International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 4 Issue 5, July-August 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Effect of Endurance on Gastrocnemius Muscle with Exercise by Employing EMG Amplitude Parameters

Gaurav Patti, Poonam Kumari

University Centre of Instrumentation and Microelectronics, Panjab University, Chandigarh, India

ABSTRACT

Muscle fatigue is a common experience in daily life. Many authors have defined it as the incapacity to maintain the required or expected force, and therefore, force, power and torque recordings have been used as direct measurements of muscle fatigue. In addition, the measurement of these variables combined with the measurement of surface electromyography (sEMG) recordings (which can be measured during all types of movements) during exercise may be useful to assess and understand muscle fatigue.

EMG signal can be easily analyzed in time domain, frequency domain and time-frequency domain. The time domain features are the most popular in EMG pattern recognition because they are easy and quick to calculate and they do not require a transformation. The purpose of this study was to analyze the fatigue and to study the endurance occurrence in the Gastrocnemius muscle with a pre-defined exercise protocol for the targeted muscle. For this purpose, sEMG Amplitude parameters were characterized. Relation between EMG features like mean, force, standard deviation, etc. is verified for fatigue detection as well as to identify the Endurance developed in the Gastrocnemius muscle.

KEYWORDS: *EMG, Fatigue, Endurance, Gastrocnemius muscle, Amplitude parameters, Mean, Force, Standard deviation*

How to cite this paper: Gaurav Patti | Poonam Kumari "Effect of Endurance on Gastrocnemius Muscle with Exercise by Employing EMG Amplitude Parameters" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-5, August 2020, pp.1564-1570, URL: www.ijtsrd.com/papers/ijtsrd33222.pdf

IJTSRD33222

I. INTRODUCTION

Electromyography is a seductive muse because it provides easy access to physiological processes that cause the muscle to generate force produce movement and accomplish the countless functions which allow us to interact with the world around us. Clinical electromyography (EMG) is the name applied to the investigation of the electrical activity of normal and diseased skeletal muscle of extracellular electrodes. EMG is sometimes referred to as myoelectric activity. It provides important information on the physiological status of skeletal muscle and its nerve supply. It is more of a qualitative than quantitative measure because it detects the difference in potential between two points along a muscle rather than single voltage. [1]

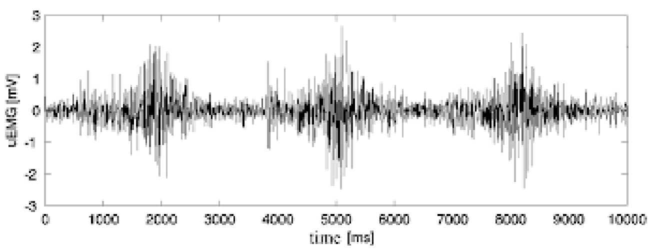

Figure 1: EMG Signal

Electromyography is an instrument for recording the electrical activity of nerves and muscles. Electro means to the electricity, myo means muscle and the graph means that the signal is written down. The electrical signals can be taken from the body either by placing needle electrodes in the muscle or by attaching the surface electrodes over the muscle. Needle electrodes are used where the clinician wants to investigate neuromuscular disease by looking at the shape of electromyogram. One may also listen to the signal by playing them through the loudspeaker, as the ear can detect subtle differences between normal and abnormal EMG signal. Surface electrodes are only used where the overall activity of a muscle is to be recorded; they may be used for clinical or physiological research but are not used for diagnosing muscle disease. [2]

There are two classes of sEMG (Non-Fatigue and Fully Fatigue). These classes relate to the status of the muscle and each class will produce different features. The features were extracted by using the EMG data recording system, which are relevant to sEMG analysis and are further used for prediction and detection of the particular leg muscle (i.e. Gastrocnemius) fatigue.

II. EMG FEATURE EXTRACTION

EMG analysis can employ Time Domain, Frequency Domain or Time-Frequency Domain analysis for parameters extraction. Some features have been used in studies to detect fatigue using EMG. These are discussed below:

1. Mean Absolute Value

Mean Absolute Value (MAV) is similar to average rectified value (ARV). It can be calculated using the moving average of full-wave rectified EMG. In other words, it is calculated by taking the average of the absolute value of sEMG signal. It is an easy way for detection of muscle contraction levels and it is a popular feature used in myoelectric control application.[3] It is defined as

$$MAV = \frac{1}{N}\sum_{n=1}^{N}|x_n|$$

2. Median Frequency

MDF is a frequency value at which the EMG power spectrum is divided into two regions with an equal integrated power. [4] It is calculated by

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j$$

where P_j is the EMG power spectrum at a frequency bin j and M is the length of frequency bin. Power spectra density *P* was calculated by the method of Periodogram Welch.

3. Standard Deviation

It is defined as the standard deviation is a measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range. The standard deviation is given by:

$$x_{std} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

where $\bar{x}$ is the mean value.

4. Force

Muscular force is the force applied using parts of the body like arms or legs. It is force that results due to the action of muscles, and is a contact force, since there is a contact between the surfaces. In our project, dynamometer is used for measuring the maximum isometric strength and force of the leg. [5]

Endurance

We always come across a fact that as one gets sore muscles after physical activity, known as delayed onset muscle soreness (DOMS), can occur when you start a new exercise program, change your exercise routine, or increase the duration or intensity of your regular workout.

When muscles are required to work harder than they're used to or in a different way, it's believed to cause microscopic damage to the muscle fibres, resulting in muscle soreness or stiffness. Anyone can develop DOMS, even those who have been exercising for years, including elite athletes. The good news is that the soreness will decrease as your muscles get used to the new physical demands being placed upon them. The soreness is part of an adaptation process that leads to greater stamina and strength as the muscles recover and build. DOMS typically lasts between 3 and 5 days. [6]

Literature Review

The following papers were studied and analyzed in detail and hence summarized in the below table:

Table 1: Papers Reviewed

Topic of Paper	Features Analyzed	Tools Used	Application
1. The Effect of Endurance Exercise on Muscle Force Generating Capacity of the Lower Limbs [7]	Maximal isokinetic torque, Mean +/- Standard deviation, Force generating capacity	Six-second cycle test, Isokinetic test, Concentric squat jump	To investigate the recovery of muscle force generating capacity (FGC) of the lower limbs following a session of cycle exercise (CE).
2. Muscle Fatigue Analysis for Healthy Adults Using TVAR Model with Instantaneous Frequency Estimation [8]	Instantaneous frequency and Mean frequency estimation	Short time Fourier Transform, Time varying auto regressive method	This study confirms that TVAR can be a better tool for analyzing the level of Muscle fatigue which further leads to better performance in sports personnel.
3. The Use of Surface Electromyography in Biomechanics [9]	Fatigue index, Motor unit firing rate, Amplitude, duration, and shape of the MUAPs	Spectral modification, Cross correlation, signal scaling	Three groups of applications are considered: those involving the activation timing of muscles, the force/EMG signal relationship, and the use of the EMG signal as a fatigue index.
4. A Surface EMG based muscle fatigue evaluation in biomechanics [10]	Muscle fibre conduction velocity (CV), median frequency (MDF), RMS value	Zero-crossing rate (ZCR), Spike analysis, Fourier-based spectral estimators, Joint analysis of EMG spectrum and amplitude (JASA)	This paper aims to present a state of art in the area of local muscle fatigue evaluation in biomechanics by using sEMG information.

5. Surface EMG signal processing during isometric contractions [11]	Amplitude variables, spectral variables and muscle fiber conduction velocity	Signal scaling, spectral compression approach, Fourier Transform, Choi–Williams transform	Modeling approach may indeed be useful for the non-invasive characterization of superficial muscles and of their motor units and interpretation of the different rate of change of spectral variables.

III. METHODS AND MATERIAL

Firstly, raw sEMG signal data of Gastrocnemius muscle was recorded using EMG system recorder. Secondly, the acquired signal was analyzed for determination of various sEMG Amplitude parameters.

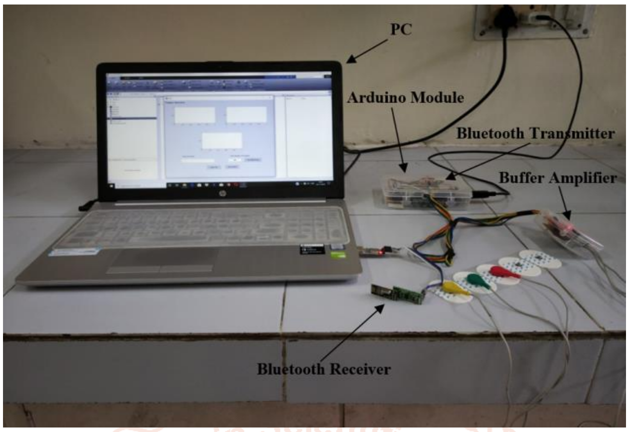

Figure 2: EMG and Fatigue recording setup

The Gastrocnemius Muscle

Gastrocnemius forms the major bulk at the back of lower leg and is a very powerful muscle. It is a two joint or biarticular muscle and has two heads and runs from back of knee to the heel. When running, walking or jumping the gastrocnemius provides a significant amount of propulsive force. Consider the amount of force required to propel the body into the air, triceps surae can generate a lot of force.

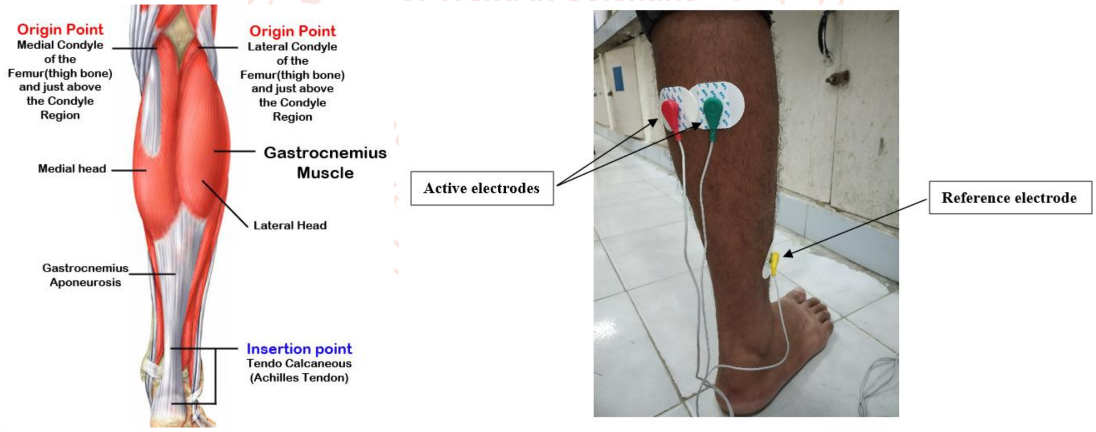

Figure 3: The Gastrocnemius Muscle

The sEMG of 11 healthy male adults (age 25±02 years) was recorded for 10 days with one-day break. The eleven participants were willing to reach physical fatigue state but not psychological one. They all were healthy and free from any pain and disease during previous year. Another thing volunteers had moderate (non-extreme) level of self-reported daily physical activity.

After being fully informed of the nature of the experiment, they signed an informed consent. First normal EMG, before starting the exercise protocol, was recorded for all of them. Then they performed the exercise and again EMG was recorded. Exercise included the three sets of calf muscle exercise as depicted in Figure 4 below.

Figure 4: Exercise Protocol

The steps involved are as follows:

1. The maximum isometric strength and force of the leg were measured using a Dynamometer.
2. Goniometer was placed on the right side of the leg muscle to measure the ankle angle w.r.t ground floor.
3. The hair were completely removed from the location where the EMG electrodes were to be placed and the skin was cleaned with ciprit in order to eliminate any wetness or sweat on the skin.
4. sEMG electrodes were placed on the participant's calves muscle to acquire sEMG readings.
5. The participants were asked to do calves exercise consisting of total three sets with a rest of 30 seconds between each set.
6. The participants were stopped when they reach fully fatigue stage and the data was recorded using the EMG data recording system.
7. The same task was repeated for 10 days.

Based on the obtained readings, the sEMG Amplitude parameters were extracted to predict the fatigue so as to obtain the desired results.

IV. RESULTS AND DISCUSSION

The purpose of this study was to analyze the fatigue and to study the endurance occurrence in the Gastrocnemius muscle with a pre-defined exercise protocol for the targeted muscle. For this purpose, sEMG Amplitude parameters were characterized.

A. Mean and Force

Table 2: Parameters values of Pre-Exercise Protocol Day

Subject	Day	Force	Mean ± Standard Deviation	Median Value
Subject 1	Normal	26.5	619.31 ± 1.189	619
Subject 2	Normal	10	618.70 ± 2.227	619
Subject 3	Normal	8	618.24 ± 1.486	618
Subject 4	Normal	11.5	620.31 ± 1.489	620
Subject 5	Normal	7	620.49 ± 1.358	621
Subject 6	Normal	18	619.31 ± 1.795	620
Subject 7	Normal	9.5	618.53 ± 1.812	619
Subject 8	Normal	12	618.09 ± 1.29	618
Subject 9	Normal	32	619.24 ± 1.214	619
Subject 10	Normal	19	619.07 ± 1.467	619
Subject 11	Normal	12	618.68 ± 1.356	619

Table 3: Parameters values of the Max Fatigue Day

Subject	Day	Force	Mean ± Standard Deviation	Median Value
Subject 1	2nd	28	618.50 ± 1.464	619
Subject 2	7th	8	617.76 ± 1.672	618
Subject 3	1st	8	618.06 ± 1.659	618
Subject 4	2nd	12.5	618.92 ± 1.584	619
Subject 5	4th	9.5	618.49 ± 1.51	619
Subject 6	3rd	21	618.07 ± 1.292	618
Subject 7	3rd	8.5	617.86 ± 1.966	618
Subject 8	1st	12	617.82 ± 1.776	618
Subject 9	4th	20.5	617.84 ± 1.143	618
Subject 10	2nd	13	618.11 ± 1.539	618
Subject 11	3rd	5	617.91 ± 1.463	618

Table 2 and Table 3 shows the Pre exercise protocol (Normal muscle) and Post Exercise EMG Parameter calculations respectively for all the subjects who underwent the experiment. Figure 5(a) & Figure 5(b) below shows the mean graph of the all the subjects for maximum fatigue after exercise.

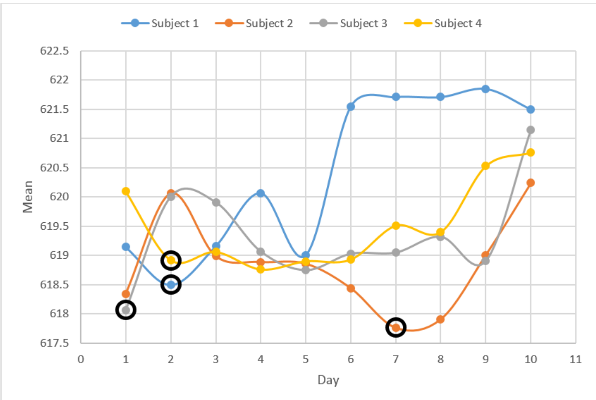

Figure 5(a): Mean variation with exercise

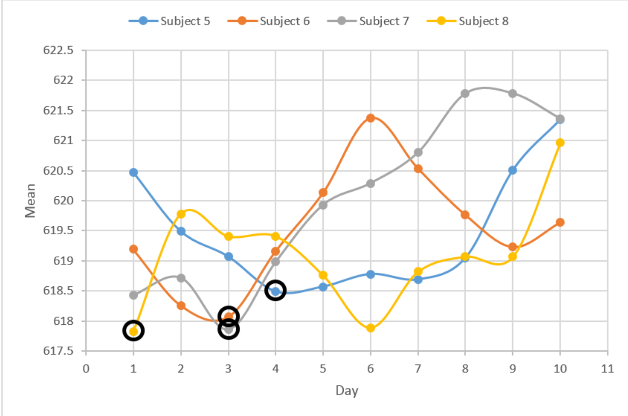

Figure 5(b): Mean variation with exercise

It is clearly seen that muscles went under fatigue 2nd to 4thday post protocol start. Mean frequency of the EMG shows decrease of value with increase of fatigue. This decrease of mean frequency is due to more recruitment of muscle fibers as main muscles can no longer maintain the same force or power to do the required exercise as they have already encountered a healthy wear and tear due to daily exercise protocol imposed to muscles. Experiencing of fatigue to muscles is a result of the physical activities (i.e. exercise protocol) done by the subjects.

But on which day subject experience maximum fatigue is completely dependent upon the type of physical work done by the subjects. Table 4 below depicts those categories.

Table 4: Activity Level of Participants

No Exercise or Sedentary Life Style	Regular Exercise or Active Life Style	BMI (kg/m²)	Max Fatigue Experienced
Subject 2	--	25.3	7th Day
Subject 4	--	34.6	2nd Day
Subject 5	--	32.3	4th Day
Subject 6	--	23	3rd Day
Subject 7	--	23.5	3rd Day
Subject 9	--	22	4th Day
Subject 11	--	21.9	3rd Day
--	Subject 1	25.3	2nd Day
--	Subject 3	23.8	1st Day
--	Subject 8	22.1	1st Day
--	Subject 10	24.3	2nd Day

To maintain the required muscle activity for the workout (muscle force), MUs with higher firing rate of their amplitude potential trains are recruited and the firing rates of initial MUAP trains increase. These increase of mean amplitude and firing rate, leads to increase of total RMS.

B. The relationship between EMG input and Force output

It is also observed that subjects who were regular in doing exercise showed negligible variation of force with exercise protocol i.e. Subject 1 in Figure 6(a) and Subject 6 and Subject 7 in Figure 6(b) respectively. Whereas Subject 2, Subject 3, Subject 3 and Subject 5 have shown a constant force adoption with time in general after 3rd or 4th day. There is a rise in force produced in muscle, this is due to the endurance developed.

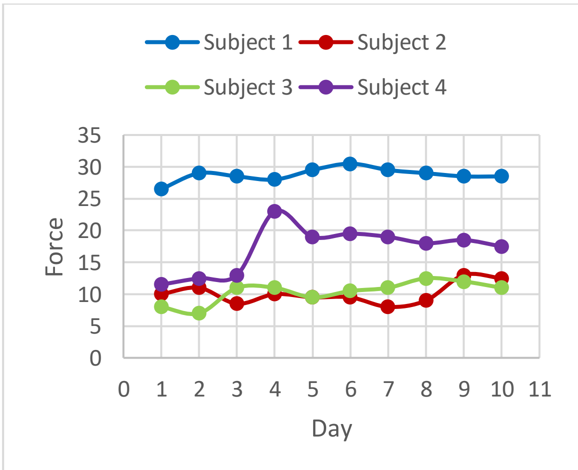

Figure 6(a): Plot of Force variation with exercise

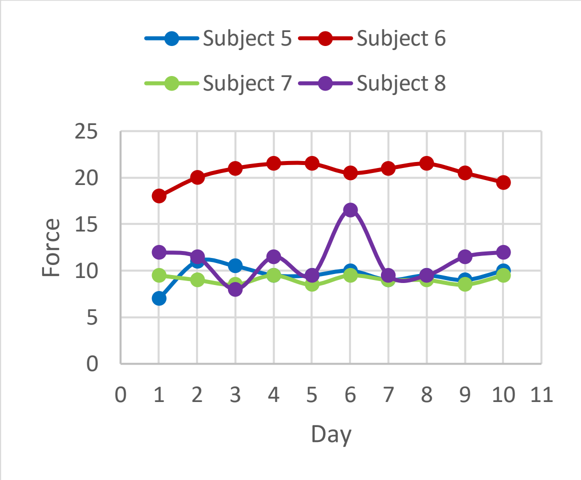

Figure 6(b): Plot of Force variation with exercise

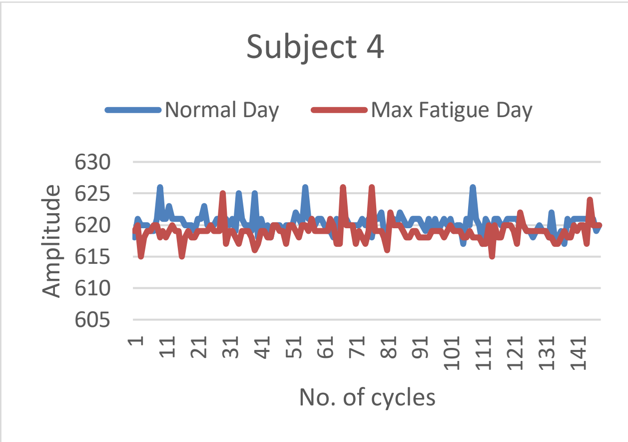

Figure 7: EMG Plot of Subject 4

EMG plot shown in Figure 7 represents that EMG amplitude also decreases with increase in fatigue of muscles. In Figure 7 two EMG signal graphs are plotted, one for non-fatigued muscle and another showing muscle fatigue before recovery of the fatigue in muscle. This is also verified with the mean variation.

C. Mean versus Force Plot

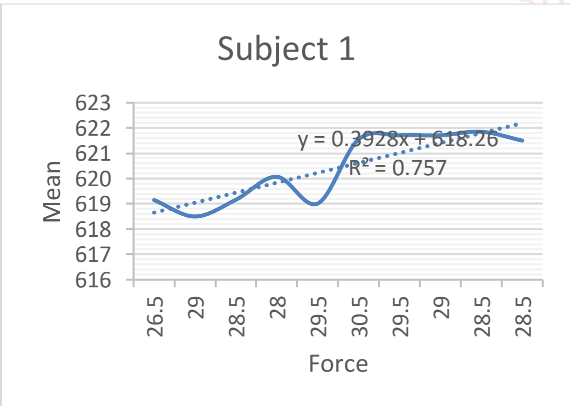

Figure 8: Mean versus Force Graph

The mean versus force graphis plotted as shown in Figure 8 and it is observed that there is a positive linear relationship between the plotted mean and its respective force values. The correlation between variables indicates that as one variable changes in value, the other variable tends to change in a specific direction. The regression analysis mathematically describes the relationship between mean and force values. Also, this described linear relationship may be used to predict the value of dependent variable with reference to the value of independent variable. [12]

A linearly increasing relationship is observed between mean and force values calculated from EMG signal. Plot shown in Figure 7 represents the R^2as 0.757 whereas R^2 ranges from 0.4821 to 0.8714. In which values lower than 0.7 are irrelevant whereas 0.7-0.99 are most significant.

D. Endurance

We also observed that muscles develop endurance after encountering fatigue on 3rd to 4th day. Endurance development is dependent upon the day to day activities taken up by the subjects under study.[13] Table 5is showing a comparison in the different muscles (Soleus and Gastrocnemius muscles) of same subjects who underwent the same exercise protocol for 10 days. Both readings were recorded simultaneously after exercise on each day. It is observed that

- Both muscles had developed the fatigue on different days. This definitely is the result of contribution of muscles in activity to be performed.
- Soleus muscle is to provide increase in angle between foot and leg whereas Gastrocnemius muscle helps Soleus muscle to work and provides flexing the leg at the knee joint.
- As Soleus muscle are always in the use while moving ankles,hence they resulted in late fatigue in muscles. At the same time Gastrocnemius which supported the calf and knee got fatigued comparatively sooner.
- Subjects having an active lifestyle develops muscle endurance sooner than the subjects having a sedentary lifestyle. [14] [15]

It was also observed that decreased values of force, mean frequency and amplitude in sEMG (which occurred in muscles due to fatigue) subsequently approaches back to their initial values as observed prior to exercise protocol as they develop endurance.

Table 5: Parameter values of Maximum Fatigue Day

	Soleus [14]			Gastrocnemius		
Subject	Day	Force	Mean	Day	Force	Mean
Subject 1	3rd	28.5	619.06	2nd	28	618.50
Subject 2	8th	8	617.76	7th	8	617.76
Subject 3	5th	8.5	618.82	1st	8	618.06
Subject 4	3rd	13	618.92	2nd	12.5	618.92
Subject 5	5th	9.5	618.68	4th	9.5	618.49
Subject 6	3rd	21	618.00	3rd	21	618.07
Subject 7	3rd	8.5	617.87	3rd	8.5	617.86
Subject 8	6th	16.5	618.04	1st	12	617.82

V. CONCLUSION

Presented work is giving us the ways to identify muscle fatigue developed due to known workout and quantifies the effect of endurance in the muscle with fatigue on Gastrocnemius muscles. It is observed that introduction of fatigue results in decrease of force (F) as well as decrease of mean frequency (MF) and amplitude (Amp) in the sEMG. It has been observed that there is linear relation between MF and F. Its further observed that endurance plays a major role when one goes take-up some physical activity or exercise. Its documented also that fatigue affects the muscular activities but due to endurance (that is definitely dependent upon the life style of the subject) of muscle fatigue dies out and muscle resumes its full activity in 5-10 days.

All the subjects were introduced to an anaerobic exercise protocol and later measurements were done. There are inordinate chances that aerobic exercise protocol may result in completely different level of endurance and hence the muscle force producing capacity rejuvenation after exercise.

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