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Quantitative Assessment of Forearm Muscle Fatigue with Repetitive Task

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Abstract: Surface Electromyography (sEMG) activity of the forearm muscle was recorded from five subjects performing isometric contraction until fatigue. The signals were recorded into three stages (Non- Fatigued, Fatigued and fully Fatigued)through which different features were extracted for analysis purposes. Subject's specific Surface Electromyography (sEMG) activity of forearm muscle was recorded after the exercise which take place for four weeks.

Amplitude parameters were extracted for each of thethree classes to quantify the potential performance of each feature, that could aid in differentiating the classes(Non-Fatigued, Fatigued and Fully Fatigued) of muscle fatigue within the sEMG signal.We use thegraphical and tabular approach to show the parameters that best distinguish and quantify class separability.

The purpose of the work presented is to show the change in various parameters which are extracted from recorded sEMG signal to detect the presence of fatigue in the forearm muscle.

Keywords: Forearm Muscle, sEMG, Mean, RMS, Force, Amplitude parameters.

I. INTRODUCTION

Electromyography (EMG) is an electro diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles. Electromyography (EMG) measures muscle response or electrical activity in response to a nerve's stimulation of the muscle.

EMG (electromyography) records the movement of our muscles. It is based on the simple fact that whenever a muscle contracts, a burst of electric activity is generated which propagates through adjacent tissue and bone and can be recorded from neighboring skin areas. An electromyography detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement [1].

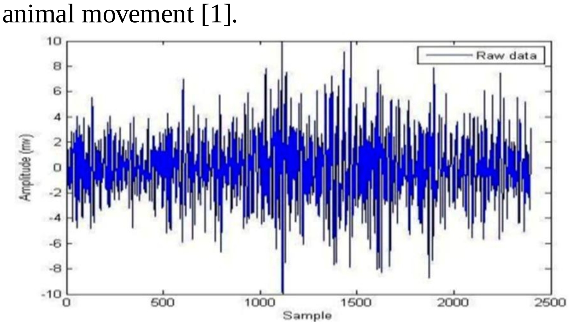

Figure 1. Raw EMG Signal.

An 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 electric signal can be taken from the body either by placing needle electrodes in the muscle or by attaching the surface electrode over the muscle. Needle electrodes are used where the clinician wants to investigate neuromuscular disease by looking at the shape of electromyogram. Surface electrodes are only used where the overall activity of a muscle is to be recorded [2].

In this study, the possibility of detecting the stages of muscle fatigue (Non-Fatigued, Fatigued and Fully Fatigue) was investigated. The presented here is focused on acquiring the sEMG, subsequently extracting different features from recorded data. Amplitude parameters were tested against the three classes for all the five subjects[3].

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

II. EMG FEATURE EXTRACTION

sEMG signals are divided into three classes (Non-Fatigued, Fatigued and Fully Fatigue). Features can be extracted by performing Amplitude Domain, Time Domain, Frequency Domain and Time frequency Domain analysis. These features helped us in acquiring the desired results, enabling discrimination between the classes. Amplitude domain features have been used in this study to extract fatigue on EMG. These are discussed below.

A. Mean Frequency (MNF)

Mean 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. Mean value is also called as mean power frequency and mean spectral frequency. 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 ith line of the power spectrum density [2].

B. Root Mean Square (RMS)

The root mean square (RMS) value of an signal is the total value of the quantity. It measures the electrical power in the signal. Basmajian & De Luca 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 [4]. The RMS value is given by :-

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

C. Force

The average force is also measure by the help of the instrument name dynamometer of all the three classes of fatigue (Non-Fatigued, Fatigued and Fully Fatigue) after the task was performed by every subject.

D. 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 the table.

Table 1. Papers Reviewed

Topic Of Paper	Features Analyzed	Tools Used	Application
The Use of Surface Electromyography in Biomechanics. [5]	Time Domain Like RMS Value, Mean etc. Frequency Domain Like Median Frequency Spectrum etc.	Muscle Fatigue Index	Three groups of applications are considered 1) The activation timing of muscles 2) The force/EMG signal relationship and 3) The use of EMG signal as fatigue index.
Surface Electromyography: Use, Design & Technological Overview” (Introduction to Biomedical Engineering). [6]	MVC (Maximum Voluntary Contraction), Amplitude Analysis & Temporal Analysis	Action Potential Mechanism, Bilateral comparison, MVC (Maximum Voluntary Contraction) -Normalization	1) Medical Research 2) Rehabilitation 3) Ergonomics 4)Sports Science

EMG Recording and Analysis Using Lab VIEW 7.0 Professional Development System. [7]	Power Spectral Density and other parameters for EMG signal like Time Domain and Frequency Domain.	With an advent of improved integrated circuit and computer technologies i:e Lab VIEW 7.0 Professional Development System	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
Stages For Developing Control Systems Using EMG and EEG Signals. [8]	Time Domain, Frequency Domain, Time-Frequency Domain	Bayesian Classifier (BC), Fuzzy Logic (FL) Classifier, Linear Discriminant Analysis (LDA) Classifier	1) Kinesiology 2) Ergonomics 3) Prosthesis Control 4) Wheelchair Controllers 5) Virtual Keyboards Diagnoses And Clinical Applications
How Muscles Work.[9]	Contraction : Isotonic & Isometric	Action Potential Mechanism	For the development of devices that can be used in, e.g., sports scenarios to improve performance or prevent injury.

It is observed that Amplitude Domain Time Domain & Frequency Domain parameters are analyzed by almost every researcher. Here, we are going to analyze few Amplitude parameters.

III. METODS AND MATERIAL

In the initial part of this research an experimental study was conducted to record sEMG emanating from forearm muscle. In the secondary part we used the extracted features to differentiate between the fatigue stages (Non-Fatigued, Fatigued and Fully Fatigue) [3]. Hence, Arduino based system was used to record EMG which usually consists of attached pre & post amplifier stages, Bluetooth receiver, PC system and further attached with Arduino.

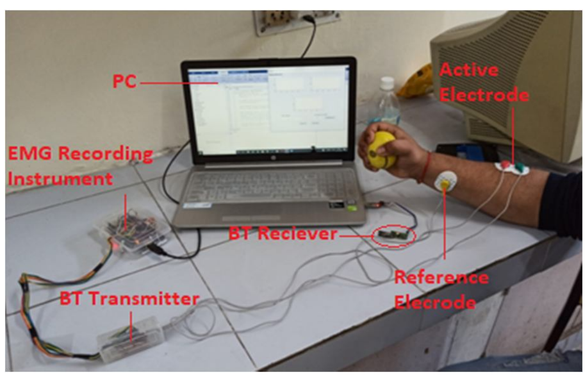

Figure 2. EMG & Fatigue Recorder Set Up.

A. sEMG Recording and Pre-processing

The data were collected from five athletic, healthy subjects (mean age 25 +/- 2 year), and non-smokers. The five participants were willing to reach physical fatigue state but not a psychological one. The participants were seated on a chair to ensure stability and forearm isolation.

Table 1. Physical Characteristics Of The Subject

S. No.	Characteristic	Mean	SD
1.	Age (year)	25.226	0.79
2.	Height (cm)	167.54	8.89
3.	Weight (kg)	80.76	12.54
4.	BMI	26.765	5.011
5.	Maximum Voluntary Contraction Force	15.569	6.85

Steps in the test bed set up:

1) Firstly, Dynamometer instrument was used for measuring the maximum isometric strength and force of the forearm.
2) Secondly, sEMG electrodes were placed on the participant's forearm muscle to acquire sEMG reading. Participants were asked to exercise with handgrip for three sets repetitively with a 30 seconds break until fatigue stage in each set.
3) Participants were instructed to stop when they reach total forearm fatigue.
4) After performing exercise repetitively for three times then the EMG data was recorded from the EMG data recording system.
5) The data has been collected once in week after performing the exercise for the whole week.
6) This process has been taken place for 4 weeks.

Then with the help of EMG data we can extract parameters from time domain, frequency domain and time-frequency domain i:e Mean, Median, Variance, Standard Deviation, Root Mean Square value. But we are going to work on Amplitude parameters i.e. Mean, Force & RMS only.

IV. RESULTS AND DISCUSSION

A. *EMG as Direct Indicator of Fatigue*

During fatigue progress, the EMG amplitude varies (either reduces or increases) gradually with the exercise protocol. Generally, EMG amplitude reduced during a maximal voluntary contraction sustained, depending on the type of muscles and protocol followed.

Table 4.1 Non-Fatigue Mean Values.

Weeks	x	y	z	p	q
1	604.867	609.071	608.755	609.295	607.734
2	610.724	610.561	610.612	610.714	610.469
3	610.765	610.571	610.704	610.877	610.898
4	610.561	611.214	610.520	610.653	610.224

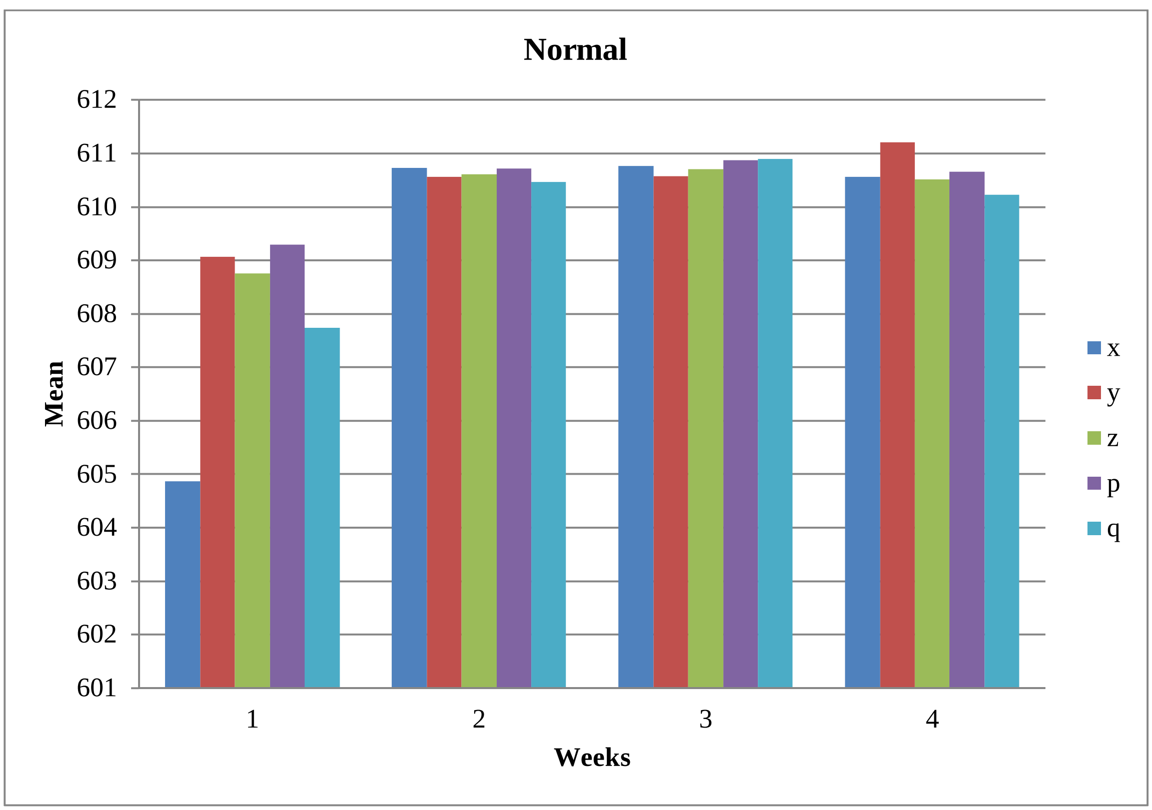

Figure 4.1 EMG Data Showing Higher Values Of The Mean For Normal (Non-Fatigued State).

As mentioned above, the mean of sEMG has been found to increase in the process of constant-force fatiguing tasks [9, 10, 11]. When the muscle tries to sustain the MVC, a progressive increase of MUAP trains firing rate take place and MUs with larger amplitude are recruited [12], which increase the firing rate hence total RMS as well as Mean increases as indicated in Non-Fatigued and Fatigued state of all subjects as shown in Figure 4.1, 4.2 & 4.3.

Table 4.2 Fatigue Mean Values.

Weeks	x	y	z	p	q
1	605.102	609.306	608.724	609.102	608.071
2	610.367	610.836	610.632	610.622	610.418
3	610.755	610.357	610.938	610.765	610.551
4	610.642	610.918	610.602	610.724	610.520

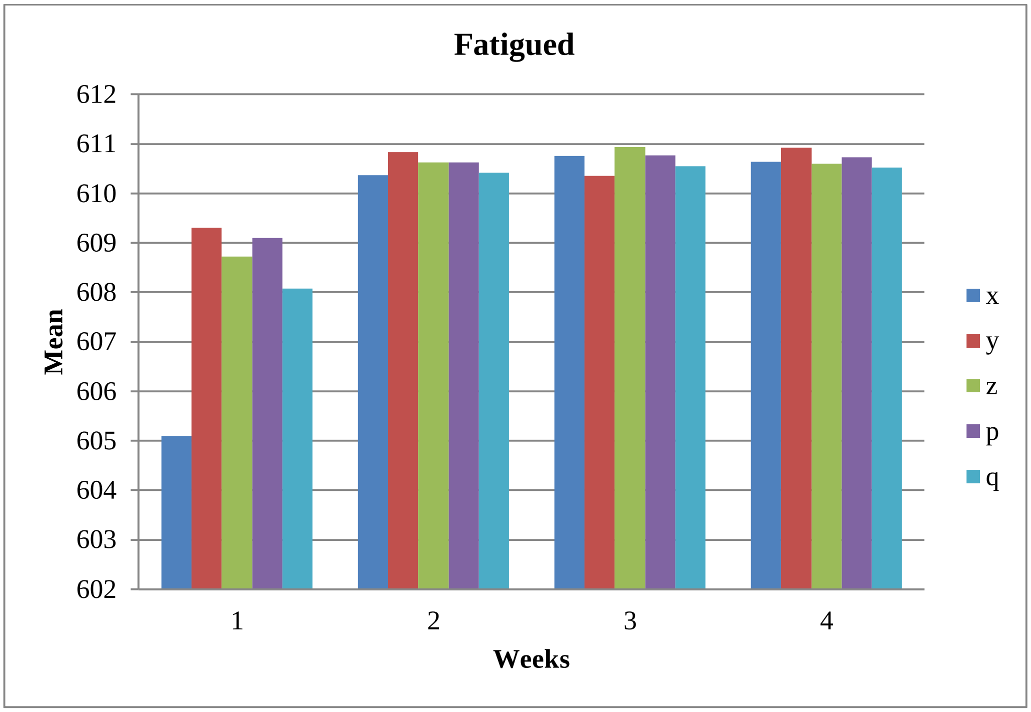

Figure 4.2 EMG Data Showing The Mean For Fatigued State.

When the procedure or protocol is continued by all the five subjects the muscle tries hard to maintain its original Force, which leads to increase off and on the other hand, as the muscle fails to maintain its original force and muscle force continues to decline, which brings about the decreases of Firing Rate and Mean Amplitude. As a consequence of this, the impact of force decline prevails over that of fatigue and decreases of Firing Rate and Mean Amplitude are observed [12].
The total Mean declines with time as it is indicated in Non-Fatigued and Fatigued state of all the subjects as shown in Figure 4.1, 4.2 & 4.3. The values of corresponding states are tabulated in the Table. 4.1, 4.2 & 4.3.

Table 4.3 Fully Fatigue Mean Values.

Weeks	x	y	z	p	q
1	604.836	609.530	608.775	609.142	607.795
2	610.765	610.438	610.540	610.612	610.693
3	610.612	609.969	610.755	610.918	610.551
4	610.275	611.193	610.510	610.622	610.091

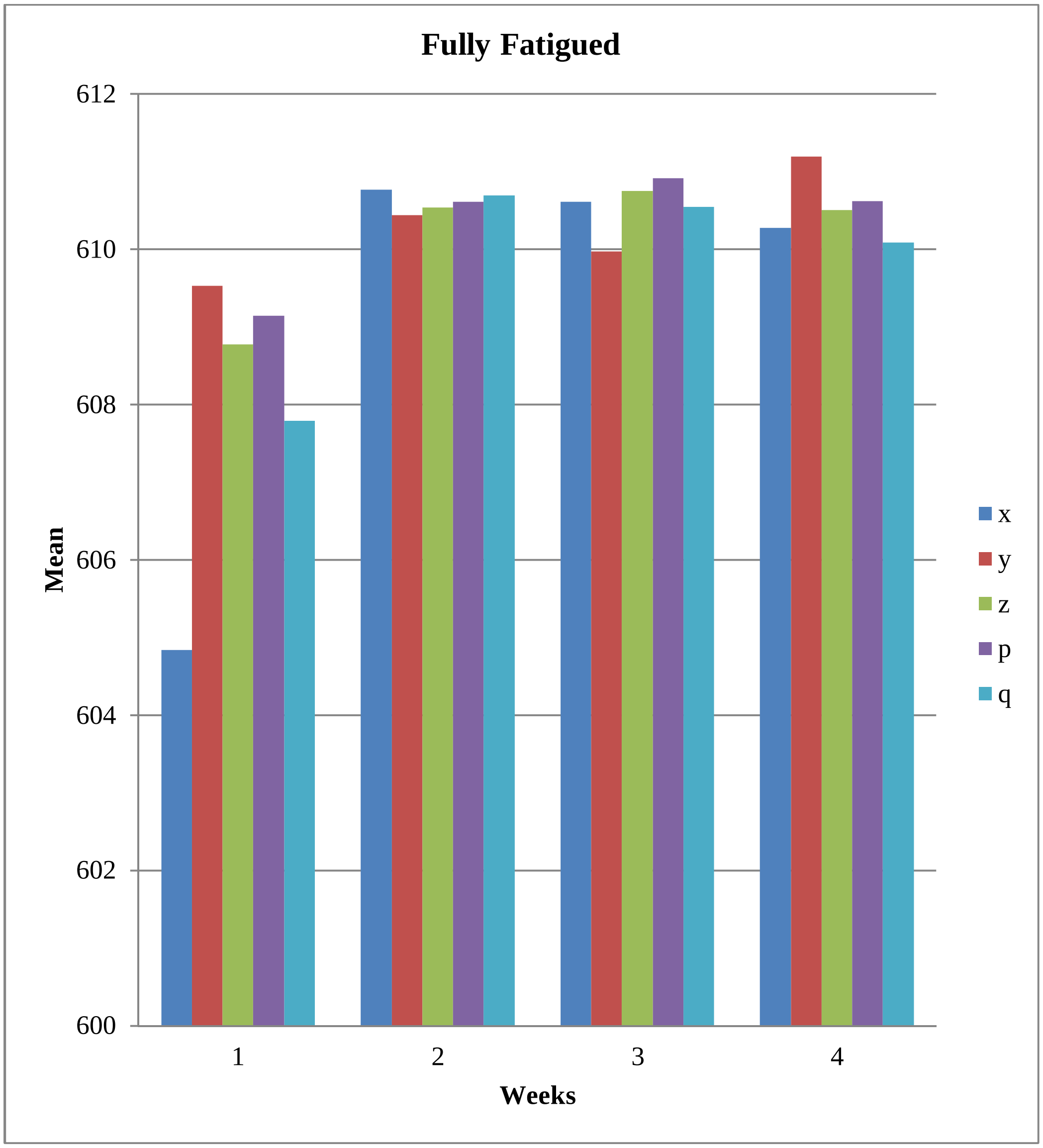

Figure 4.3 EMG Data Showing The Mean For Fully-Fatigued State.

B. Correlation

A strong correlation is found between mean values of the EMG and force of muscle values recorded from the upper limb muscle of the arm as on-average all the correlation values are more than 0.7 (i.e. $p \geq 0.7$)for all states of muscle viz Non-Fatigued, Fatigued and Fully Fatigued states. Tabulation of the correlation values is given below in Table 4.4. Higher the Force higher EMG signals and higher corresponding Mean values.

Table 4.4 Correlation Between Force and Mean Values.

Name	Normal	Fatigued	Fully Fatigued
x	0.728	0.769	0.953
y	0.905	0.67	0.607
z	0.423	0.809	0.843
p	0.837	0.7	0.608
q	0.869	0.55	0.882
Average	0.752	0.699	0.778

C. Force and Mean Relationship

When exercise is performed and fatigue increases, muscle force declines as shown in Figure 4.4 and Table 4.5, 4.6 & 4.7.

Table 4.5 Non-Fatigue Force Values.

Weeks	x	y	z	p	q
1	29	30	33	26	33
2	30	33	33	29	34
3	33	34	34	32	35
4	33	39	36	33	35

Table 4.6 Fatigued Force Values.

Weeks	x	y	z	p	q
1	17	24	21	16.5	24
2	19	25	22	17	24
3	24	27	24	19	24.5
4	25	29	24	20	25

Table 4.7 Fully Fatigued Force Values.

Weeks	x	y	z	p	q
1	14.5	15.5	14	14.5	15.5
2	16	16	15.5	15	16.5
3	16.5	17	16	16	17
4	16.5	17	17	17.5	17

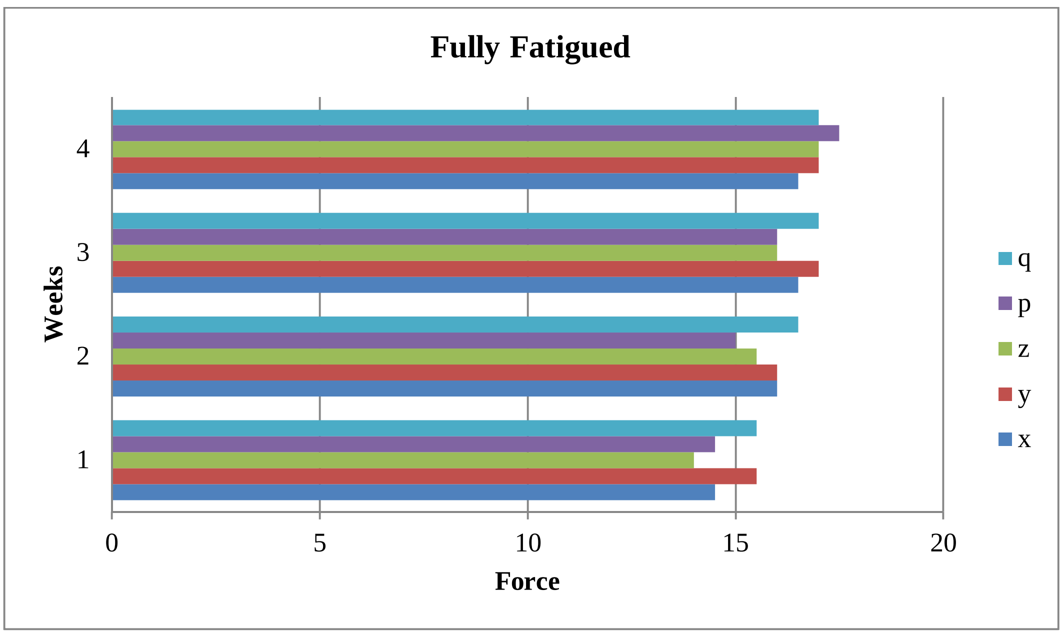

Figure 4.4 Force Variation For Fully-Fatigued State.

By visualizing the Table 4.8 a.), b.), c.) and analyzing through the graph it was found that r^2 ranges between 0.778 to 0.907. That shows a better fit relationship between the two variables.

The linear relationship was found between the mean and the muscle force values during the simple contraction session. This clear relationship between mechanical and the electrical responses of human muscle is well documented in researches [13, 14]under voluntary isometric contractions i.e. Force.

Mean	Force
604.8673	29
610.7245	30
610.7653	33
610.5612	33

a.) Non-Fatigued

Mean	Force
605.102	17
610.3673	19
610.7551	24
610.6429	25

b.) Fatigued

Mean	Force
604.8367	14.5
610.7653	16
610.6122	16.5
610.2755	16.5

c.) Fully Fatigued

Table 4.8 Mean Vs. Force

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.

V. CONCLUSION

In this work, a simple way to identify the sEMG response to fatigue was tested on upper limb i.e. forearm. The impact of fatigue on muscle mean and force is changes in both parameters. Average Mean varies i.e. decreases (Refer Table 4.1, 4.2 & 4.3) and Force is also decreasing with increase in muscle fatigue (Referring To Table 4.6, 4.7 &4.7).Result showed that the sEMG response to fatigue increases along with the fatigue protocol, which implies that more and more extra effort is needed as muscle fatigue intensifies that's why there is increase in Amplitude parameters in 2nd and 3rd week values whereas net Force is varying due to endurance.

We have verified Amplitude parameter variation (increase) with muscle fatigue. Previously the variations of Time and Frequency domain parameters have also been reported and verified. Time parameters are increasing whereas frequency parameters are showing decrease in frequencies with increase of fatigue[15].

Thus, it would be promising to use the mean response exclusively to fatigue as an indicator of muscle fatigue.

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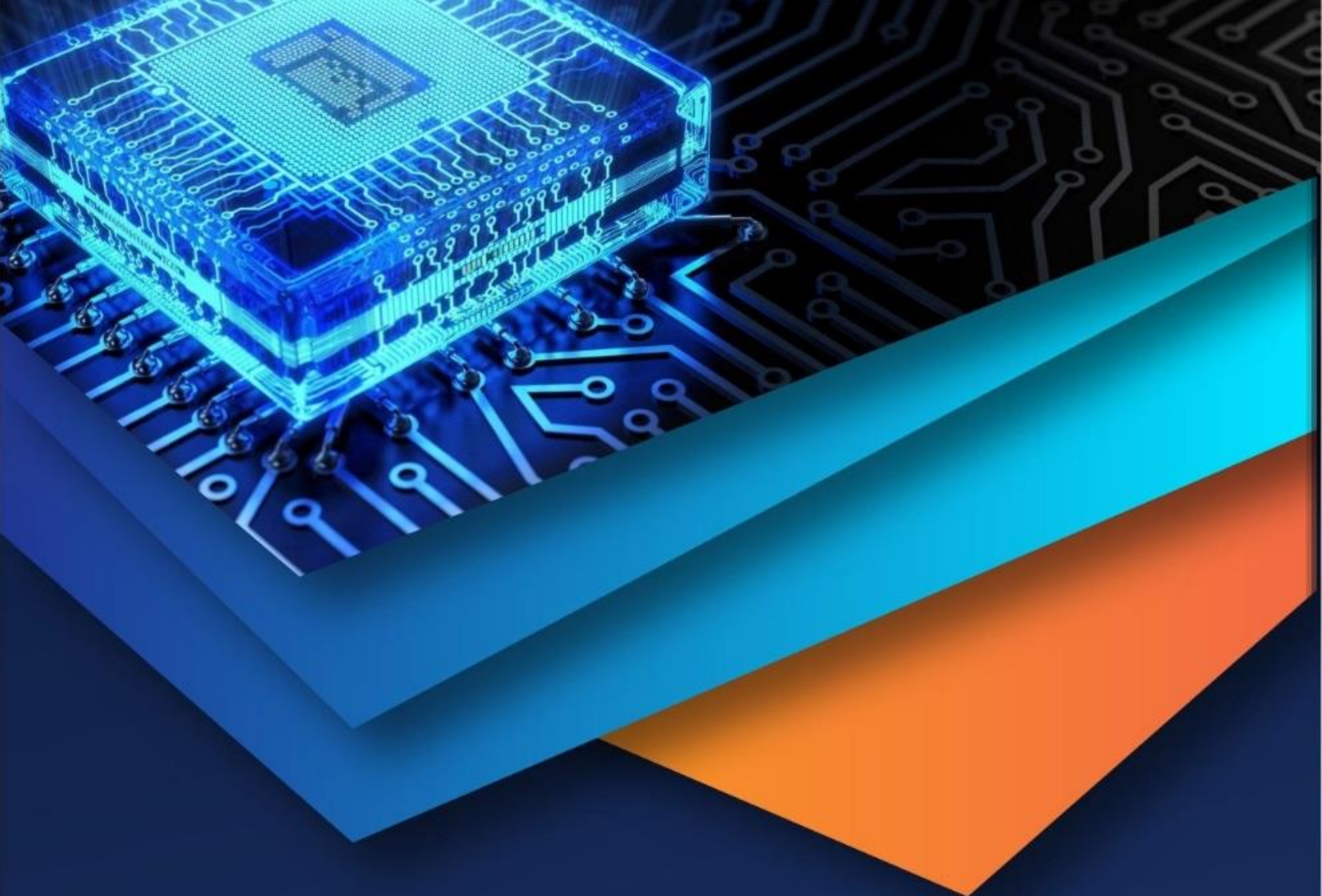

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