment of distance that the EMG must travel decreased the overall EMG signal (6). Furthermore, Petrofsky (13) also found a direct correlation between skinfold and signal loss from the skin, where subcutaneous fat behaves as a resistor to electrical stimulation (13). This would suggest, in concurrence with our findings, that subcutaneous tissue has an effect on the frequency content of the surface EMG signal as described by previous investigations (3, 6, 12-14).

One possible limitation of this study was the variability among the test subjects. Subjects were chosen based on availability,

with no preference for gender, fitness level, cycling experience, or body composition, all of which could have been sources of error in the present investigation. Another limitation may include the small sample size. Due to the small population of subjects, it may have caused irregularities in the statistical analysis of the results. Using a larger population of subjects, with specific criteria, may yield more accurate data. Although the methodology used in this study was practical, it was not optimal for this investigation. Assessing subject  $MPF_{FT}$ , having direct control over the skinfold thickness, such as shaving subjects reducing their body fat percentages and then assessing  $MPF_{FT}$  again would have provided a more direct effect of skinfold on the surface EMG signal. This methodology, however, is extremely impractical. For that reason it was decided to use a split design for the analysis by separating the data into two groups of larger and smaller skinfold and then comparing their  $MPF_{FT}$  values. This methodology has been used by previous studies (16) to analyze the effect of subcutaneous tissue on the MMG signal during dynamic muscle actions. Through understanding these limitations, it can be speculated that physical fitness levels may have also affected our results, as an increased fitness level is suggested have a negative correlation with body fat percentage (14). If assumed that those who had a greater skinfold were less physically fit, then the results of the present investigation would show a relationship between a greater  $MPF_{FT}$ , and overall physical fitness.

Future studies should further examine the relationship of skinfold and  $MPF_{FT}$ . Narrowing test subject criteria by reducing within group variance would be beneficial

in repeating this study. Gender difference could be investigated due to the physiological differences between men and women. For example, women typically have a higher amount of subcutaneous tissue than men suggesting an effect on the relationship between skinfold and MPF<sub>FT</sub>.

In conclusion, the present study found that skinfold thickness may affect the assessment of MPF<sub>FT</sub>, and as hypothesized, the high skinfold group had a lower mean MPF<sub>FT</sub> value. The findings of this study suggest that researchers need to take subcutaneous tissue into consideration when using surface EMG procedures as it may affect the accuracy of the data. Further investigation is needed to determine if MPF<sub>FT</sub> and other neuromuscular fatigue measurements are affected by subcutaneous tissue.

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