# Assessment of Muscles Fatigue during 400-Meters Running Strategies Based on the Surface EMG Signals

**Article** *in* Journal of Biomimetics Biomaterials and Biomedical Engineering · July 2019

DOI: 10.4028/www.scientific.net/JBBBE.42.1



Hayder A. Yousif
University of Warith Al-Abnbiyaa


Norasmadi Abdul Rahim
Universiti Malaysia Perlis


Ahmad faizal Salleh
Universiti Malaysia Perlis


Ammar Zakaria
Universiti Malaysia Perlis

*Journal of Biomimetics, Biomaterials and Biomedical Engineering*
*ISSN: 2296-9845, Vol. 42, pp 1-13*
*doi:10.4028/www.scientific.net/JBBBE.42.1*

*Submitted: 2019-03-28*
*Revised: 2019-05-28*
*Accepted: 2019-05-28*
*Online: 2019-07-23*

# Assessment of Muscles Fatigue during 400-Meters Running Strategies Based on the Surface EMG Signals

Hayder A. Yousif[1,2,a*], Norasmadi Abdul Rahim[3,b], Ahmad Faizal Bin Salleh[3,c], Ammar Zakaria[1,d] and Khudhur A. Alfarhan[1,e]

[1]Centre of Excellence for Advanced Sensor Technology (CEASTech), School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

[2]Al-Hussain University College, Iraq.

[3]School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia

[a]hayderabdulazeez@huciraq.edu.iq, [b]norasmadi@unimap.edu.my, [c]ahmadfaizal@unimap.edu.my, [d]ammarzakaria@unimap.edu.my, [e]khudhur@studentmail.unimap.edu.my

**Keywords:** sEMG, leg muscles, 400-meter running strategies, muscles fatigue.

**Abstract.** The aim of this research work is to assess the muscles fatigue of the male runner during 400 meters(m) running with three types of running strategies. The Electromyography (EMG) signals from the Rectus Femoris (RF), Biceps Femoris (BF), Gluteus Maximus (GM), Gastrocnemius Lateralis (GL), and Gastrocnemius Medialis (GMS) were collected by using bipolar electrodes from the right lower extremity's muscles. EMG signals were collected during the run on the tartan athletic track. Five subjects (non-athletes) had run 400m with three various types of running strategies. The first type: the first 200m running 85-93% of full speed and the last 200m sprinting (full speed), second type: the first 300m running 85-93% of sprinting and the last 100m sprinting, and third type: running 85-93% of sprinting for 400m. The EMG signals were transformed to the time-frequency domain using Short Time Fourier Transform to calculate the instantaneous mean frequency (IMNF) and instantaneous median frequency (IMDF). The less index fatigues were during 1$^{st}$ strategy, while the RF, BF, GM, and GL muscles got recovered with IMNF and IMDF with the three strategies, and the GMS muscle has less negative regression slope value with IMNF with 1$^{st}$ strategy during the 4$^{th}$ 100m of the 400m running event. From the results, it can be concluded the running with the 1$^{st}$ strategy get less fatigues compared with the 2$^{nd}$ and 3$^{rd}$ strategy based on the results of time-frequency domain features (IMNF and IMDF).

## Introduction

The number of runners keeps increasing in each year, with many different distances to be applied. Hence, an appropriate phase of running is needed to lower the possibility of injuries and muscles fatigue, also to enhance the sprinting event in a comfortable manner. Muscular fatigue can be specified as an inability of muscles to keep a reasonably estimated force production [1]. Exhaustion typically happens after mental or physical effort, insufficient rest or other short-term occurrences. Sometimes it is called as healthy or acute because the fatigue is commonly relieved with rest [2]. Exhaustion of the muscles during running may lead to difficulty or inability in continuity to run. For this reason, it is necessary to develop the strategy of sprinting to overcome the muscles fatigue in early time during sprinting.

The muscle fatigue describes the decline in muscle maximum force during contraction [3]. The fatigue occurs in our daily life activities. When fatigue occurs in the muscle fiber cells, nerves will produce a high activity to gain the maximum contraction. However, it cannot sustain the high activity for a long time, and that leads to a decline in muscle force. Normally, the fatigue in the muscle fibers occurs due to low nutrition and accumulation of metabolites [4]. Prolonged muscle activities will lead to acute fatigue which affects our ability to move any part of the body. There are many factors affect fatigue like muscle fiber composition, regulation of ionic component in blood supply, energy supply, and many other factors [5].

Generally, muscle fatigue is recognized by the EMG signal as long as there is a mutual decline in parameter examined in the frequency domain [6] and an increment in the parameter evaluated in the time domain [7].

Many researchers have detected muscles fatigue from different muscles during running, where most of them recording the EMG signals during running over a treadmill and overground for one phase of sprinting only [8]. Many ongoing of researchs have studied the detection of muscle fatigue. Many of the detection methods are applied to muscle signals in order to detect fatigue [9]. Nevertheless, EMG is the main method to record and study muscle functions [10]. For instance, in 2000, Mizrahi collected the EMG signals from the Gastrocnemius muscles of the subjects during running on the treadmill for 30 minutes, then calculated the average integrated EMG, MPF and applied statistical analysis to detection the muscles fatigues [11]. In 2012, Mastalerz collected the EMG signals from biceps femoris and rectus femoris muscles (right and left leg) during running on the tartan athletic track for 400m with variables intensity, the 1st distance of 400 m took 90 s, the 2nd took 70 s, the 3rd took 60 s, and the last one was covered with a maximal velocity until exhaustion. Then calculated the mean power frequency and applied the linear regression to detect the muscles fatigue. The results of his study had shown the effects of the fatigue were observed with the last case of running, where the biggest change in mean power frequency were with the rectus femoris and biceps femoris of the left leg [12]. In 2014, Zuniga collected the EMG signals from the Vastus lateralis, Vastus medialis, and Rectus Femoris muscles of the subject during running on treadmill. The test starts with walking the subject then increased the velocity of the treadmill by 1.6 km/h for each minute until fatigue, and then analyzed the muscles fatigue in frequency domain by calculated the mean power frequency (MPF) [13]. In 2015, Crozara collected the EMG signals of the Rectus Femoris, Vastus lateralis, Biceps Femoris, and Gastrocnemius Lateral muscles of the subjects during running on the treadmill, where the test started at 8 km/h then increases the velocity 1km/h each 3 minutes, where extracted the RMS features and then applied the statistical analysis for muscles fatigues detection [14]. In 2017, Ridzuan collected the EMG signals from the Gastrocnemius muscles of the subject during running on a treadmill with constant speed for 30 minutes, then calculated the MPF in frequency domain and applied a statistical analysis to detection muscles fatigues [15].

In this research work, EMG signals of RF, BF, GM, GL, and GMS muscles were collected by using bipolar electrodes from the right leg of five subjects (non-athletes) during running 400-meter for three strategies of run, then the IMNF and IMDF features were extracted in the time-frequency domain to use it as an indicator of the muscles fatigue. Finally, the linear regression applied to these features separately to detect the muscles fatigue of each 100m to know which strategy get less fatigue.

## Materials and Methods

The EMG signals are collected from the RF, BF, GM, GL, and GMS muscles of the right leg during running for 400-meters with three strategies. Next signals are processed, then extracted the features of IMNF and IMDF to detect the muscles fatigue.

### Subjects

Five active young male adults volunteered to participate in this study for running 400-meter. All subjects gave their written informed consent before participation. Subject's mean and standard deviation of age, height, heart rate, and body mass index were 22.2 (0.83) years, 170.6 (2.70) cm, 192 (3.2) bpm, and 25.06 (3.31) kg, respectively. Furthermore, the subjects were mentally prepared and physically healthy throughout the experiment.

### Procedures

The EMG electrodes were fixed on the selected muscles after preparing the skin. However, the electrodes wires were tightened using tape and bandages to avoid disturbing the subject and be tighten so it will not be disconnected when the subject runs. The heart rate monitor was connected to the subject's chest to monitor their heart rate with each strategy [16]. To prove the subjects running with max speed with the 1st and 2nd strategies the heat rate beat has been recorded for all subjects [17]. However, the heart rate was recorded by using heart rate monitor model (HRM-Run™, Garmin Ltd. Lenexa, Kansas, U.S.A). EMG measurements were recorded during the run on the tartan athletic track for three strategies on separate days by using the Eego amplifier and bipolar disposable electrodes (Eego™sports). The time for each 100-m has been recorded where cones were used to determine each 100-m of the tartan athletic track. The first cone to indicate the start point, the second cone to indicate the end of the 1st 100-m, the third cone was for the 2nd 100-m, the fourth cone was for the 3rd 100-m, and so on. However, the subjects were asked to warm up for 5 minutes (jogging) before starting the running. After the warming up procedure, the subject was rest for 5 minutes. Eego amplifier has been placed in the back bag of the subject as shown in Fig. 1.

Fig. 1. Eego amplifier.

Then the subject was started running for 400-m on an outdoor running track (tartan athletic) for three types of running strategies, as shown in Table 1.

Table 1. The type of running strategies.

| No | Strategy |
|---|---|
| 1 | 1st 200-meter 85-93% of sprinting and last 200-meter sprinting |
| 2 | 1st 300-meter 85-93% 0f sprinting and last 100-meter sprinting |
| 3 | 400-meter 85-93% of sprinting speed. |

**EMG Data Collection**

Surface EMG has continuously recorded the data from five lower limb muscles (RF, BF, GM, GL, and GMS) using the eego amplifier during the testing. However, after located the muscles location according to SENIAM recommendations [18] and prepared the skin for fixing the electrodes on the skin muscles, then shaving the hair and dead skin with a disposable blade. Next, the shaved area was cleaned with cotton dipped in alcohol until the area turned red. After letting the alcohol evaporate, the electrodes were placed in a bipolar configuration, each electrode is a 10 mm sized circle with an inter-electrode distance of 20 mm. The placement was done by tapping the electrodes on all sides to ensure that they would not detach during testing, or due to excessive sweating during running. The cable of the electrodes was tightly fixed to minimize the movement of the cables during running and preventing the cables from coming off. where the electrodes fixed to the selected muscles: RF, BF, GM, GL, and GMS muscles, the electrodes placement is shown in Fig. 2.

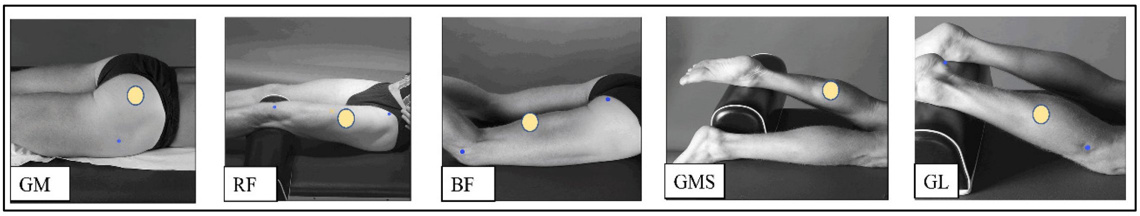


Fig. 2. The yellow-colored ball represented electrodes placement [18].

The EMG signals were collected from the subjects by using the Eego amplifier. However, the EMG signals were recorded with a sampling rate of 2000 Hz and filtered with two different types of filters, namely; band stop filter 50 Hz for removing line noise, and 2$^{nd}$ order Butterworth bandpass filter (20-450 Hz). These filters are recommended for sEMG during dynamic movements [18]. The sEMG signal contained the original signal measured from the muscle and it was contaminated with unavoidable different types of noise, especially during dynamic movements [19]. The raw and filtered EMG signal is shown in Fig. 3.

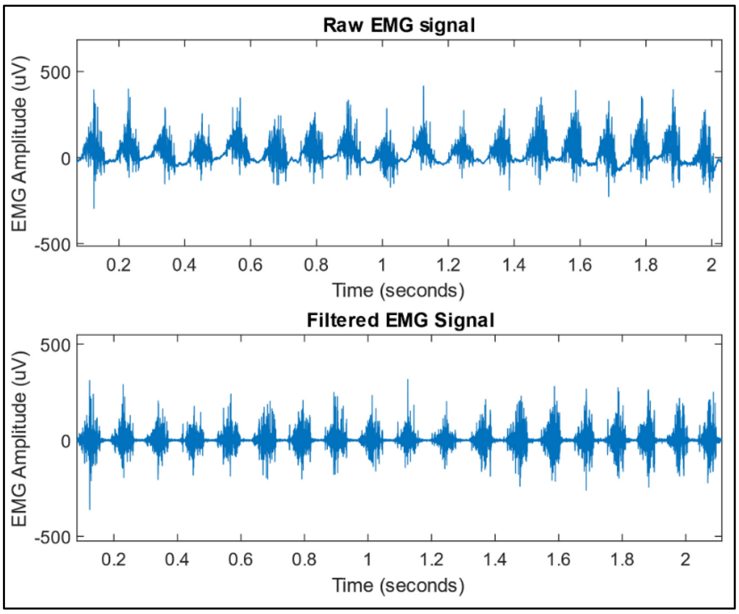


Fig. 3. The raw and filtered EMG signal for one muscle only as an example.

**Data Transformation**

Short-Time Fourier Transform (STFT) was used to transfer the EMG signals from the time domain to the time-frequency domain. The time-frequency distributions look at the frequencies that exist at a certain time of the signal. STFT takes a small part of the time (window) and applies fourier transform for that part then moves to the next window and does the same thing. At each window a different spectrum is obtained, and the totality of these spectrums is a time-frequency distribution [19]. Then, the EMG signal was segmented into half second (window size = 1000 samples) and the windows of the EMG signal were overlapped with 50% of the window size. The spectrogram uses STFT to calculate power spectral density for each window, which was used to extract the instantaneous features (IMDF and IMNF).

**Statistical Analysis**

Statistical analysis converts numbers into meaningful conclusions. Whereas the statistical analysis should be applying to extracted features in order to determine whether or not there is a significant difference between each strategy (running strategy) on the muscle fatigue [20]. In this research the linear regression and analysis of variance has been used as a statistical analysis method.

### Linear Regression

Linear Regression is a modeling approach to show the relationship between the dependent variables and the independent variable (time) and was applied to the IMNF and IMDF for each muscle. The negative slope of linear regression indicates the fatigue index. The results are compared for all subjects on individual muscles under three strategies.

However, in order to quantify the distribution of time-frequency domain features during the experiment of 400-meters, a linear regression analysis was applied to evaluate the trend of fatigue indices [21]. The linear function is defined in equation (1).

$$y = mx + b \tag{1}$$

Where y is the feature of time-frequency domain and $x$ is the time interval, $m$ is the regression slope value (fatigue index), and $b$ is the intercept (the value of **y** when **x** = 0). If the values of $m$ were negative that is mean there is fatigue, but if were positive that is mean there is no fatigue. Indeed, with time frequency domain the muscles fatigue based on the pattern of the features, where if the patterns of the features are decreased toward the negative slope that's mean fatigue. While if the patterns of the features are increased toward the positive slope that's mean recovery (non-fatigue), because the fatigue is known to be reflected in the EMG signal as an increase of its amplitude and a decrease of its spectral characteristics [22].

### Analysis of Variance

Analysis of Variance (ANOVA) is a statistical model used to analyze the variation among and between different groups. In this research, one-way ANOVA statistical analysis has been used to compare and find the significance of the slope values of linear regression for IMNF and IMDF at each strategy. One-way ANOVA was applied for each muscle separately of all subjects to find the significance for each muscle between the types of running strategies.

## Results

### Instantaneous Median Frequency (IMDF) Results

IMDF features were extracted from the preprocessed sEMG signal. Fig. 4 shows the continuous plots for IMDF for one muscle (GL) of one subject during the 3rd strategy of running as an example. The x-axis is the running duration time in seconds and the y-axis is the median frequency with regards to the running time. Linear regression method was applied to the IMDF for each signal. The slope orientation indicates the fatigue index, as shown in Fig. 5.

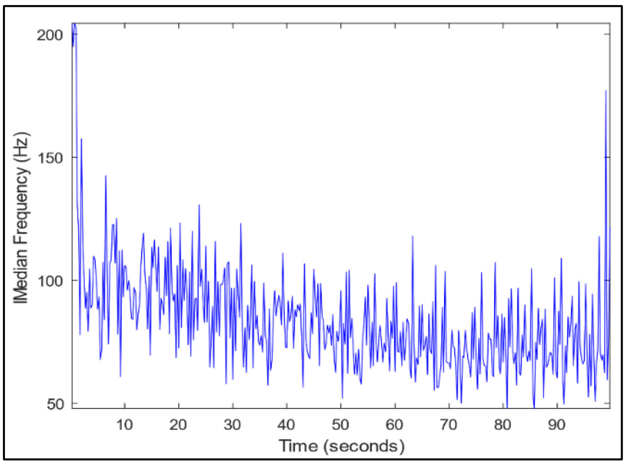


Fig. 4. IMDF for GL muscle for one subject during the 3rd strategy of running.

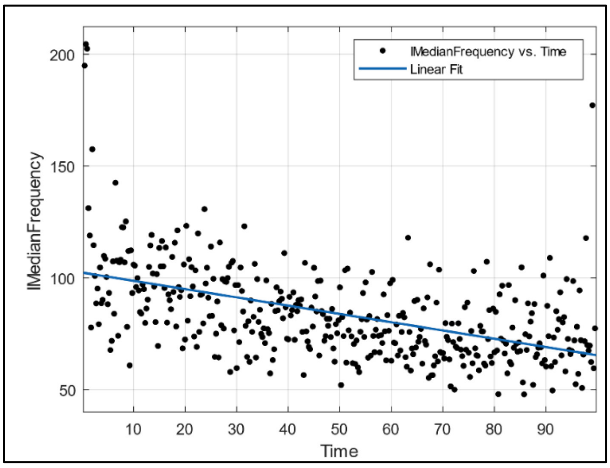


Fig. 5. Linear regression applied to IMDF for GL muscle for one subject during the 3rd strategy of running without segmenting the signal.

It is noticeable from Fig 5, the slope regression had a negative slope that indicates there is fatigue. After recording each slope for each muscle at the three strategies, the mean and standard deviation (STD) for the slope regression values were calculated for all subjects at each 100m to get more details about the results, check Table 2.

Table 2. Mean and STD values for linear regression slope applied to IMDF for individual muscles with three types of running strategy. (a)1st 100-m, (b) 2nd 100-m, (c) 3rd 100-m, and (d) 4th 100-m.

(a)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 1st 100 | MEAN | -0.232 | -0.187 | 0.089 | -0.021 | -0.052 |
| | | STD | 0.092 | 0.124 | 0.063 | 0.019 | 0.059 |
| 2nd strategy | 1st 100 | MEAN | -1.554 | -1.393 | -0.364 | -0.085 | 0.162 |
| | | STD | 2.003 | 1.381 | 0.565 | 0.605 | 0.265 |
| 3rd strategy | 1st 100 | MEAN | -0.410 | -0.381 | -0.257 | -0.400 | -0.193 |
| | | STD | 0.276 | 0.609 | 0.317 | 0.231 | 0.194 |

(b)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 2nd100 | MEAN | -0.0004 | 0.025 | 0.016 | -0.062 | -0.016 |
| | | STD | 0.043 | 0.052 | 0.032 | 0.051 | 0.016 |
| 2nd strategy | 2nd100 | MEAN | 0.098 | 0.262 | -0.040 | 0.042 | 0.093 |
| | | STD | 0.092 | 0.313 | 0.321 | 0.182 | 0.116 |
| 3rd strategy | 2nd100 | MEAN | -0.005 | -0.454 | -0.025 | 0.017 | 0.028 |
| | | STD | 0.288 | 0.474 | 0.249 | 0.221 | 0.174 |

(c)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 3rd 100 | MEAN | -0.018 | 0.016 | -0.014 | -0.007 | 0.007 |
| | | STD | 0.018 | 0.024 | 0.022 | 0.024 | 0.049 |
| 2nd strategy | 3rd 100 | MEAN | -0.145 | -0.151 | -0.350 | -0.058 | -0.153 |
| | | STD | 0.592 | 0.832 | 0.742 | 0.050 | 0.257 |
| 3rd strategy | 3rd 100 | MEAN | 0.008 | 0.005 | 0.001 | 0.077 | 0.024 |
| | | STD | 0.110 | 0.084 | 0.170 | 0.178 | 0.168 |

(d)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 4th 100 | MEAN | 0.040 | 0.051 | 0.027 | 0.015 | -0.043 |
| | | STD | 0.109 | 0.075 | 0.064 | 0.019 | 0.024 |
| 2nd strategy | 4th 100 | MEAN | 1.108 | 0.226 | 0.306 | 0.411 | 0.875 |
| | | STD | 1.870 | 0.369 | 1.301 | 0.494 | 1.228 |
| 3rd strategy | 4th 100 | MEAN | 0.713 | 0.909 | 0.727 | 0.667 | 0.699 |
| | | STD | 0.889 | 1.575 | 1.237 | 1.563 | 1.384 |

Fig. 6 shows the plot for mean and STD results for the applied linear regression slope to IMDF for one muscle with three strategies of running.

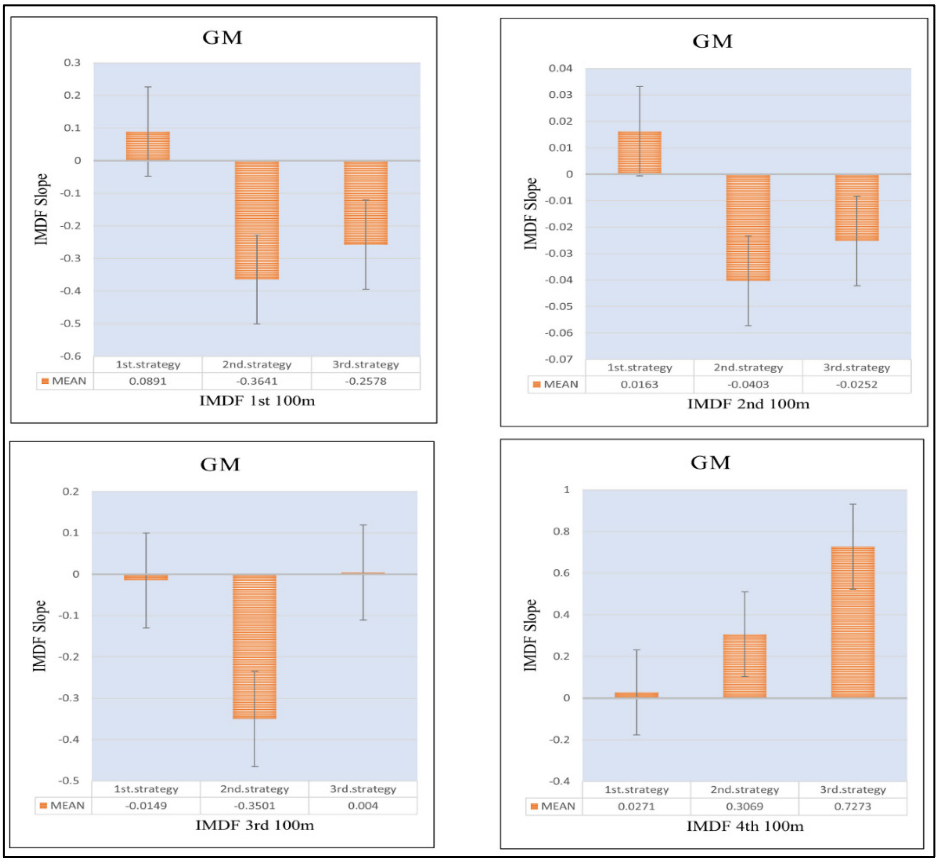


Fig. 6. IMDF, means, and STD of linear regression slope for GM muscle for all subjects with three types of running strategies.

It is noticeable from Fig 6, the GM muscle got less fatigue with the 1$^{st}$ strategy during the 3$^{rd}$ 100m compared to the other strategies. The GM muscles did not get any fatigue with the 1$^{st}$ strategy at 1$^{st}$ 100-m, while it got recovery and resting with the 2$^{nd}$ and 3$^{rd}$ strategies at the 4$^{th}$ 100m.

One-way ANOVA was applied for each muscle separately (mean of regression slope) with three strategies of running, to find the significance for each muscle between the strategies at each 100m. Table 3 shows the *p*-value results for linear regression slope of all tests.

Table 3. The p-value of ANOVA results for three strategies test to find the significance of the linear regression slope (IMDF) between 1$^{st}$ strategy, 2$^{nd}$ strategy, and 3$^{rd}$ strategy for each 100m. (a)1$^{st}$ 100-m, (b) 2$^{nd}$ 100-m, (c) 3$^{rd}$ 100-m, and (d) 4$^{th}$ 100-m.

| (a) | | | (b) | | |
|---|---|---|---|---|---|
| **Muscles** | **p-value** | **ANOVA test** | **Muscles** | **p-value** | **ANOVA test** |
| RF | 0.009 | P < 0.05 | RF | 0.621 | P > 0.05 |
| BF | 0.104 | P > 0.05 | BF | 0.014 | P < 0.05 |
| GM | 0.179 | P > 0.05 | GM | 0.925 | P > 0.05 |
| GL | 0.268 | P > 0.05 | GL | 0.606 | P > 0.05 |
| GMS | 0.038 | P < 0.05 | GMS | 0.383 | P > 0.05 |
| (c) | | | (d) | | |
| **Muscles** | **p-value** | **ANOVA test** | **Muscles** | **p-value** | **ANOVA test** |
| RF | 0.762 | P > 0.05 | RF | 0.405 | P > 0.05 |
| BF | 0.829 | P > 0.05 | BF | 0.341 | P > 0.05 |
| GM | 0.391 | P > 0.05 | GM | 0.576 | P > 0.05 |
| GL | 0.178 | P > 0.05 | GL | 0.563 | P > 0.05 |
| GMS | 0.266 | P > 0.05 | GMS | 0.383 | P > 0.05 |

It is noticeable from Table 3 (a), only RF and GMS muscle had significant results between the 1st, 2nd, and 3rd strategies for the 1st 100-m of running. Table 3 (b) shows only BF muscle had significant results between the strategies of running for the 2nd 100m of running. Table 3 (c) and (d) shows no significant results for all strategies at the 3rd and 4th 100m of the running.

**Instantaneous Mean Frequency (IMNF) Results**

IMNF feature was extracted from preprocessed sEMG signals. Fig. 7 demonstrates the continuous plots for IMNF for one muscle (GL), for one subject during the 3rd strategy of running as an example. The x-axis is the running duration time in seconds and the y-axis is the mean frequency regarding the running time. Linear regression method was applied to the IMNF for each signal. The slope orientation indicates the fatigue index, as shown in Fig. 8.

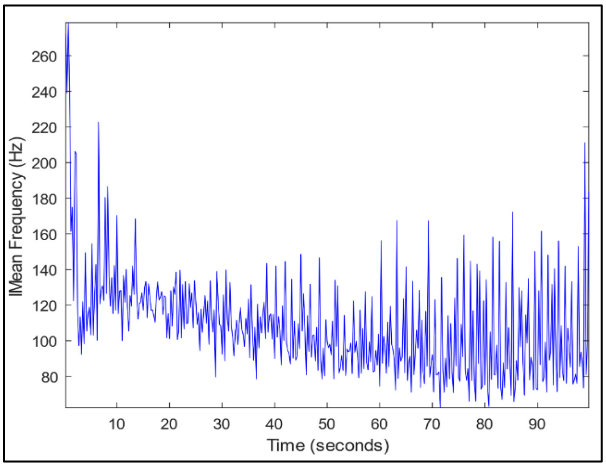


Fig. 7. IMNF for GL muscle for one subject during the 3rd strategy of running.

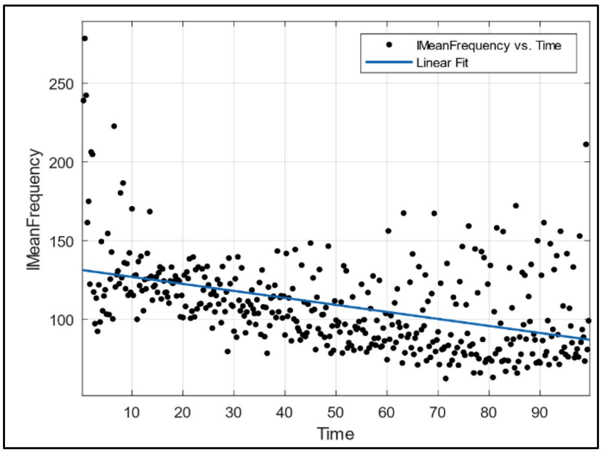


Fig.8. Linear regression applied to IMNF for GL muscle for one subject during the 3rd strategy of running without segmenting the signal.

It is noticeable from Fig. 8, the slope regression has a negative slope, that means there is fatigue. After recording each slope for each muscle with the three strategies, the mean and standard deviation for the regression slope were calculated for all subjects at each 100m to get more details about the results, check Table 4.

Table 4. Mean and standard deviation results for linear regression slope applied to IMNF for individual muscles with three types of running strategies. (a)1st 100-m, (b) 2nd 100-m, (c) 3rd 100-m, and (d) 4th 100-m.

(a)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 1st 100 | MEAN | -0.211 | -0.158 | -0.067 | -0.038 | -0.067 |
| | | STD | 0.065 | 0.098 | 0.043 | 0.015 | 0.046 |
| 2nd strategy | 1st 100 | MEAN | -1.678 | -1.439 | -0.641 | -1.194 | -0.356 |
| | | STD | 0.979 | 1.049 | 0.817 | 1.032 | 1.081 |
| 3rd strategy | 1st 100 | MEAN | -0.387 | -0.339 | -0.300 | -0.361 | -0.301 |
| | | STD | 0.126 | 0.522 | 0.522 | 0.201 | 0.178 |

(b)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 2nd 100 | MEAN | 0.004 | 0.014 | 0.015 | -0.055 | -0.002 |
| | | STD | 0.025 | 0.029 | 0.026 | 0.036 | 0.019 |
| 2nd strategy | 2nd 100 | MEAN | 0.152 | 0.357 | -0.079 | 0.060 | 0.008 |
| | | STD | 0.136 | 0.388 | 0.348 | 0.191 | 0.459 |
| 3rd strategy | 2nd 100 | MEAN | -0.021 | -0.666 | -0.031 | 0.008 | 0.076 |
| | | STD | 0.226 | 0.613 | 0.290 | 0.219 | 0.273 |

(c)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 2nd 100 | MEAN | -0.0007 | 0.016 | -0.014 | -0.006 | 0.0007 |
| | | STD | 0.009 | 0.014 | 0.020 | 0.015 | 0.033 |
| 2nd strategy | 3rd 100 | MEAN | 0.004 | -0.274 | -0.375 | -0.1736 | -0.207 |
| | | STD | 0.451 | 1.131 | 0.970 | 0.272 | 0.208 |
| 3rd strategy | 3rd 100 | MEAN | -0.002 | 0.026 | -0.047 | 0.080 | -0.050 |
| | | STD | 0.073 | 0.147 | 0.084 | 0.129 | 0.192 |

(d)

| Type of strategies | | | RF | BF | GM | GL | GMS |
|---|---|---|---|---|---|---|---|
| 1st strategy | 4th 100 | MEAN | 0.031 | 0.036 | 0.063 | 0.008 | -0.038 |
| | | STD | 0.088 | 0.059 | 0.079 | 0.016 | 0.030 |
| 2nd strategy | 4th 100 | MEAN | 1.874 | 0.054 | 1.011 | 0.587 | 1.063 |
| | | STD | 1.780 | 0.450 | 1.228 | 0.924 | 0.924 |
| 3rd strategy | 4th 100 | MEAN | 0.539 | 0.682 | 0.665 | 0.515 | 0.594 |
| | | STD | 0.741 | 1.170 | 1.089 | 1.245 | 1.215 |

Fig. 9 shows the plot for mean and STD results for the linear regression slope applied to IMNF for one muscle with three types of running strategies as an example.

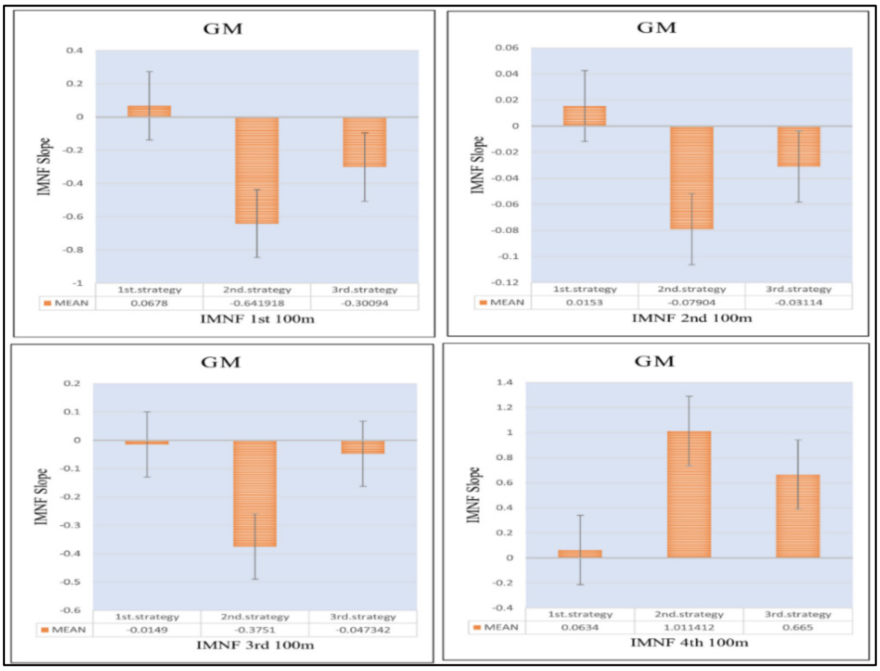


Fig.9. IMNF means and STD of linear regression slope for one muscle for all subjects with three types of running strategies for GM muscle.

It is noticeable from Fig. 9, GM muscle got less fatigue (linear regression slope rate value) with the 1st strategy during the 3rd 100m compared to the other strategies. However, it did not get any fatigue with the 1st strategy at the 1st 100-m. while it got recovery and resting with the 2nd and 3rd strategy at the 4th 100m.

One-way ANOVA was applied for each muscle separately (mean of regression slope) with the three strategies of running, to find the significance for each muscle between the variable strategies at each 100m. Table 5 shows the *p*-value results for linear regression slope.

Table 5. The p-value of ANOVA results for three strategies test to find the significance of the linear regression slope (IMNF) between 1st strategy, 2nd strategy, and 3rd strategy for each 100m. (a)1st 100-m, (b) 2nd 100-m, (c) 3rd 100-m, and (d) 4th 100-m.

| (a) | | | (b) | | |
|---|---|---|---|---|---|
| **Muscles** | **p-value** | **ANOVA test** | **Muscles** | **p-value** | **ANOVA test** |
| RF | 0.002 | **P < 0.05** | RF | 0.193 | P > 0.05 |
| BF | 0.023 | **P < 0.05** | BF | 0.006 | **P < 0.05** |
| GM | 0.155 | P > 0.05 | GM | 0.852 | P > 0.05 |
| GL | 0.028 | **P < 0.05** | GL | 0.567 | P > 0.05 |
| GMS | 0.751 | P > 0.05 | GMS | 0.907 | P > 0.05 |
| (c) | | | (d) | | |
| **Muscles** | **p-value** | **ANOVA test** | **Muscles** | **p-value** | **ANOVA test** |
| RF | 0.999 | P > 0.05 | RF | 0.086 | P > 0.05 |
| BF | 0.721 | P > 0.05 | BF | 0.311 | P > 0.05 |
| GM | 0.550 | P > 0.05 | GM | 0.314 | P > 0.05 |
| GL | 0.105 | P > 0.05 | GL | 0.555 | P > 0.05 |
| GMS | 0.158 | P > 0.05 | GMS | 0.299 | P > 0.05 |

It is noticeable from Table 5 (a), GL, BF, and RF muscles have significant results between the 1st, 2nd, and 3rd strategies for the 1st 100-m of running. Table 5 (b) shows only BF muscle has a significant result between the strategies of running for the 2nd 100m of running. Table 5 (c) and (d) shows no significant result for all strategies at the 3rd and 4th 100m of the running.

## Discussion

Performance of the 400 m runners influenced by some factors like fitness level, psychological readiness, and training methods. Formation of lactate during the 400-m event influences the performance of the athlete. However, the sprinting requires repetitive action carried out by lower limbs. Thus, one of the consequences of repetitive action is fatigue which associated with decreased physical functioning and decreased running performance. This effect must be highly avoided in sprinting sport. The fatigue can be detected by analyzing the EMG signal.

In biomechanics, the EMG is one of the best methods to analyze and provide a helpful detail about muscle activity which may be beneficial in optimizing the performance or reducing the possibility of harms. This is critical for athletes such as runners since the likelihood of injury increases with sprinting.

Sprinting performance in track and field sprinters takes muscular strength and power to complete a 100 or 200-meter dash. Maximum sprinting speed is defined as the time to reach peak stride length and stride frequency [23].

From the results of Table 2(a) for IMDF feature it can be observing the following: the lowest fatigue of RF, BF, GL, and GMS muscles were (-0.232), (-0.187), (-0.021), and (-0.052) respectively during the 1st strategy. For GM muscle was (-0.257) during the 3rd strategy. GM muscle did not get fatigue during the 1st strategy while the GMS muscle did not get fatigue during the and 2nd strategy. From the results of Table 4(a) for IMNF feature it can be observing the following: the lowest fatigue of RF, BF, GM, GL, and GMS muscles were (-0.211), (-0.158), (-0.067), (-0.038), and (-0.067) respectively during the 1st strategy. The results show the time-frequency domain features of most the selected muscles get less fatigues with the 1st strategy of running during the 1st 100-m. However, the speed of running is varying from one subject to another. We calculated the mean value and standard deviation of the slope regression for all subjects to detect the fatigue and to evaluate running strategies using fatigue index. Sometimes the sprinters reduce their force as reported in Elena Bergamini [24] trying to save their energy at the beginning.

From Table 3 and Table 5, we can observe that the p-value of ANOVA test was $P < 0.05$ for RF and GMS muscles for the 1st 100-m with IMDF feature during the 1st, 2nd, and 3rd strategy, that mean there is a significance between the slope regression of the muscles after getting the muscle fatigue. While with IMNF the p-value was $P<0.05$ for RF and GL muscle only.

From the results of Table 2(b) for IMDF feature. it can be observing the following: the lowest fatigue of RF, GL, and GMS muscles were (-0.0004), (-0.062), (-0.016) respectively during the 1st strategy. For BF, and GM muscles were (-0.454) and (-0.025) respectively during the 3rd strategy. However, most of the selected muscles did not get fatigue during the 2nd strategy. From the results of Table 4(b) for IMNF feature it can be observing the following: the lowest fatigue of RF, BF, and GM muscles were (-0.021), (-0.6660, and (-0.031) respectively during the 3rd strategy. For GL, and GMS muscles were ( -0.055), and ( -0.002) respectively during the 1st strategy. However, most of the selected muscles did not get fatigue during the 2nd strategy. The results show the time-frequency domain features of most the selected muscles get less fatigue with the 1st strategy of running during the 2nd 100-m.

From Table 3 and Table 5, we can observe that the p-value of ANOVA test was $P < 0.05$ for BF muscle for the 2nd 100m with IMDF and IMNF features during the 1st, 2nd, and 3rd strategy, that mean there is a significance between the slope regression values of the muscles after getting the muscle fatigue.

From the results of Table 2(c) for IMDF feature, it can be observing the following: the lowest fatigue of RF, GM, and GL muscles were (-0.018), -0.014), and ( -0.007) respectively during the 1st strategy. For BF and GMS muscles were (-0.151) and (-0.153) respectively during the 2nd strategy. However, the selected muscles did not get fatigue during the 3rd strategy. From the results of Table 4(c) for IMNF feature it can be observing the following: the lowest fatigue of RF, GM, and GL muscles were (-0.0007), (-0.014), and ( -0.006) respectively during the 1st strategy. For BF muscle was (-0.274) during the 2nd strategy, and for GMS muscle was ( -0.050) during the 3rd strategy. Some of the selected muscles did not get fatigue during the 1st and 3rd strategies. However, as the results show that the time-frequency domain features of most the selected muscles, get less fatigue with the 1st strategy of running during the 3rd 100-m.

From Table 3 and Table 5, we can observe that, the p-value of ANOVA test was $P >0.05$ for all muscle with the two features (IMNF and IMDF) that mean, there is no significant between the results of slope regression for the selected muscles during running with three strategies at the 3rd 100m of 400m running event.

From the results of Table 2(d) for IMDF feature and Table 4(d) for IMNF feature, it can be observing the following: the lowest fatigue of GMS muscle was ( -0.043), (-0.038) respectively during the 1st strategy and did not get fatigue with the 2nd and 3rd strategies while the RF, BF, GM, and GL muscles did not get fatigue during the 1st, 2nd, and 3rd strategy (got recovery), sometimes these phenomena occur when the subject reduce his force, or sometimes the muscles recovery [24]. However, as the results show that the time-frequency domain feature of most the selected muscles, did not get any fatigues with the 1st, 2nd, and 3rd strategies of running during the 4th 100m.

From Table 3 and Table 5, we can observe that, the p-value of ANOVA test was $P >0.05$ for all muscle with the two features (IMNF and IMDF) that mean, there is no significant between the results of slope regression for the selected muscles during running with three strategies at the 4th 100m of 400m running event.

## Conclusion

As stated previously, the IMNF and IMDF values indicating the fatigue of muscles. The relationship between IMNF and IMDF and the level of fatigue are directly proportional to each other at most times. From all the results we can notice that the lowest negative values of the regression slope, were as following:

During the 1st 100-m, most of the selected muscles get less fatigue with the 1st strategy of running. Also, for the 2nd 100m, most of the selected muscles get less fatigue with the 1st strategy of running. For the 3rd 100, most of the selected muscles get less fatigues with the 1st strategy of running. For the 4th 100m, the RF, BF, GM, and GL muscles were having a positive slope values for IMNF and IMDF with the three strategies. The GMS muscle has less negative slope value with IMNF during 1st strategy, that means there is no fatigue with the last 4th 100m of running event, except the GMS muscle get less fatigue. From the results of all strategies with the selected muscles, the lowest fatigue and highest recovery times were during the 1st strategy for most selected muscles.

## References

[1] A. Gefen, M.Megido-Ravid, Y. Itzchak, and M. Arcan, Analysis of muscular fatigue and foot stability during high-heeled gait. Gait & posture, 15 (2002), 56-63.

[2] C. Fritschi, and L. Quinn, Fatigue in patients with diabetes: a review. Journal of psychosomatic research, 69(2010), pp.33-41.

[3] R.M. Enoka, and J. Duchateau, Muscle fatigue: what, why and how it influences muscle function. The Journal of physiology, 586 (2008), pp.11-23.

[4] A. Koller, J. Mair, W. Schobersberger, T. Wohlfarter, C. Haid, M. Mayr, B. Villiger, W. Frey, and B. Puschendorf, Effects of prolonged strenuous endurance exercise on plasma myosin heavy chain fragments and other muscular proteins. Cycling vs running. The Journal of sports medicine and physical fitness, 38(1998), pp.10-17.

[5] G.C. Bogdanis, Effects of physical activity and inactivity on muscle fatigue. Frontiers in physiology, 3 (2012), p.142.

[6] A.M. Hunter, A.S.C. Gibson, M.I. Lambert, L. Nobbs, and T.D. Noakes, Effects of supramaximal exercise on the electromyographic signal. British journal of sports medicine, 37(2003), pp.296-299.

[7] D. Roman-Liu, T. Tokarski, and K. Wójcik, Quantitative assessment of upper limb muscle fatigue depending on the conditions of repetitive task load. Journal of Electromyography and Kinesiology, 14(2004), pp.671-682.

[8] A.T. Nummela, K.A. Heath, L.M. Paavolainen, M.I. Lambert, A.S.C. Gibson, H.K. Rusko, and T.D. Noakes, T.D, Fatigue during a 5-km running time trial. International journal of sports medicine, 29 (2008), pp.738-745.

[9] M.R. Al-Mulla, F. Sepulveda, and M. Colley, A review of non-invasive techniques to detect and predict localised muscle fatigue. *Sensors*, *11*(2011), pp.3545-3594.

[10] M. Hu, T. Finni, M. Alen, J. Wang, L. Zou, W. Zhou, and S. Cheng, Myoelectrical manifestations of quadriceps fatigue during dynamic exercise differ in mono-and bi-articular muscles. Biology of Sport, 23(2006), pp.327-339.

[11] J. Mizrahi, O. Verbitsky, and E. Isakov, Fatigue-related loading imbalance on the shank in running: a possible factor in stress fractures. Annals of biomedical engineering, 28 (2000), pp.463-469.

[12] A. Mastalerz, L. Gwarek, J. Sadowski, and T. Szczepanski, The influence of the run intensity on bioelectrical activity of selected human leg muscles. Acta Bioeng Biomech, 14 (2012), pp.101-107.

[13] J.M. Zuniga, and M.H. Malek, Electromyographic responses of the superficial quadriceps femoris muscles during incremental treadmill running. Muscle & nerve, 48 (2013), pp.938-944.

[14] L.F. Crozara, A. Castro, A.F. De Almeida Neto, D.P. Laroche, A.C. Cardozo, and M. Gonçalves, Utility of electromyographic fatigue threshold during treadmill running. Muscle & nerve, 52 (2015), pp.1030-1039.

[15] N. Ridzuan, A. Azaman, K. Soeed, I. Zulkapri, and A.A. Wahab, Muscle Fatigue Evaluation using Non-invasive Infrared Thermography Technique with Assisted Electromyography: A Preliminary Study, International Medical Device and Technology Conference, 2017, 251-251.

[16] Garmin., United Kingdom., 2016, http://www.garmin.com/en-GB.

[17] A. Jeukendrup, and A.V. Diemen, Heart rate monitoring during training and competition in cyclists. Journal of Sports Sciences, 16(1998), pp.91-99.

[18] H.J. Hermens, B. Freriks, R. Merletti, D. Stegeman, J. Blok, G. Rau, C. Disselhorst-Klug and G. Hägg, European recommendations for surface electromyography. Roessingh research and development, 8(1999), pp.13-54.

[19] C.J. De Luca, L.D. Gilmore, M. Kuznetsov, and S.H. Roy, Filtering the surface EMG signal: Movement artifact and baseline noise contamination. Journal of biomechanics, 43(2010), pp.1573-1579.

[20] M. Sarillee, M. Hariharan, M.N. Anas, M.I. Omar, M.N. Aishah, and Q.W. Oung, November. Assessment muscle fatigue using statistical study and classification: A review. In 2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE) (pp. 206-211). IEEE.

[21] H. Xie and Z. Wang, "Mean frequency derived via Hilbert-Huang transform with application to fatigue EMG signal analysis," vol. 2, 2006, pp. 114–120.

[22] M. Hakonen, H. Piitulainen, and A. Visala, Current state of digital signal processing in myoelectric interfaces and related applications. Biomedical Signal Processing and Control, 18 (2015). 334-359.

[23] M. Krzysztof, A. and Mero, A kinematics analysis of three best 100 m performances ever. Journal of human kinetics, 36(2013), pp.149-160.

[24] E. Bergamini, Biomechanics of sprint running: a methodological contribution (Doctoral dissertation, Arts et Métiers ParisTech), 2011.