Fatigue Detection in Soleus Muscle By Characterizing Its Electro- Myogram

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Abstract- *Surface Electromyography activity of the calf muscle was recorded against two different classes i.e Fatigue and Non-Fatigue through which different features were extracted for analysis purposes. Subjects specific Surface Electromyography (sEMG) activity (for the primary Leg's lower calf muscle i.e Soleus muscle)after exercise of Eight subjects was recorded.*

A total of five features were extracted for each of the two classes to quantify the potential performance of each feature, that could aid in differentiating the classes of muscle fatigue within the sEMG signal. Graphical and Tabular approach was used showing features that can best distinguish between the classes. The aim of this paper is to present the change in various parameters which are extracted from recorded sEMG signal to detect the presence of fatigue in muscle.

Keywords- sEMG, RMS, Median, Force.

I. INTRODUCTION

Electromyography (EMG) is an electro diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles.

Researchers investigated the detection of localized muscle fatigue of surface electromyography (sEMG) is mainly focused on differentiating two classes, the non-fatigue and fatigue. Such studies on muscle fatigue during isometric contraction have actualized typical sEMG readings when conducted in controlled settings. Changes in sEMG amplitude and center frequency were studied. The authors established a decrease in the center frequency of the spectrogram of all the muscle groups. Research in this field also shows that a development in muscle fatigue correlates with changes in amplitude and median frequency (MDF) [1]. Atieh et al. tried to design more comfortable car seats by identifying and classifying sEMG signals using data mining techniques and statistical analysis to determine sEMG localized muscle fatigue[2]. Kumar et al. have discussed the effectiveness of the using wavelet transform to identify muscle fatigue on EMG signals [4].

In this study, the possibility of detecting the stages of muscle fatigue (Non-Fatigue and Fatigue) was investigated. It is important to note that the ability to successfully classify the fatigue stage within the sEMG will have tremendous benefits in predicting muscle fatigue before it takes place. Our research focused on acquiring the sEMG, subsequently extracting different features from recorded data. Five features were tested against the classes for all subjects.[3]

Estimating the relative class overlapping between Non-Fatigueand Fatigue classes was tested with the graphical and tabular approach to show the features that best distinguish and quantify class separability.

II. EMG FEATURE EXTRACTION

There are two classes of sEMG (Non-Fatigue and Fully Fatigue). These classes can be classified by features described in the following sections. These features helped us in acquiring the desired the results, enabling discrimination between the classes. Several of these features have been used in various studies to extract fatigue on EMG.

2.1 Root Mean Square:-The root mean square (RMS) value of an signal is the total value of the quantity. It measures the electrical power in the signal[6]. Basmajian & DeLuca [7] encouraged the use of this process in analyzing the EMG signal since the value of the RMS produces the moving average. RMS is related to the constant force and non-fatiguing contraction [8]. The value of RMS is given by:

$$RMS_k = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}$$

2.2 Mean Frequency :-MNF is an average frequency which is calculated as the sum of product of the EMG power spectrum and the frequency divided by the total sum of the power spectrum [9]. The Mean frequency is given by:

$$F_{MN} = \frac{\sum_{i=1}^{M} f_i PSD_i}{\sum_{i=1}^{M} PSD_i}$$

where M is the length of the power spectrum density, fi = (i∗ sampling rate)=(2 ∗ M), and PSDi is the i^{th} line of the power spectrum density.

2.3 Median Frequency:-We can define the median frequency as "the frequency which divides the power spectrum in two parts with equal areas" [6].

Mean frequency (MNF) and Median power frequency (MNP) of thepower spectrum are usually applied as indices to characterize EMG signals, especially for muscle contractions[11]. The Mean frequency (MNF), Median frequency (MDF) are extracted to detect muscle fatigue.[12].

$$F_{MD} = \frac{1}{2}\sum_{i=1}^{M} PSD_i$$

where M is the length of the power spectrum density, and PSDi is the i^{th} line of the power spectrum density.

2.4 Variance :-Variance is the average of the squared deviation of a random variable from its mean. Informally, it measures how far a set of (random) numbers are spread out from their average value. The VAR is given by[13]:-

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

Where x¯ is the mean value of the segment k.

2.5 Standard Deviation :-

It is defined as the standard deviation is a measure of the amount of variation or dispersion of a set of values. The standard deviation is given by[14] :-

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

where x¯ is the mean value.

2.6 LITERATURE REVIEW:-

Various papers were studied in which sEMG as primary data source was employed. These EMG input papers had various application domains. These are tabulated below in Table 1.

Table 1. Papers were reviewed while working are as follows:-

Topic of Papers	Feature Analyzed	Tool Used	Applications
1. A Review of non-invasive techniques to detect and predict localized muscle fatigue.	Average rectified value, Root mean square, Mean frequency, Median frequency, Instantaneous frequency	Modified Moore-Garg Strain Index, Force gauge	For the development of devices that can be used in, e.g., sports scenarios to improve performance or prevent injury.
2. Assessment of force and fatigue in isometric contractions of the upper trapezes muscle by surface EMG signal and perceived exertion scale.	Muscle fiber conduction velocity (CV), root mean square value (RMS), mean frequency of the power spectrum (MNF).	Subjective perception (based on Borg scale CR10)	Quantify muscle fatigue in designing ergonomic work stations, in planning appropriate work-rest patterns, and in preventing/assessing the progress of disorders.
3. Techniques of EMG signal analysis: detection, processing, classification and applications.	Wavelet coefficients and the time-frequency plane, time and frequency domain.	Wavelet transform, Wigner-Ville Distribution, Fourier transform, Genetic Algorithm.	It is used for clinical/biomedical applications. Also, as a diagnostics tool can include neuromuscular diseases, low back pain assessment, kinesiology and disorders of motor control.
4. Stages for Developing Control Systems using EMG and EEG Signals: A survey.	Mean Absolute Value, Root mean square, Variance, Auto Regressive coefficients, Frequency median.	Bayesian classifier, Fuzzy Logic Classifier, Linear Discriminant Analysis Classifier.	Diagnoses and clinical applications, such as functional neuromuscular stimulation and detection of preterm births, mechanics of muscle contraction and gait.
5. SEMG signal processing and analysis using wavelet transform and higher order statistics to characterize muscle force.	Root Mean Square difference and Signal to Noise Ratio values.	Wavelet transform and Higher Order Statistics, Gaussian and Linearity Tests.	Helps in increasing efficiency at various muscle contraction stages like rest, strong contraction and contraction with load for biceps muscle and at various walk styles slow, medium, fast walking style.

It is observed that Time &Frequency Domain parameters are analyzed by almost every author. Hence, we are also going to analyze few TD & FD parameters.

III. METHODS AND MATERIALS

In the initial part of this research an experimental study was conducted to record sEMG emanating from soleus muscle. In the secondary part we used the extracted features to differentiate between the fatigue stages (Non-Fatigue and Fatigue).[3]

Hence, Arduino based system was used to record EMG which usually consists of attached pre & post amplifier stages, blue tooth receiver, PC system and further attached with Arduino.

Fig. 1 EMG SET UP FOR RECORDING

3.1 sEMG recording and pre-processing

The data were collected from a total of eight subjects, healthy subjects (mean age 25 +/- 2yr), and non-smokers. The eight participants were willing to reach physical fatigue state but not a psychological one. The subjects were in a straight standing position precisely 90 degree and then performed their exercise until fully fatigue.

Table 1: Subjects Physical Characteristics :-

S.No.	Characteristic	Mean	SD
1.	Age (year)	25.125	0.78
2.	Height (cm)	169.75	9.66
3.	Weight (kg)	78.125	12.47
4.	BMI	26.425	4.098
5.	Max. Voluntary Contraction Force	14.568	6.58

Steps are as follows:

1. Firstly, Dynamometer instrument was used for measuring the maximum isometric strength and force of the leg.
2. Goniometer was placed on the right side of the leg muscle to measure the ankle angle.
3. The observer have to check the Goniometer which placed on the participant that indicates the angle of the leg for distinguishing between non-Fatigue and Fully Fatigue
4. Secondly, sEMG electrodes were placed on the participant's calf muscle to acquire sEMG reading. Subjects were asked to exercise three sets repetitively with a 30 sec. break while doing calves muscle exercise until fatigue stage in each stage.
5. Participants were stopped when they finish the exercise protocol or if they feel fatigue /uncomfortable.
6. After performing exercise repetitively for three times then the EMG data was recorded from the EMG data recording system
7. This data was recorded regularly for 10 days.

The physical aspects such as drop in the leg angle of the leg was considered as they are the most reliable indicators of fatigue [7] and can correctly classify the signals.

<u>Results</u>

1. EMG and RMS

Monotonous and significantly linear relationship (Pearson's test: r = 0.74; p< 0.001) was found between muscle force and RMS values in the simple contraction session (shown in Fig.1). Larger muscle force corresponds stronger EMG signals or their RMS values. This is further verified from Table-3 also.

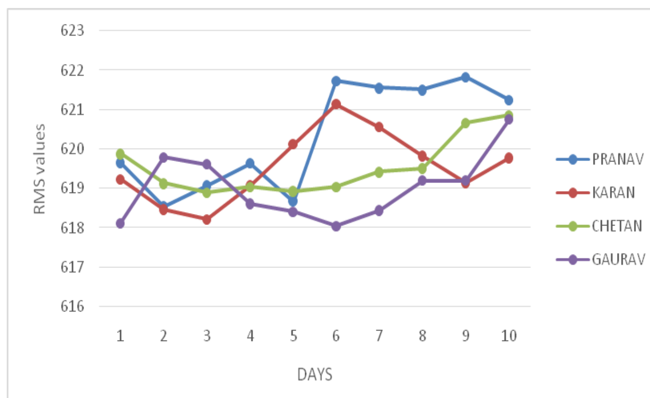

Fig-1:RMS values during simple contraction session (Subject 1-4)

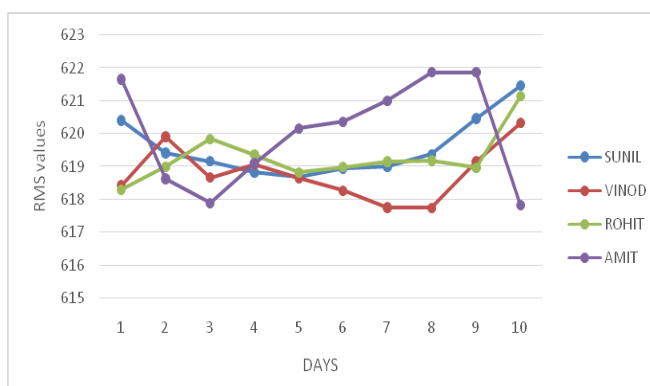

Fig-2:RMS values during simple contraction session (Subject5-8)

Surface EMG RMS response exclusively to fatigue was determined. Result shows that RMS increases with fatigue strengthening. There are four students which showed decrease in RMS value with introduction of fatigue in muscle as shown in Fig:2.

2. Force and RMS

When exercise is performed as fatigue increases, muscle force declines and, the amplitude of EMG decreases along the fatigue process. As shown in Fig 3 to Fig 7. Also, the corresponding max fatigued force value is tabled in Table-3.

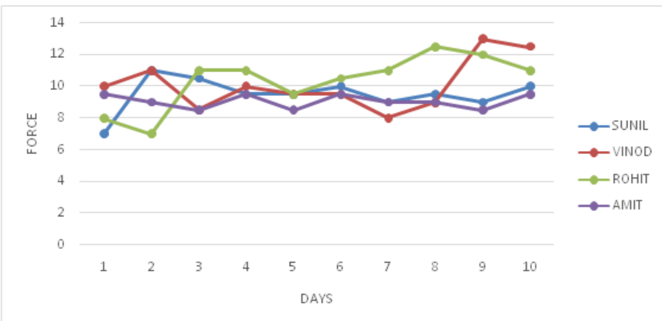

Fig 3: Graphical Representation of Force

Table2: Force Ranges for every Subject

Maximum Voluntary Contraction(MVC), FORCE in N				
SUBJECT		RF1	RF2	RF3
X1	MVC VALUE	26.5-28	28-29.5	29-30.5
	MVC %	86.8-91.8	91.8-96.7	96.7-100
X2	MVC VALUE	7-8.5	8.5-10	10-11.5
	MVC %	60.7-74	74-87	87-100
X3	MVC VALUE	8-9.5	9.5-11	11-13
	MVC %	61.5-73.1	73.1-84.6	84.6-100
X4	MVC VALUE	7-8.5	8.5-10.5	10.5-12.5
	MVC %	56-68	68-84	84-100
X5	MVC VALUE	18-19	19-20	20-21.5
	MVC %	83.7-88.3	88.3-93	93-100
X6	MVC VALUE	7-8	8-9	9-10
	MVC %	70-80	80-90	90-100
X7	MVC VALUE	11.5-15	15-19	19-23
	MVC %	50-65	65-82.6	82.6-100
X8	MVC VALUE	8-11	11-14	14-16.5
	MVC %	48.5-66.7	66.7-84.8	84.8-100

Table3: Parameter Values of the Max Fatigue Day							
Subject	Day	Force	MVC (Force Range)	Mean Value	Median Value	RMS Value	EMG (Normal) Reading
X1	3rd Day	28.5	RF2	619.06	619	619.063	619.265
X2	5th Day	9.5	RF2	618.68	619	619.684	620.691
X3	8TH Day	8	RF1	617.76	618	617.75	618.503
X4	5TH Day	8.5	RF2	618.82	619	618.83	618.800
X5	3RD Day	21	RF3	618	618	618.22	619.333
X6	3RD Day	8.5	RF2	617.87	618	617.90	618.299
X7	3RD Day	13	RF1	618.92	619	618.9	620.136
X8	6TH Day	16.5	RF3	618.04	618	618.05	618.021

Discussion:

Linear relationship was found between muscle forces and RMS values during the simple contraction session. This clear relationship between mechanical and the electrical responses of human muscle is well documented in researches [15] under voluntary isometric contractions.

With the increase of muscle force, MUs with higher firing rate of their amplitude potential trains are recruited and the firing rates of initial MUAP trains increase. These increases of mean amplitude and firing rate, leads to increase of total RMS.

RMS during Fatigue Process

During fatigue progress, the RMS reduced usually on third to fifth day of the exercise protocol. Mostly, EMG amplitude reduced during a maximal voluntary contraction sustained, depending on different muscles and protocols [15].

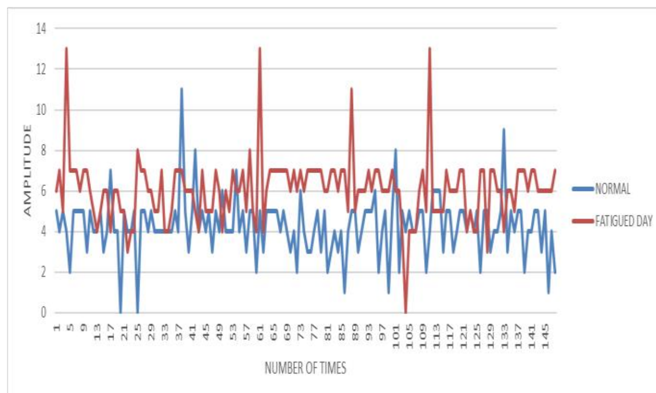

Fig 4: EMG Data Showing Higher Amplitude (X5)

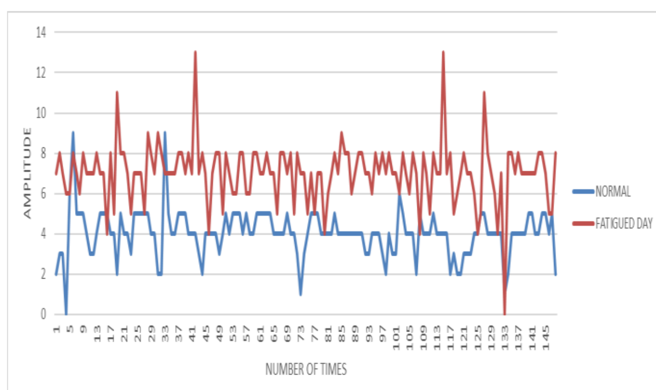

Fig 5: EMG Data Showing Higher Amplitude (X3)

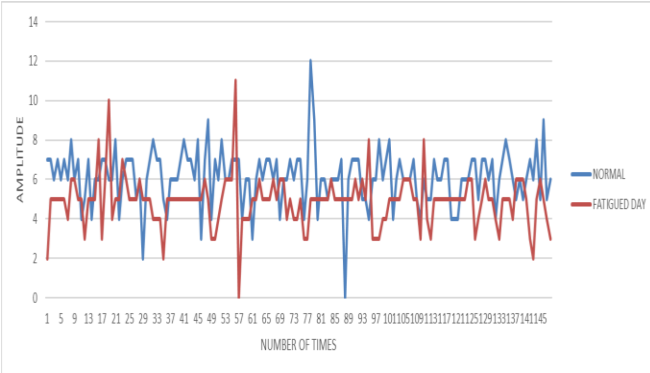

Fig 6: EMG Data Showing Lower Amplitude (X2)

As mentioned above, the RMS of sEMG has been found to increase in the process of constant-force fatiguing tasks [16, 17]. When the body tries to maintain the target forces, a progressive increase of MUAP trains firing rate take place and MUs with larger amplitude are recruited [15], which increase the firing rate hence total RMS increases.

When procedure is continued for longer durations/or days in our case, muscle tries hard to maintain its original force, which leads to increases off and on the other hand, as the muscle fails to maintain its original force, muscle force continues to decline, which brings about the decreases of firing rate and mean amplitude. As a consequence, the impact of force decline prevails over that of fatigue and decreases of firing rate and mean amplitude are observed [15], the total RMS declines with time.

EMG during Fatigue

As shown in fig 4 and 5 the amplitude of the EMG wave gets affected by the fatigue. Pattern of variation is similar to the RMS variation pattern i.e. during initial days with fatigue introduction EMG amplitude increases because of more recruitment muscle fibers whereas when exercise pattern is continued the EMG amplitude starts decreasing as shown in Fig6. This is because fatigue prevalence doesn't allow the force to be sustained longer, hence decrease in amplitude is observed.

Median during Fatigue

Literature shows that there is downwards shift in median frequencies with introduction of the fatigue. Same is being validated here. Fig 7 and 8 shows us the box plots of the non-fatigued and fatigued values. Fig 8 clearly indicates the down shift in median frequencies.

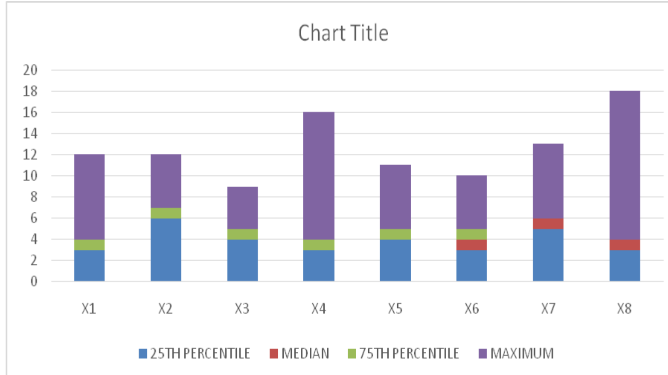

Fig 7: Median for Non-Fatigued day

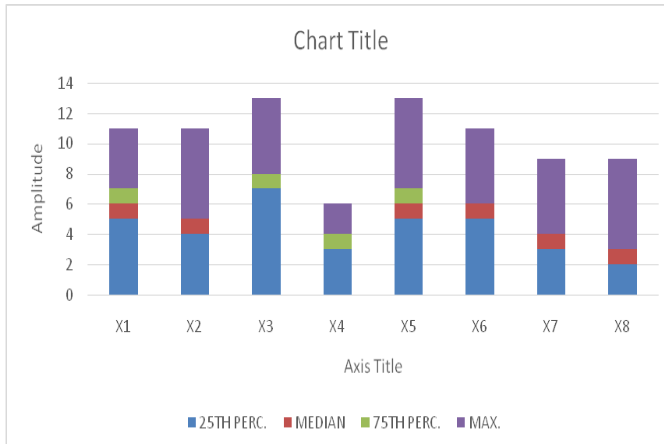

Fig 8: Median for Fatigued day

IV. CONCLUSION

In this work, a simple way to identify the sEMG response to fatigue was tested on soleus muscles. The impact of fatigue on muscle force and RMS is changes in both parameters. Result showed that the sEMG RMS response to fatigue increases along with the fatigue process, which implies that more and more extra effort is needed as muscle fatigue intensifies. Whereas when muscle is completely fatigued decline in the RMS is observed. Thus, it would be promising to use the RMS response exclusively to fatigue as an indicator of muscle fatigue. Median shift towards down frequencies is also validated here.

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