Identifying the Effects of Chiropractic Intervention on the Anterior Tibialis Muscle using High Density Surface Electromyography

Author
TAHA AL MUHAMMADEE JANJUA
Registration Number
119058

Supervisor: Dr. Ernest Nlandu Kamavuako
Co-Supervisor: Dr. Muhammad Nabeel Anwar

DEPARTMENT OF BIOMEDICAL ENGINEERING AND SCIENCES,
SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
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Author

TAHA AL MUHAMMADEE JANJUA

Registration Number

119058

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Thesis Supervisor:

Dr. Ernest Nlandu Kamavuako

Co-Supervisor:

Dr. Muhammad Nabeel Anwar

Thesis Supervisor's Signature: ____________________________________

DEPARTMENT OF BIOMEDICAL ENGINEERING
SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,
ISLAMABAD

SEPTEMBER, 2017

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Signature: ______________________
Name of Supervisor Ernest N. Kamavuako
Date: 08.01.2017

Signature (HOD): ______________________
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We hereby recommend that the dissertation prepared under our supervision by:

Taha Al Muhammadee Janjua, Registration Number: ____________119058______________

Titled: _Identifying the effects of chiropractic intervention on the anterior tibialis muscle physiology using high density surface electromyography of the requirements for the award of **Master** degree. Grade (A)

Examination Committee Members

Name: __Dr. Omer Gilani___ Signature: ______________________

Name: __Dr. Imran Khan Niazi__ Signature: Imran Khan

Supervisor's Name: Dr. Ernest Kamavuako Signature: Kamavuako

Co-Supervisor's Name: Dr. Muhammad Nabeel Anwar Signature: ______________________

____
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I certify that this research work titled "*Identifying the Effects of Chiropractic Intervention on the Anterior Tibialis Muscle using High Density Surface Electromyography"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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119058

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119058

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Copyright Statement

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Abstract

Understanding the muscle physiology allows scientists to work out new ways of training athletes, aiming to substantially improve their performance in a specified duration. It can also help researchers come up with new rehabilitation methods for patients recovering from injuries and muscle fatigue. The muscles require contraction and relaxation in a precise manner during a motor task. As a result, action potential propagates through the muscle fibers with certain conduction velocity (MFCV). This study aims at studying MFCV and how it can be enhanced allowing the subject to respond faster to a given stimulus using minimum amount of effort on part of the user.

Chiropractic intervention is a type of alternate medicine that uses spinal stimulation to affect the subject's ability to use his limbs effectively. The practice has been adopted as a rehabilitation technique for people suffering from spinal degeneration or injuries that may lead to neurological handicap of the patients. This research focuses on whether chiropractic spinal stimulation results in a change in the muscle physiology. A relatively new technique known as, 'high density surface electromyography (HD sEMG)' was adopted to measure the EMG signals during dorsiflexion from 12 subjects. Signal processing techniques such as Power Spectral Density (PSD), cross-correlation, root mean square (rms), most likelihood (ML) method, were used to identify modifications in the muscle physiology of the anterior tibialis muscle of all subjects during this protocoled exercise.

Results show that chiropractic intervention has a significant impact on the MFCV. It also leads to an increase in the amount of force generated by the anterior tibialis muscle during dorsiflexion.

Key Words: *HD sEMG, Muscle Fiber Conduction Velocity, Cross Correlation, Maximum Likelihood Method, Anterior Tibialis Muscle*

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CHAPTER 1: INTRODUCTION

The anterior tibialis muscle is considered the one of the most effected muscles in athletics [1]. Football players are known to damage the shin muscle during practice and while participating in a match. To recover faster from such injuries, athletes undertake rehabilitative measures that help them recover faster from injuries as well as improve their overall performance. These rehabilitative techniques require ample knowledge about the muscle anatomy and how it is affected by various exercises.

One such rehabilitative method, chiropractic intervention, is a form of alternate medicine that uses techniques involving spinal manipulation to improve the body functionality, offers a way to use spinal manipulation to improve a subject’s physiological condition, making this technique useful for rehabilitation as well as muscle training [2]. This study is focused on the role of spinal manipulation in increasing the muscle fiber conduction velocity as well the overall force generated by the muscle during an exercise.

To achieve this, a relatively new technique known as High Density surface electromyography (HD sEMG) has been adopted that offers an insight into the muscle physiology, demonstrating a new way of using signal processing techniques to understand how a muscle functions and how this function can be improved. It is a technique which uses multiple channels to get a monopolar configuration instead of the previous bi-polar configuration used by earlier studies[3].

Once this data is collected it can be applied in ergonomics, muscle and fatigue training as well as be used as a diagnostic tool for subjects that are suffering from a neuromuscular disease or disorder[4][5]. This study also acts as a basis of understanding how a muscle behaves upon the application of isometric and dynamic loading. Using HD sEMG also allowed this research to make topographical heat maps of the AT muscle which can then be used to identify motor units and innervation zones on the muscle.

CHAPTER 2: LITERATURE REVIEW

The significance of this research and the dynamics involved in utilizing different techniques to get the results can be only be realized after having a firm grip of the following concepts:

1. Human Anatomy
2. Chiropractic intervention
3. Different surface electromyography techniques
4. Relevant signal processing techniques.

Each of these have been explained further as follows:

2.1 Musculoskeletal Anatomy:

The human body's physical limitations and functionality is discussed with respect to the research goals. To understand the changes incurred in the anterior tibialis muscle, muscle physiology needs to be understood. This in turn leads to successful application of relevant signal processing techniques using high density surface electromyography.

2.1.1 Introduction to the Muscle System

Specialized cells work together in a specific manner to make up the muscular system. These specialized cells, known as muscle fibers mainly have the function of contraction. This contractibility is responsible for movement of the whole-body part depending on where the muscles are fixed. Those found with internal organs such as bones and blood vessels, take part in movement. Movement of any part of the human body involves the integration of different joints with bones and skeletal muscles. Muscles are also involved in subtle changes in the facial expressions as well eye movements and breathing.

Other than movement, other functions of muscles as include posture control, stabilizing the joints, and producing heat [6]. Joint stability is achieved through fine contractions made by muscles attached to joint that keep the movement controlled. The production of heat is a basic part of homeostasis specially when maintaining the temperature of the body. Muscle metabolism is responsible for approximately 85% of the human body's heat [6], [7].

2.1.2 Muscle Types

Three kinds of muscle are found in the body. These are categorized as follows: smooth, cardiac, and skeletal.

2.1.2.1 Smooth Muscle

Internal organs like arteries and veins that are hollow have smooth muscles attached to them. GI tract is another example of organs with such muscles attached to them controlled by the autonomous nervous system. This category of muscles cannot be voluntarily controlled. They are not striated like the skeletal muscles but instead have a spindle shape with a single nucleus centrally placed. Slow rhythms are generated by these muscles as they operate.

2.1.2.2 Cardiac Muscle

Another branch of muscles controlled by the autonomous nervous system are the cardiac muscles. Located in the walls of the heart, these muscles also have a single central nucleus, but they are striated, unlike the smooth muscles. These rectangular shaped cells form a cardiac muscle tissue which contracts involuntarily and with great strength and a controlled rhythm [7].

2.1.2.3 Skeletal Muscle

The bones in the human body can only be moved using the muscles. Skeletal muscles contact to make such movements possible Controlled by the Peripheral part of the brain in the central nervous system, these muscles are under voluntary control of the body. The muscles of this category have multiple nuclei and a striated structure allowing each muscle fiber to act independently when a movement is required.

2.1.3 Muscle Physiology

The amount of force produced by a muscle is directly proportional to physiological cross-sectional area (PCSA), and muscle velocity- the speed at which the muscle contracts, is proportionate to length of the muscle fiber [7], [6]. Muscles are normally arranged opposite to one another to allow them to act as pulleys. This arrangement is called antagonism. This arrangement is also found in the nerves stimulating the muscles. The neurological system of the body ensures that two antagonistic muscles do not get stimulated at the same instance. Athletes undergo intense training to learn to control the way their antagonist muscles relax and contract so that there is increased force output as well as co-ordination between these muscles.

An important information regarding muscles is the sound produced as they move. It has been discovered that fibers twitching slowly produce up to 30 such contracting sounds per second while those moving faster produce a proportionally faster sound [8]. This rumbling sound is vital information for our research since this noise can act as a hindrance to the results that have been achieved.

2.1.4 Muscles of the Lower Extremity

Muscles involved in the movement of the lower part of the body, specifically the thigh (legs) originate from a part of the pelvis and inset into the femur. The largest of these, is part of the posterior group. The illustration in figure 1, indicates some of the muscles in the lower extremity of the human body.

The leg is actuated using the muscles located in the thigh region. The leg is straightened using the quadriceps femoris muscle group whereas hamstrings-antagonists to the quadriceps femoris muscle group, are responsible for flexing the leg at the knee. Muscles found in this area are further anatomically categorized into anterior, posterior as well as the lateral portions of the leg. Specific to this research, the tibialis anterior is antagonistic to the gastrocnemius and soleus muscles, which are responsible for plantar flexion [9].

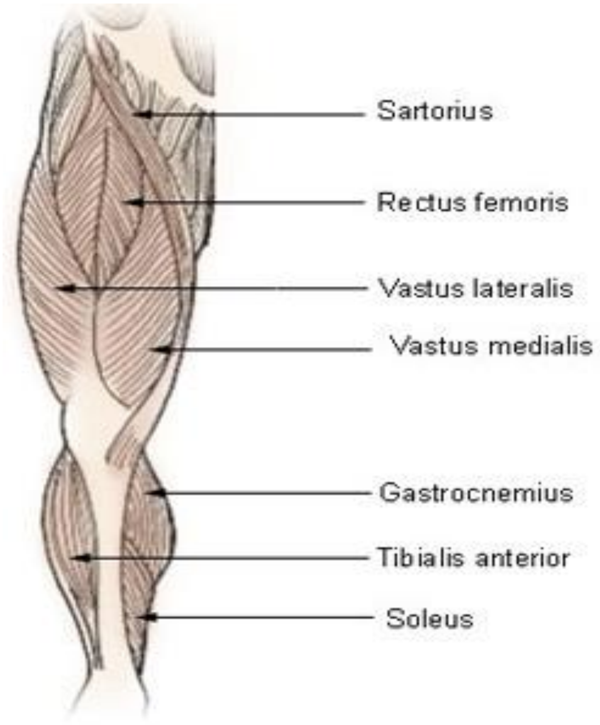


Figure 1: Muscles of the lower extremity.

2.1.5 Anterior Tibialis Muscle

Located in the anterior part of the lower leg, the anterior tibialis muscle is the largest muscle found in the lower part of the body. The blood supplied to this muscle comes from the anterior tibial artery. The basic function of this muscle is dorsiflexion i.e. flexing the foot upward [10]. Anatomically, the AT muscle is attached to the upper lateral surface of the shinbone. The base of the metatarsal bone in the foot is where the muscles inserts itself allowing dorsiflexion function to be possible [1].

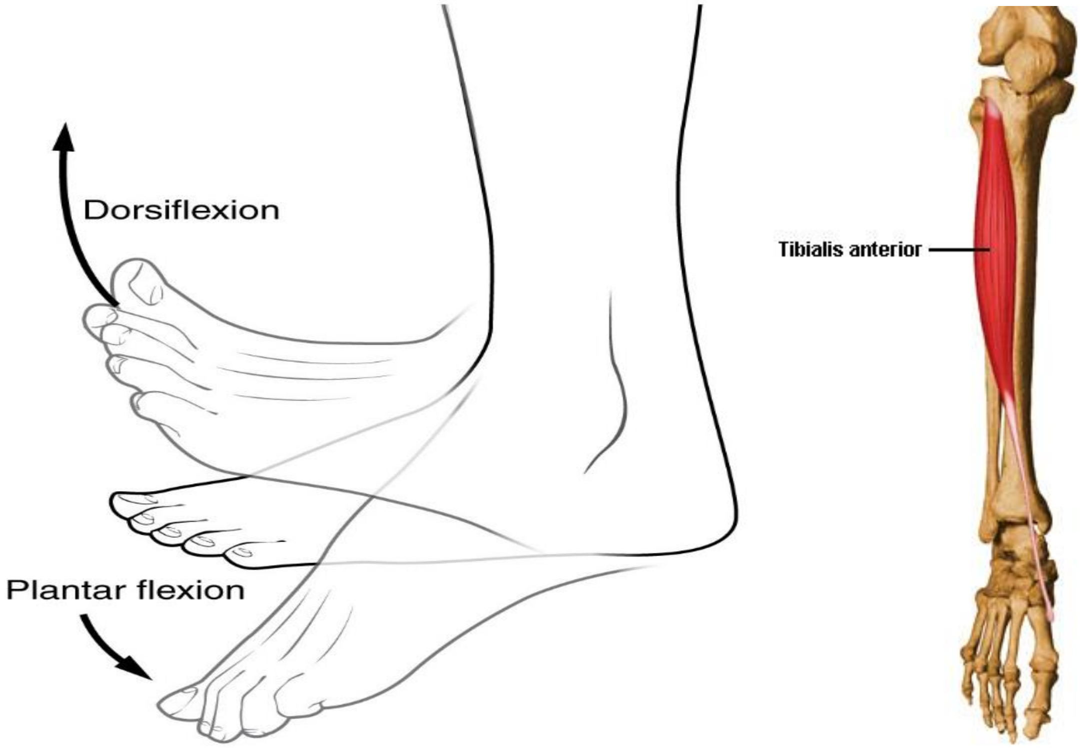


Figure 2 : Dorsiflexion and planter flexion and tibialis anterior

2.1.6 Research

Studies conducted on the skeletal muscles demonstrate how the amount of force generated and the contraction speed of the muscles changes with different parameters that effect the body. Once the contraction speed is known, the fiber composition can be inferred based on the results of those experiments. However, for a complete picture of the muscle and its properties in vitro testing is required [11].

Electromyography is used to record the two physiological responses of the skeletal muscle. Relaxation and contraction both, both result in an electrical impulse generation in the muscles which can be measured by an electrode configuration [11]. The action potential recorded occurs due to hyperpolarization of the motor axons because of nerve impulses that are sent to the muscle. This can also be used to indicate of muscle fatigue [12].

In different studies involving EMG, the maximal voluntary contraction (MVC) is frequently performed by the skeletal muscle under consideration. This allows a calibrated measure of the rest of the tasks performed by the muscle [5], [13].

2.1.7 Muscle Fiber Conduction Velocity:

Conduction velocity refers to the speed at which a nerve impulse propagates through a medium. It is called ‘nerve conduction velocity’ when passing through the nerve and it is referred to as ‘muscle fiber conduction velocity’ while passing through the muscle fibers.

In the human body, this conduction velocity ranges from 4 m/s to 10 ms/s [12]. It depends on the following factors:

- Axon Diameter
- Myelin sheet thickness
- Temperature.
- Muscle Fiber type

2.2 Chiropractic Intervention

Emphasizing on the stimulation of the spine, as well as the musculoskeletal system, chiropractic is a method considered as an alternate form of medicine [2], [4]. Chiropractic originated from bone setting which is a form of folk medicine. It further included vitality and had a spiritual meaning according to early chiropractors. Chiropractic initially did not rely on scientific methodology but rather on inferential reasoning for its treatment. With time, however, practitioners adopted a mixture of science and inferential reasoning to apply new methods of spinal manipulation [14].

Even though chiropractors are known to have different techniques based on their own ideologies, they all agree to the fundamental teaching that there is a relationship between the nervous system and the spine. Spinal manipulation can have an effect on the neural pathways and lead to improving the conditions of the patients suffering from various ailments including irritable bowel syndrome and asthma[15]. Chiropractic intervention has the potential to improve the conditions of multiple ailments and it remains yet to be explored how it can be applied for rehabilitative techniques.

Pain experienced in the musculoskeletal system is relieved by using chiropractic techniques. These involves areas such as the spine, neck, arms or legs and each area is targeted by a different variation of stimulation through chiropractic methods. The aim of the process is to improve the connection between the muscles and then nervous system by stimulating the spine, bones, connecting tissues and the neuromuscular system.

Most people address issues relating to neck and back pain or spinal discomfort through chiropractic intervention and chiropractors depend on vertebral subluxation along with other forms of chiropractic techniques as the focal point of their therapy.

In this research, professional chiropractic help was taken to stimulate specific parts of the spine that are hypothesized to influence the anterior tibialis muscle. The spine was stimulated all the neurological pathways connect to the brain via the spine. Any form of manipulation to it was expected to result in immediate reaction from the body.

2.3 Surface Electromyography Techniques

Electromyography (EMG) is a biomedical signal produced when a muscle performs a certain movement e.g. contraction [16] .

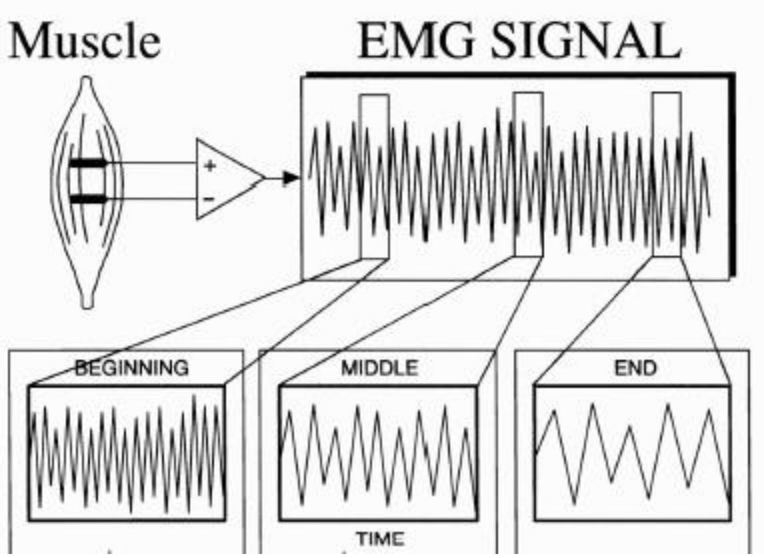


Figure 3 : Demonstration of how an EMG signal is measured.

In the early stages of biomedical researches, a two-electrode configuration was adopted to obtain the signal from a contracting muscle. One of the electrodes was placed on the bone, acting as a reference while the other was placed on a calibrated center of the muscle. This technique allowed researchers to find the response time of a muscle and how a nerve propagates through it once the actuation signal has been given by the brain.

The problem with this, however, was repeatability of the experiment. Each time, the electrode was placed, a professional needed to carefully mark the point of measurement during each research. There was also significant noise in the channels that extracted the signal from the electrodes which needed to be cancelled out through different band pass filters.

Typically, a normal EMG signal lies between 100 Hz and 1000 Hz frequencies. In case of this study a band of 150Hz and 750Hz has been applied during pre-processing.

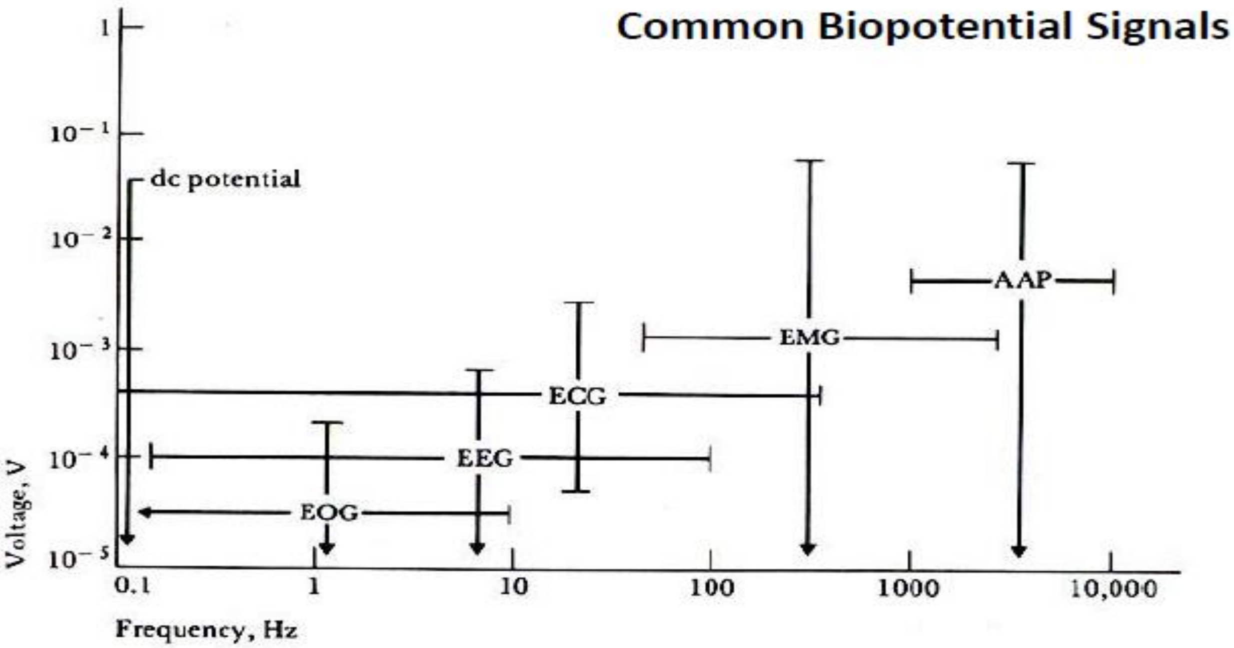


Figure 4: Common Bio potential signals

To improve the signal to noise ratio, this technique was improved by adding another electrode to the configuration and using spatial filtering to remove the noise from the signal attained during a muscle contraction. Furthermore, invasive methods using an array of sterile needles were explored as a potential option for EMG.

This technique allowed researches to get a better-quality signal from the muscle with multiple points of entry. It allowed isolation of individual motor units and gave a better outlook to the human muscle physiology. The disadvantage was the lack of spatial resolution since the electrode could only be fixed in one region of the muscle, it could not be taken out and re-inserted near the previous installation area. There was a risk of infection considering the invasive proceedings of the experiments and each time a professional practitioner was needed to install and remove the electrodes which was both time consuming and expensive.

Due to these reasons High Density Surface Electromyography (HD sEMG) was introduced. Used for the measurement of EMG signals generated by the muscles, this non invasive technique used multiple electrodes instead of the conventional two electrode configuration. Using muliple electrodes in a limited space allows better spatial resolution as well as the application of different algorithms adopted from EEG analysis. HD sEMG relies on the superimposition of the motor unit action potentials of the muscle region; these can also be individually located using spatial filtering. Motor units can also result in a change in the sEMG signal’s ampitude. Using multiple electrodes to collect the information improves the accuracy of the muscle physiology analysis. Another advantage of HD sEMG compared to invasive methods that cause infections, this technique does not.

2.4 Signal Processing Techniques

The use of HD sEMG can only be effectively applied in this research by successfully adopting signal processing techniques based on the data attained from the exercises performed during the pre-recording and post recording sets (elaborated in the methodology section). Essentially, the focus of this research required the 2D representation of the muscle being recorded to better understand what region of the muscle was undergoing a change due to the chiropractic intervention.

Previous brain studies showed how a multiple channel EEG electrode cap can be used to highlight the increase in EEG activity in specific regions of the brain while performing motor tasks [17]. Adopting the same concept, the topographical heat map of the anterior tibialis muscle was made.

2.4.1 Topographical Heat Map

A heat map is a graphical representation of data where the individual values contained in a matrix are represented as colors. Heat maps help you get an instant feel for an area by grouping places into categories and displaying their density visually. The darker the color is, the higher is the density.

Recent applications of heat maps include: weather forecasting, real time analytics of websites, studying of the world disease patterns. Heat maps are important in this study since they allow access into the physiological features of the muscle based on its anatomical features. They can be used to identify motor units, innervation zones and map out the regions of the muscle that are actively involved in the task being performed [18]. Another example more relevant to biomedical applications is of the human brain which is mapped using EEG signals [19].

The same concept was used to spatially divide the 64-electrode array mesh of the EMG signals and demonstrate how the muscle behaved while performing dorsiflexion. Since the muscle was now divided into 64 parts interconnected with each other, it was now possible to show where the EMG activity originated from as well as open doors for more research using spatial filters such as Laplacian filter which could enhance the resolution of the image obtained by integrating the 64-channel mesh.

Creating a topographical map of the human muscle provides an opportunity to locate the motor units as well nerve endings present on the muscle in real time[1]. Therefore, it was an important milestone for this research.

2.4.2 Cross Correlation

There are various types of signal processing techniques that were tried and tested for this research which included the wavelet transform (WT), which is an efficient mathematical tool for local analysis of non- stationary and fast transient signals[20][21][4]. Cross correlation was in turn finalized as the technique for finding the conduction velocity in the AT muscle. The technique was used with the ML method to ensure minimal mean square error was obtained while calculating the time delay between two adjacent electrodes recording the same signal. Cross correlation is a signal processing technique which involves mathematically matching one signal with another to find if there are any similarities between the two.

Mathematically, cross correlation of a continuous function can be represented as follows:

$$(f \star g)(\tau) \overset{\text{def}}{=} \int_{-\infty}^{\infty} f^*(t)\, g(t+\tau)\, dt,$$

Where, f* represents the complex conjugate function of f and τ denotes the displacement or lag.

Submarines and radars were one of the first applications of correlation. They were used to detect the delay in receiving a signal by breaking the signal into shorter intervals of time and detecting the difference between the amplitude at each point of the signal. Cross correlation involves the same methodology, but instead of using the same signal after it is reflected, it uses two different signals and tries to find the closeness of the two signals. Cross correlation has resulted in a breakthrough in the signal processing research in the past, however, it becomes ineffective while studying non-linear systems where the certain non-linear aspects are not considered in the mathematical equation. This leads to two very closely related signals being considered different due to their non-linear nature [22].

Due to the stochastic nature of EMG signals, cross correlation alone could not provide sufficient validation for the claim that chiropractic intervention influences the anterior tibialis muscle. It was therefore, essential to inculcate another technique for reliable results from the study. A statistical method of improving the results from cross correlation between relevant signals is to adopt Maximum Likelihood (ML) Method in the frequency domain as carried out by Farina et.al [12]. The way cross correlation is used to estimate the muscle fiber conduction velocity is further elaborated in the methodology section.

2.4.3 Maximum Likelihood Method

A statistical model of a set of recordings or observations can have its parameters estimated using a statistical technique known as Maximum Likelihood Estimation (MLE) or Maximum Likelihood Method. This technique assumes there is an irregular distribution of parameters for the set of data provided.

The mathematical representation of MLE calculation on a set of discrete data can be denoted as follows:

$$lik(\theta) = \prod_{i=1}^{n} f(x_i|\theta)$$

The maximum likelihood estimate is specifically the value of theta that makes the data observed from the recording “the most probable” [23]. This estimated value provides information regarding the parameters of the data set provided. The ML method was adopted in previous studies for improving the reliability of the results. The method was used with various signal processing techniques such as cross correlation, root mean square error function for the calculation of conduction velocity in the muscle fibers[12], [24].

Once, this estimation was made, the data was ready for further statistical analysis to signify the effect of chiropractic intervention on the conduction velocity of the anterior tibialis muscle fibers. This statistical measure was added to the research to ensure the validation and reliability of the recordings made in the pre-recording and post-recording sets of the experiments.

Hence, with the knowledge about the human anatomy, and the signal processing techniques that can be adopted for this research, it was possible to move on to the methodology phase where all these methods have been connected to lead to the results as further discussed in this dissertation.

CHAPTER 3: METHODOLOGY

The purpose of this research is to identify the changes in the Anterior Tibialis muscle due to chiropractic intervention using HD sEMG. To accomplish this goal, a 64-channel electrode array sensor, namely, ELSCH064R3S, was vertically strapped on to the anterior tibialis muscle of 12 subjects. The 13x5 matrix configuration of the electrode array with inter-electrode distance (IED) of 8 mm, is shown in figure 1. Each subject was then asked to follow a specific protocol to minimize uncontrolled variables. During the protocol, OT Bioelettronica was used to record the sEMG signals generated in the anterior Tibialis muscle.

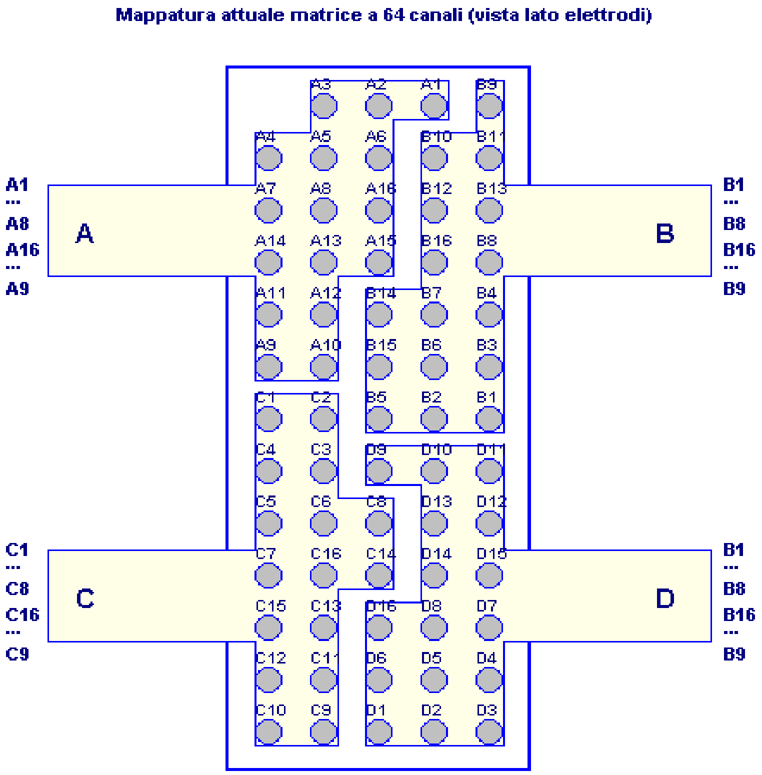


Figure 5: the matrix configuration of ELSCH064R3S

3.1 Signal Recording Protocol:

As shown in figure 2, before the recording set the device was calibrated by asking the subject to apply the maximum voluntary contraction (MVC) 3 times with 2 minutes rest between each exercise. During these MVCs, the force generated by the muscle was also recorded using a force transducer. The three attempts were averaged to find the mean force produced by everyone during MVC.

Once the calibration was done, the subject was asked to perform two types of exercises in each recording set.

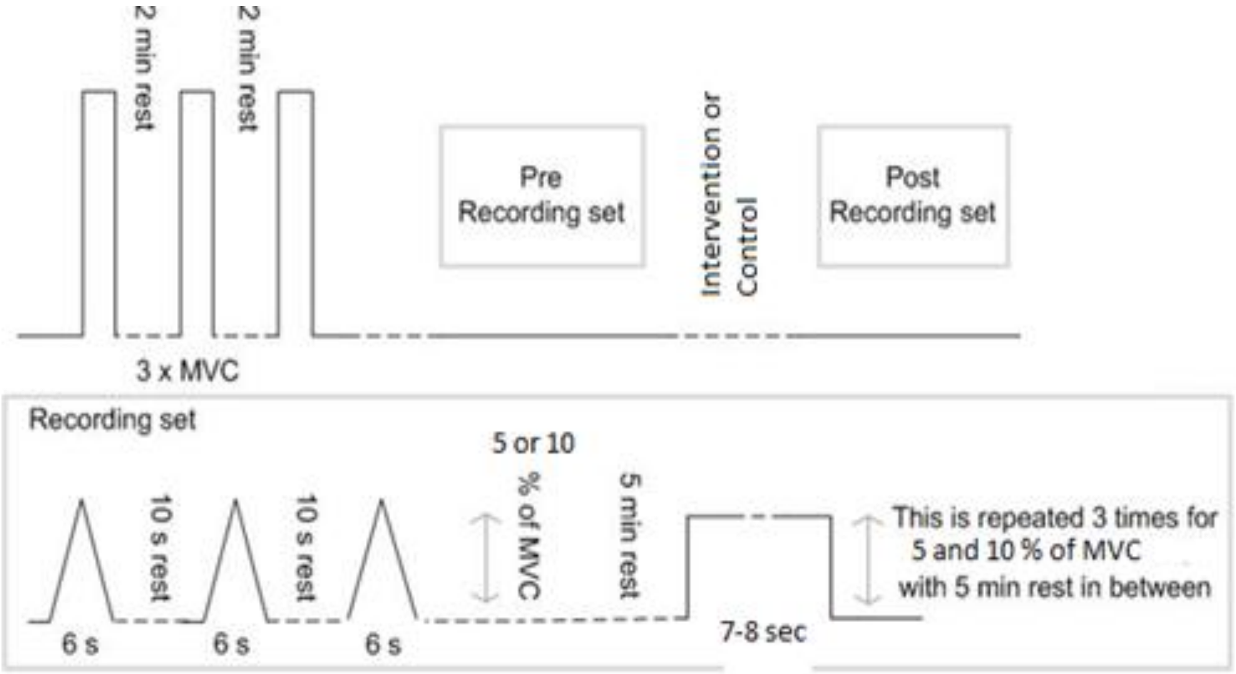


Figure 6: The protocol followed by each subject

1.1.1 Recording set 1:

Once, the calibration was complete, the subject was shown a mark on a screen in front of him/her. This mark represented 5% of the MVC. The subject was asked apply force (dorsiflexion) until that mark is reached. He was asked to relax his muscle at the same rate at which he applied force. The whole exercise took approximately 6 seconds. To ensure reliable readings were taken, the task was performed twice more with a 10 second interval between each exercise to ensure fatigue was minimal.

At this point, the subject was made to rest for 5 minutes after which time, the subject was required to apply the same amount of force (5% of MVC) but this time maintain that applied force for 7-8 seconds before relaxing. This exercise was also performed thrice to ensure that the research was robust.

1.1.2 Recording set 2:

The same procedure as recording set 1 was carried out but this time 10% of the MVC force value was taken as a mark for the subject to attempt to reach on the screen using dorsiflexion.

1.1.3 Control and intervention:

These recording sets were used to recording the sEMG signal from the subject before and after intervention. To find out if there was any connection to the neurological pathways to the brain of the subjects, a control group was introduced where the same subject would first be asked to perform the pre-recording set and the post-recording set, without any form of therapy or spinal stimulation.

The subject was subjected to this procedure after his spine had stimulated through chiropractic intervention.

A summary of all the recordings that took place is shown in the flow chart given in figure 3. Once the signal was attained from the exercise, it was categorized as either being part of the control group or the intervention group. Each of this groups, had sub-groups of pre-recording and post recording sets. The control group did not have any form of chiropractic intervention while the intervention did. The ramp exercise refers to the task of reaching a marked point through dorsiflexion and then coming back via planter flexion at the same rate. The Maintained exercise denotes the steady state exercise where the subject had to maintain the marked value by controlling the amount of force produced in his anterior tibialis muscle during dorsiflexion.

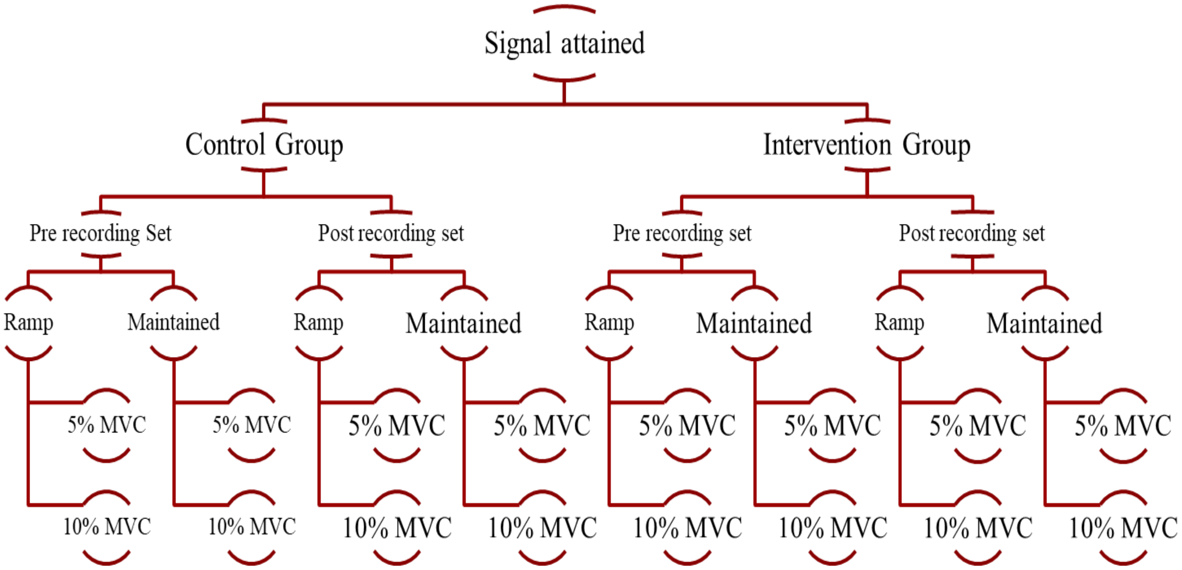


Figure 7: Flowchart of the protocol followed by the subject in the study

1.1.4 Pre-processing of the EMG signal:

The signal obtained from the 64-channel array was amplified by a gain of 2000 while being sampled at 2048 Hz. Once amplified it was measured in mV Signal gain: 2000. To isolate the EMG signal from random noise, band pass of 750 Hz upper limit and 10 Hz lower limit was applied on each of the signals obtained through the 12-bit ADC channel.

3.2 Signal Analysis:

The signals attained from the ramp exercise and the maintained (steady state) exercise were dealt with using a different algorithm keeping the stochastic nature of EMG signals in mind. This is further elaborated in figure

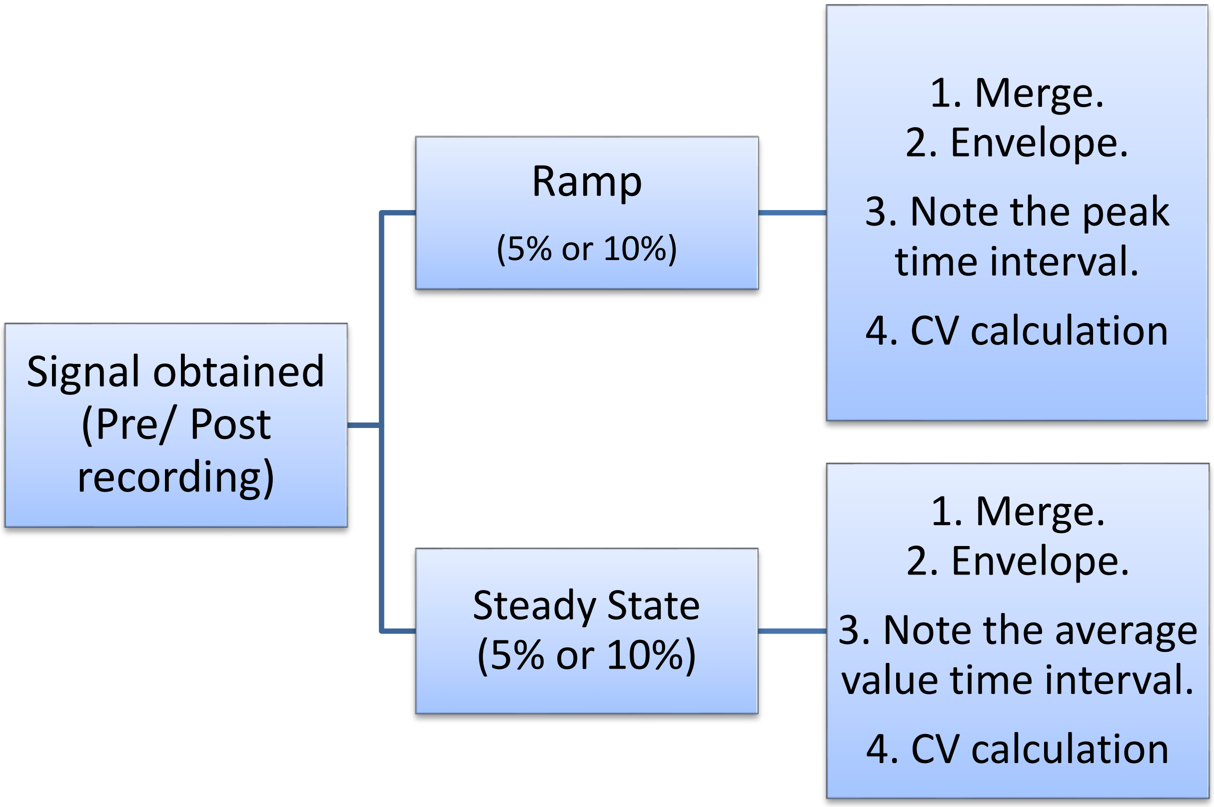


Figure 8: Summary of the algorithms used to analyze the EMG signal attained from each recording set.

3.2.1 Ramp exercise:

3.2.1.1 Obtained signal:

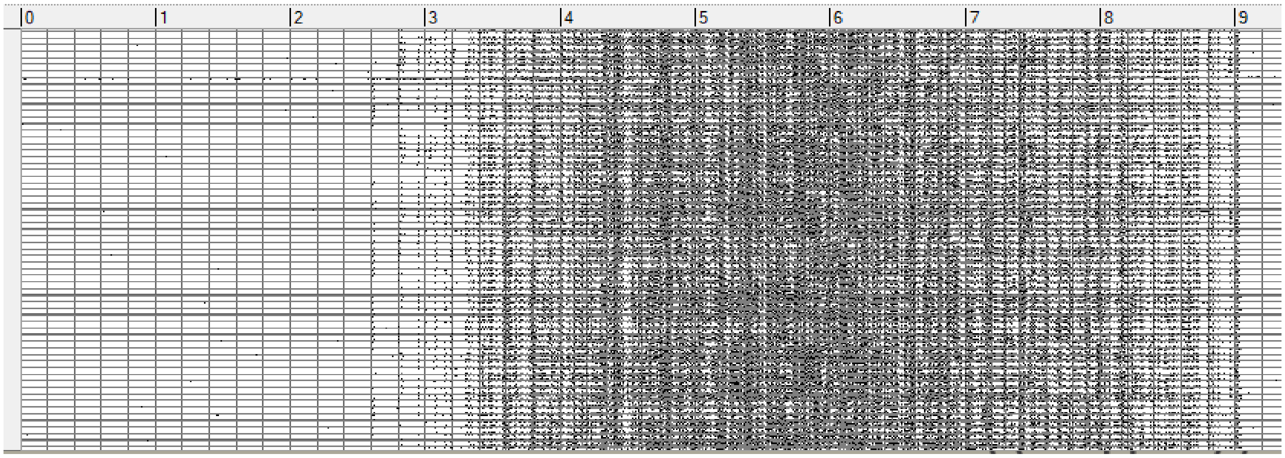


Figure 9: Obtained Signal shown in BioLab

The 64-channel signal was imported into the software as shown in Figure 9.

3.2.1.2 Step 1: Merge the Signals

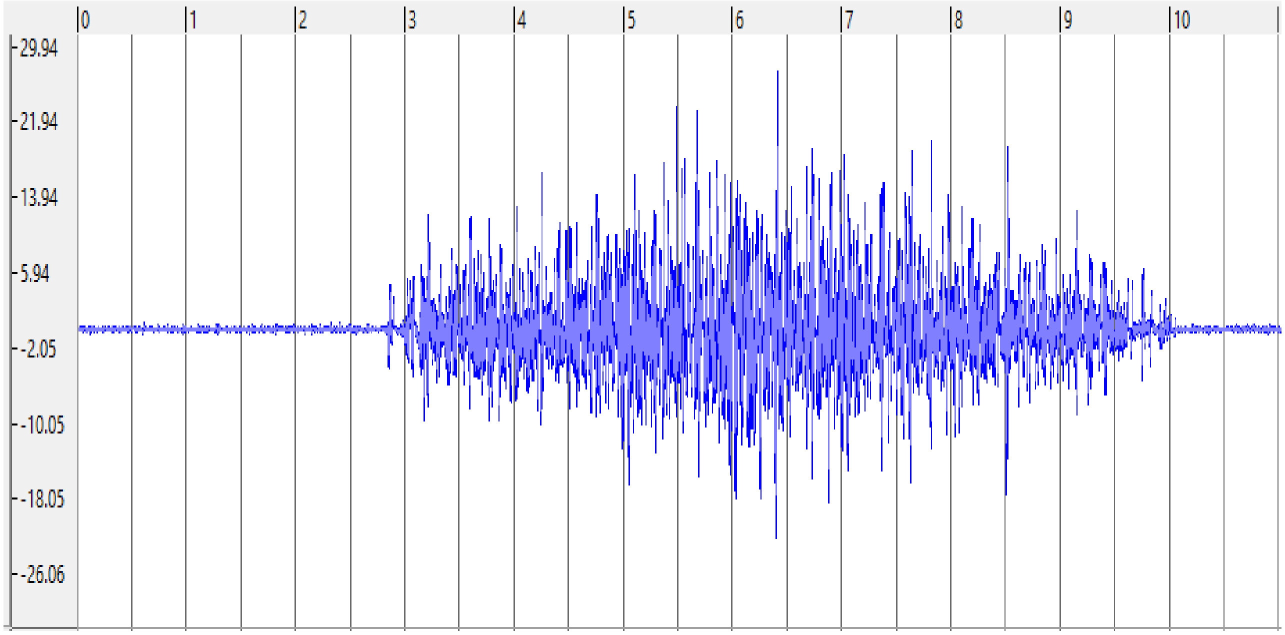


Figure 10: 64 channels merged together

As demonstrated in figure 10, all 64 channels were merged together into one signal through superimposition.

3.2.1.3 Step 2: Envelope the RMS of the merged signals.

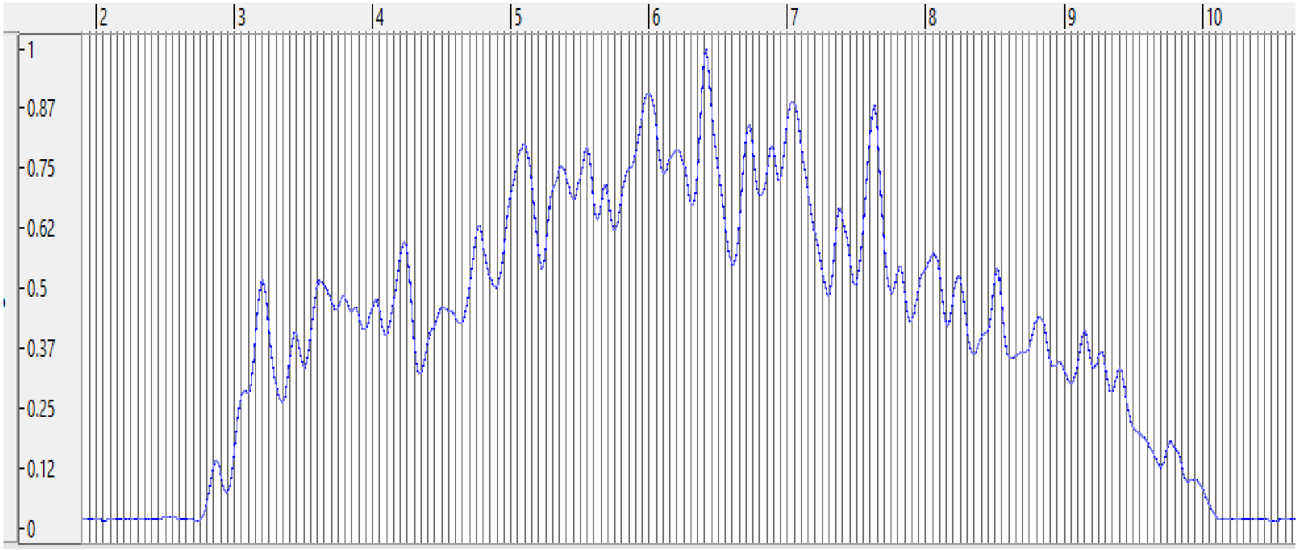


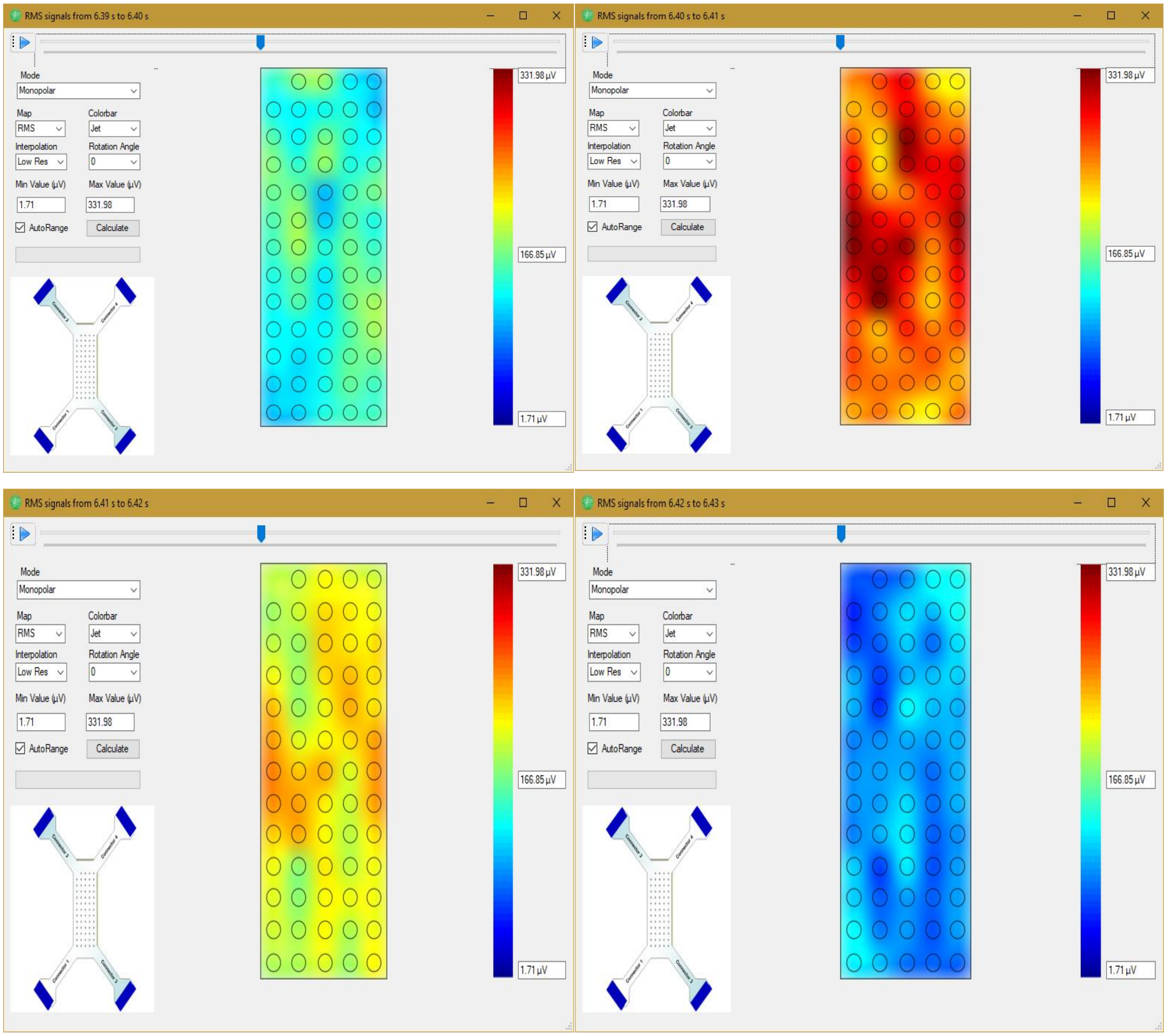
Figure 11: Enveloped signal

The room mean square (rms) of each epoch (0.001 ms) was taken and the merged signal was enveloped using a second order Butterworth filter. The result can be seen in figure 11. At this stage, the 500 ms time window which had the peak at its center was also noted.

3.2.1.4 Step 3: Make a topographical map of the electrode array at the peak interval.

The root mean square values over the epoch are displayed in the OT BioLab main window[13] shown below. The interpolation technique used was the “bicubic interpolation” with three different resolutions: Low, Medium and High. Low interpolation option was selected for this study. Once calibrated, these maps demonstrated the regions of the muscle areas that are most effected by the exercise carried out by the subject before and after the chiropractic intervention. This represents the most affected area of the muscle during the peak interval of the ramp exercise.

These heat maps can also be used to determine the innervation regions of the muscle and to isolate motor units but for this thesis they are being used to isolate those channels on the HD sEMG sensor that detect the greatest change in muscle activity.


RMS signals from 6.39 s to 6.40 s

Mode: Monopolar
Map: RMS
Colorbar: Jet
Interpolation: Low Res
Rotation Angle: 0
Min Value (µV): 1.71
Max Value (µV): 331.98
☑ AutoRange

RMS signals from 6.40 s to 6.41 s

Mode: Monopolar
Map: RMS
Colorbar: Jet
Interpolation: Low Res
Rotation Angle: 0
Min Value (µV): 1.71
Max Value (µV): 331.98
☑ AutoRange

RMS signals from 6.41 s to 6.42 s

Mode: Monopolar
Map: RMS
Colorbar: Jet
Interpolation: Low Res
Rotation Angle: 0
Min Value (µV): 1.71
Max Value (µV): 331.98
☑ AutoRange

RMS signals from 6.42 s to 6.43 s

Mode: Monopolar
Map: RMS
Colorbar: Jet
Interpolation: Low Res
Rotation Angle: 0
Min Value (µV): 1.71
Max Value (µV): 331.98
☑ AutoRange

Figure 12 : Topographical Heat maps of the AT muscle

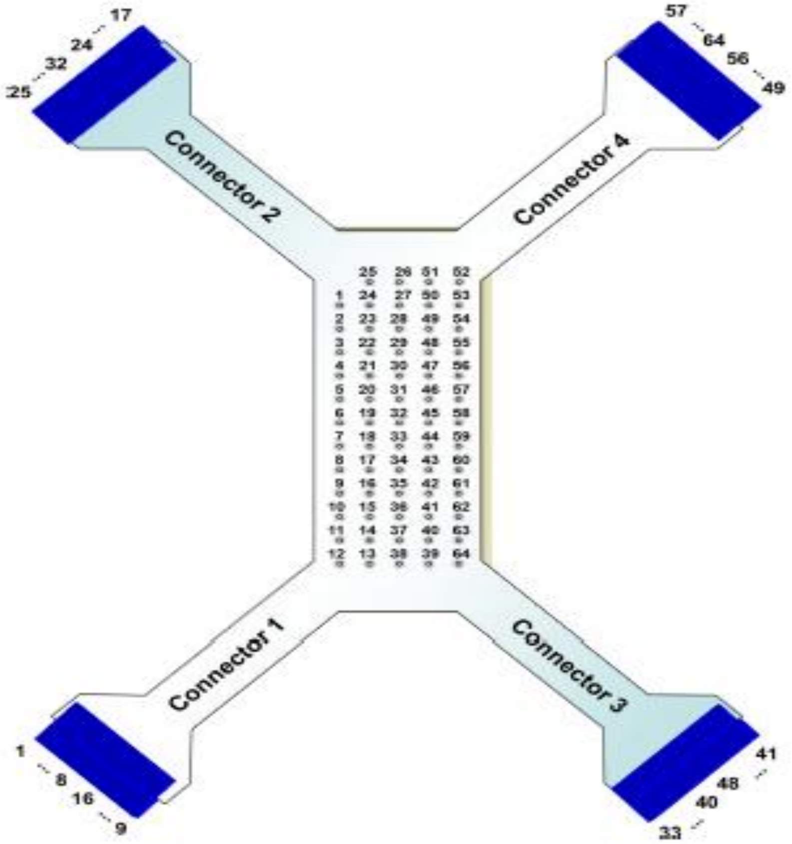


Figure 13: ELSCH064R3S Pin Out (posterior view)

3.2.1.5 Step 4: Calculate the Conduction Velocity

An estimation of the CV was done from all 64 channels in the given time interval (250 ms on either side of the peak EMG value), making sure that the mean square error (mse) between aligned signals was minimal. This minimization of the mse was achieved by operating in the frequency domain, without limitation in the time resolution and with an iterative computationally efficient procedure[13]. To reduce computational time, a unity gain was used during this calculation. The algorithm is for calculating CV velocity was adopted from previous studies[12] which utilized Maximum Likelihood (ML) method to identify maximum correlation between the signals under consideration. Once the delay is estimated, CV is obtained dividing the distance (8 mm) between electrodes by the delay obtained.

3.2.2 Maintained exercise:

3.2.2.1 Obtained signal:

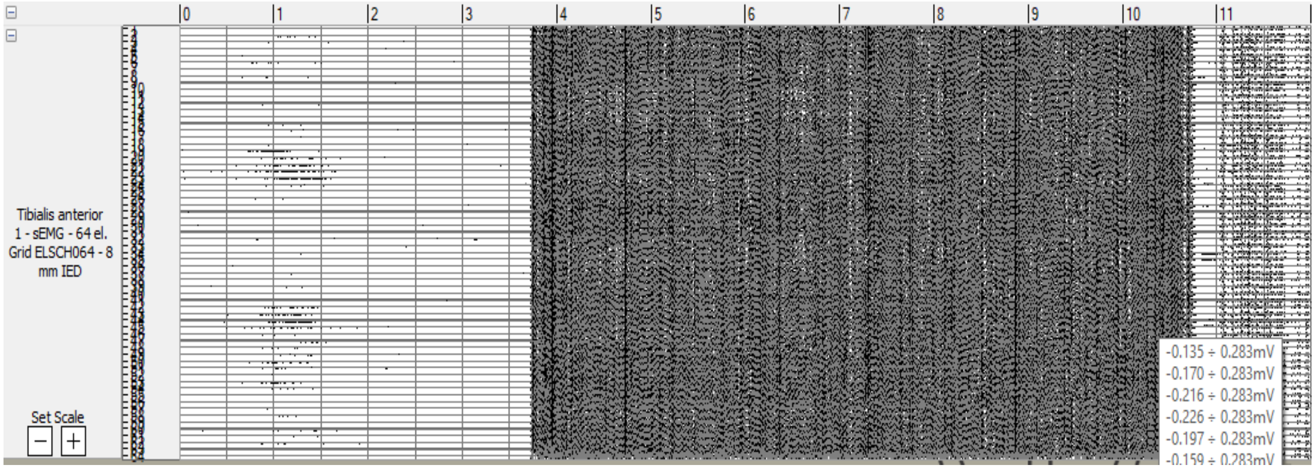


Figure 14: Obtained EMG signal after a sustained contraction

3.2.2.2 Step 1: Merge the Signals

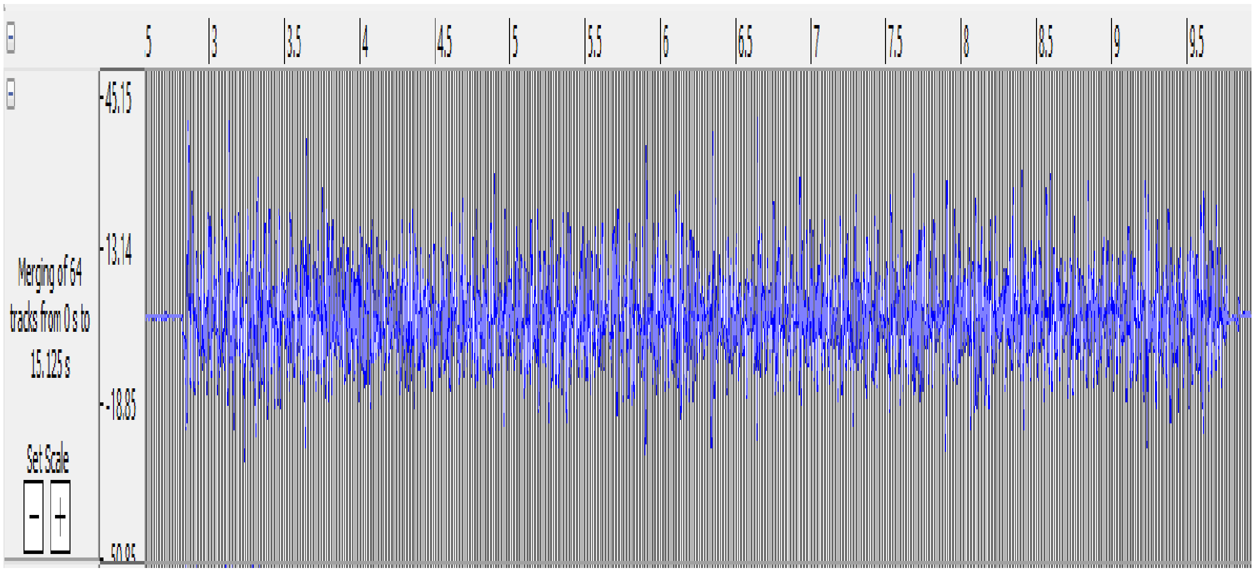


Figure 15: Merged EMG signal of 64 channels during steady state exercise

3.2.2.3 Step 2: Envelope the RMS of the merged signals.

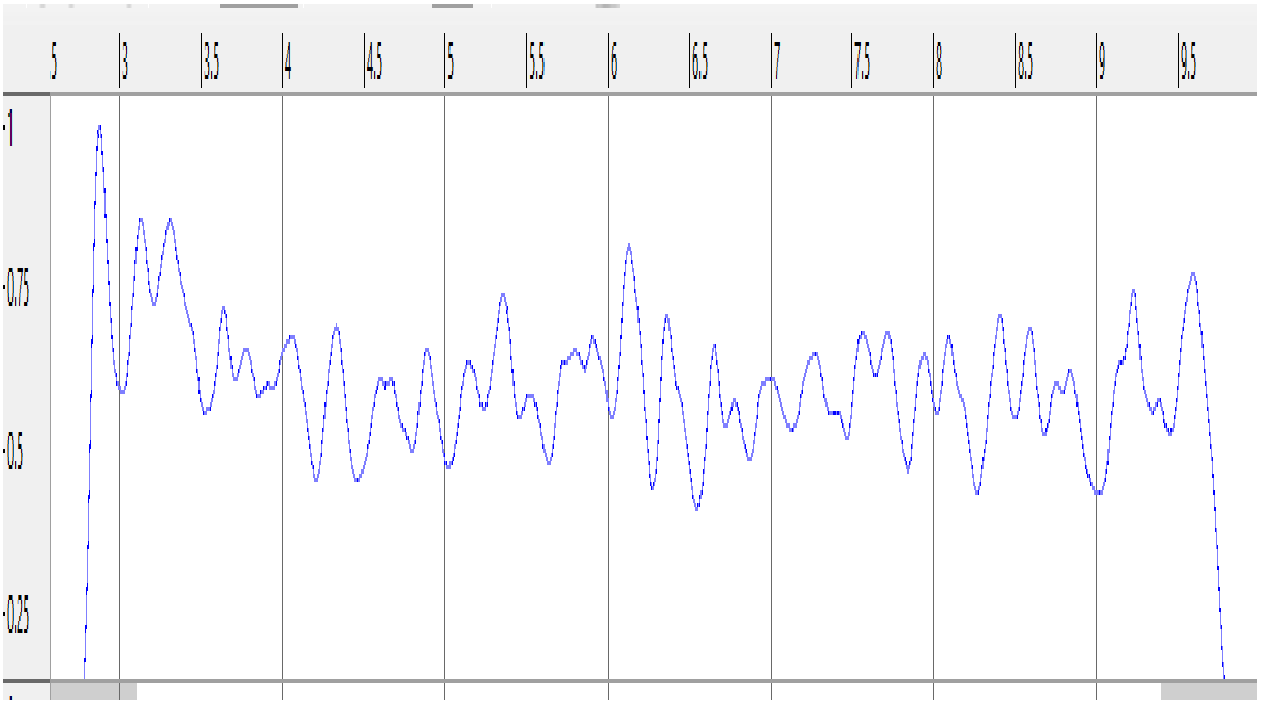


Figure 16: Enveloped RMS of the 64 channels merged signal

3.2.2.4 Step 3: Take an average of the overall signal.

Since the maintained exercise had multiple peaks, it became difficult to use the same algorithm for finding out the conduction velocity. Thus, a different approach was used i.e. the average of the whole signal was calculated.

3.2.2.5 Step 4: Find a small interval that matches the overall signal's average.

The overall average was then compared to shorter intervals which had a similar average value.

3.2.2.6 Step 5: Calculate the Conduction Velocity

Conduction velocity was calculated using the same iterative method that had been adopted earlier for ramp exercise calculations. The time interval selected however, was the one that had the same average as the overall signal.

3.3 Statistical Analysis:

Once the conduction velocity values have been calculated from the signals obtained by the Ramp and steady state exercises, the control group and the intervention group were compared by using a student's t test of dependent variables.

In each group the difference between the conduction velocities of the pre-recording set and the post recording set were calculated. The variable 'cA' was used to denote the difference in CV of the pre-recording and post recording set of the control group whereas, the intervention group's sub groups' difference was denoted by the variable 'iA'. The variables 'iA' and 'cA' were statistically analyzed for the 12 subjects involved in the study using a dependent variable t test with α=0.05.

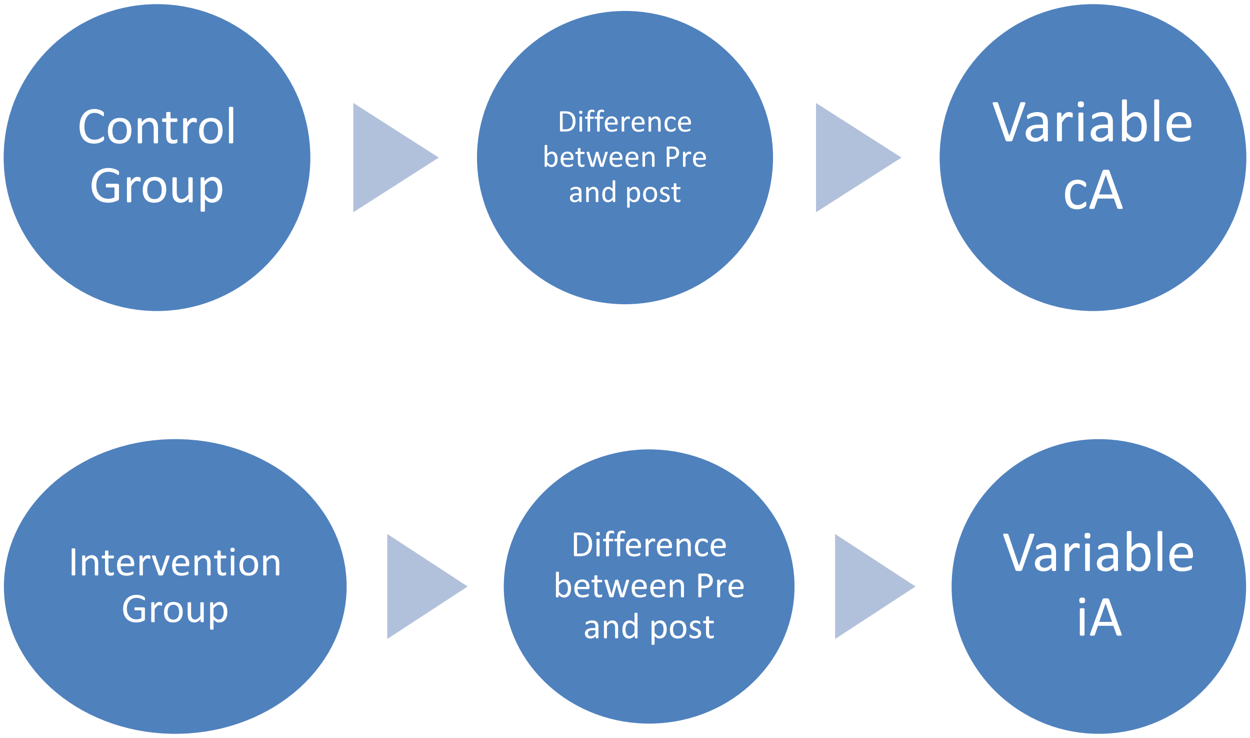


Figure 17: Flowchart demonstrating the formation of variables used for statistical analysis

CHAPTER 4: RESULTS AND CONCLUSION

4.1 Force Profile:

The average force recorded using a force transducer during maximum voluntary contractions was used to find out if chiropractic intervention results in a significant change in the amount of force generated by the anterior tibialis muscle of the subject.

The graphical representation of the results demonstrates a rise in the percentage difference of force produced by the AT muscle as shown in figure 18.

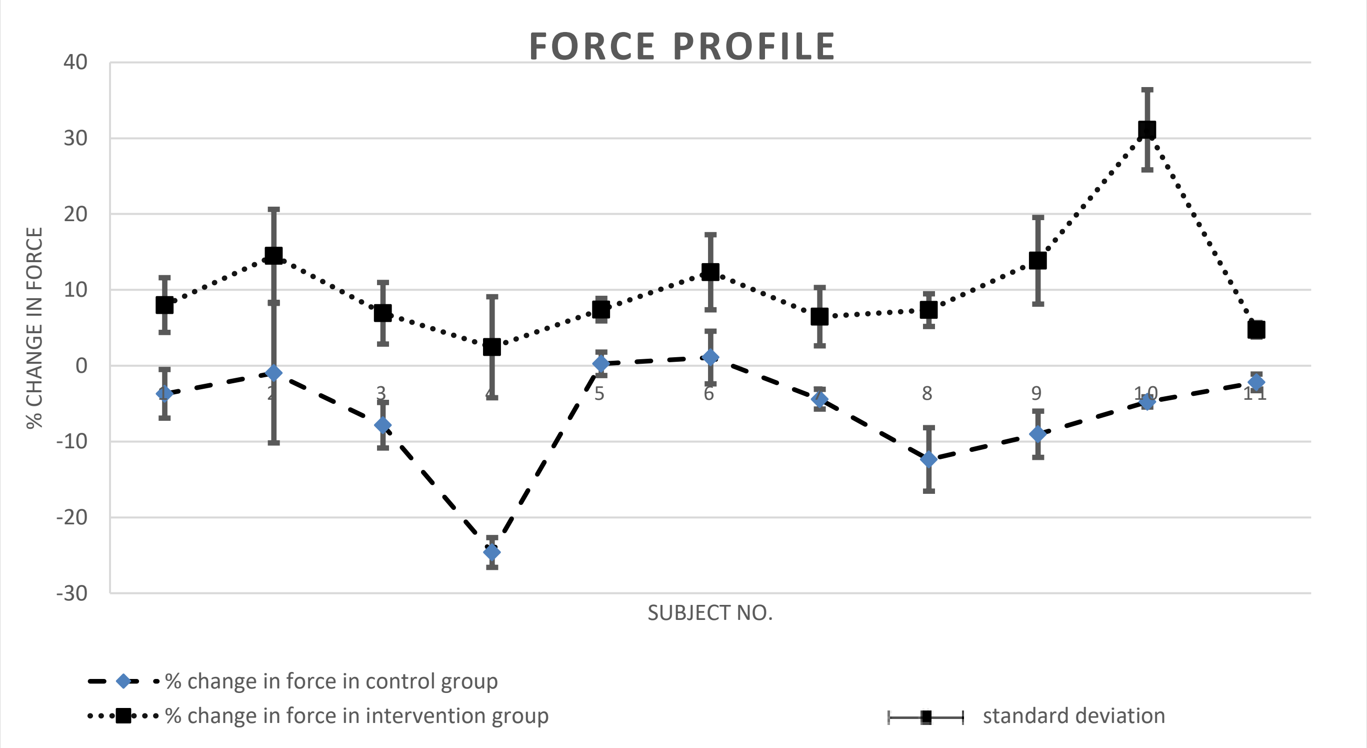
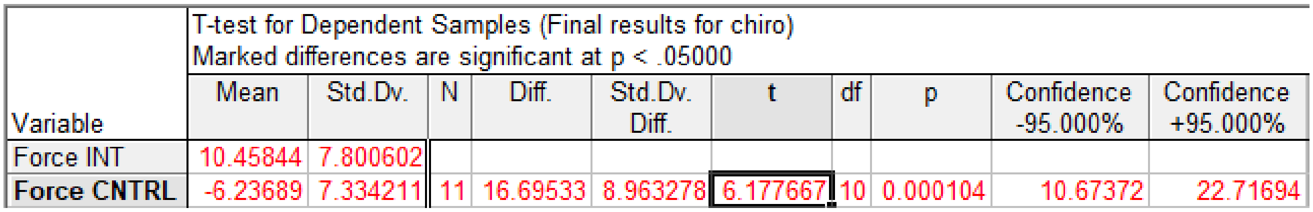


Figure 18: Graphical representation of force profile of AT muscle.

The graph in figure 18, denotes how the intervention group experienced a higher force produced after the intervention in each of the subjects. The mean value of each subject's force is shown and the error bars denote the standard deviation from the mean value of the force produced in the three attempts of the exercise. Without the chiropractic intervention, some subjects even produced less forced in their post recording set as compared to the pre-recording set. The decrease in the amount of force produced could possibly be due to muscle fatigue and this can be validated using Mean Frequency (MNF) and Median Frequency (MDF) analysis.

To confirm if there was a significant difference in the difference in the amount of force produced by chiropractic intervention, a student's test (t test) was performed on a sample of 11 subjects since the data from one of the subjects was corrupted due to possibly misplaced attachment of the HD sEMG electrode array. Multiple channels of the same subject showed a random noise through the course of the experiment therefore, the anomaly was removed from the data set. The results are shown in table 1, where 'Var1' represents the mean difference of force in the group without chiropractic intervention and 'Var2' signifies the mean difference of force in the group with chiropractic intervention.



T-test for Dependent Samples (Final results for chiro)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
Force INT	10.45844	7.800602								
Force CNTRL	-6.23689	7.334211	11	16.69533	8.963278	6.177667	10	0.000104	10.67372	22.71694

Table 1: Results of t test of force profile after chiropractic intervention.

The value of α was set 0.05 minimizing the Type 1 error from the statistical analysis of the experiment. The value of p was much less than 0.05 which demonstrates that there was significant difference between variables 'Var1' and 'Var2'. Upon further analysis, it was calculated that the Cohen's d effect size of the test was 2.205142, which is a categorized as a huge effect size[25]. The formula is given as:

$$\text{Cohen's } d = (M_2 - M_1) / SD_{\text{pooled}}$$

Where:

$$SDpooled = \sqrt{((SD12 + SD22) / 2)}$$

4.2 Conduction Velocity:

The conduction velocity calculations were done on 10% ramp exercise and 10% steady state exercise and the results of the change in muscle fiber conduction velocity (MFCV) were recorded. The results are as follows:

4.2.1 Ramp exercise:

The peak interval was selected with a time window of 500ms. The average conduction velocity was found during this interval each time the task was performed (thrice). The values of conduction velocity varied from 4 m/s to 12 m/s which was expected considering the previous studies showed similar results[12], [26].

Figure 19 shows the graphical representation of the results of this study. The figure shows the mean values of the conduction velocity difference calculated for each subject with the error bars denoting the standard deviation from the mean since the data was averaged through three attempts. The intervention group shows substantial increase in the conduction velocity due to chiropractic intervention in each subject. All the subjects' conduction velocity increased except one in the study. The control group on the other hand showed a range of results varying from increase in CV to a decrease in the conduction velocity which can be inferred as fatigue playing a part in slowing down the conduction velocity in a muscle[27], [28].

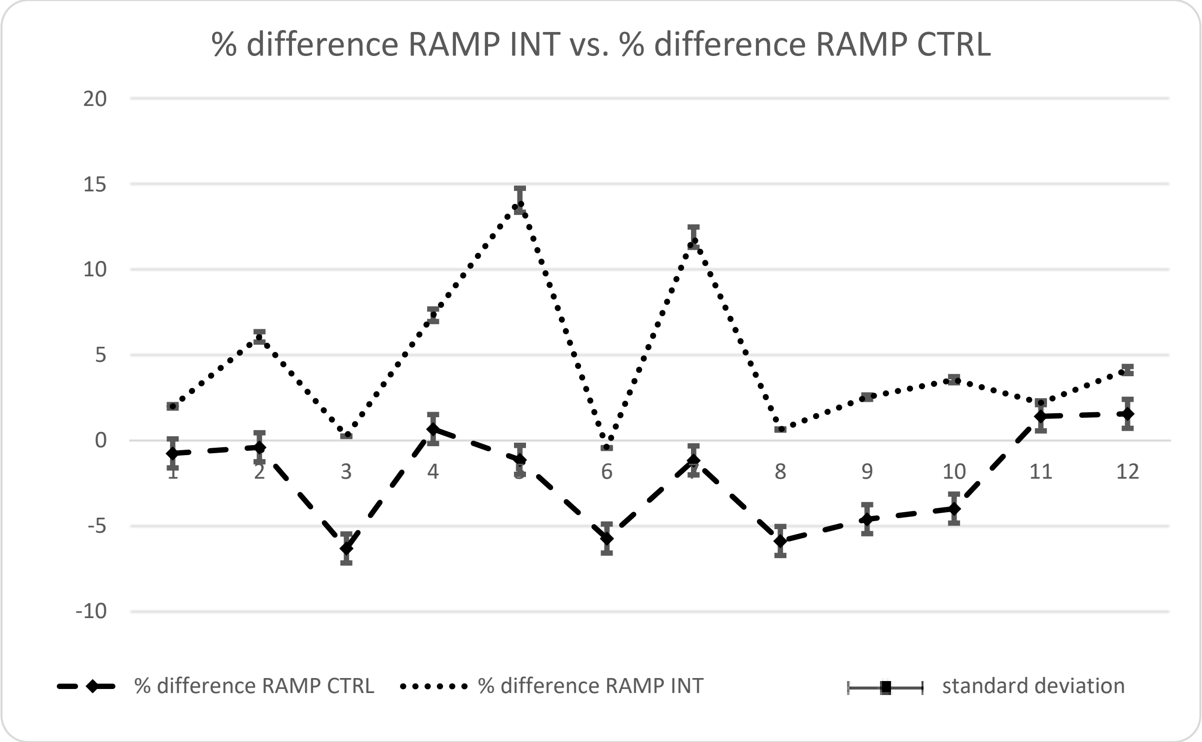
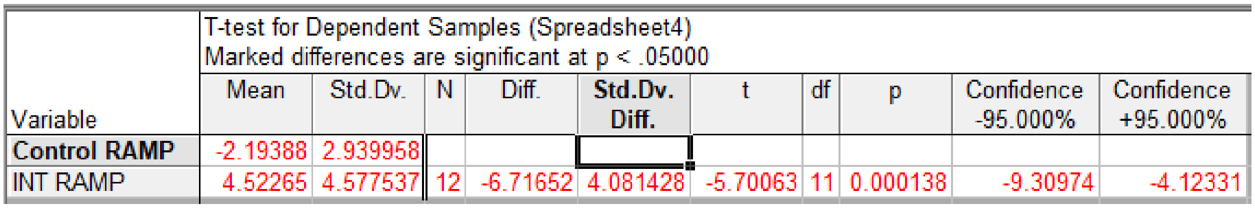


Figure 19: Graphical representation of the percentage change in the conduction velocity of the anterior tibialis muscle with and without chiropractic intervention during ramp exercise

T test results shown in table 2, demonstrate how there is a significant difference in change in conduction velocity due to chiropractic intervention. The value of p was less than 0.05 (0.00138) which means validates the graphical results of this study i.e. there is a change in the conduction velocity due to chiropractic intervention. The value of α was 0.05 thereby reducing the Type 1 error.



T-test for Dependent Samples (Spreadsheet4)
Marked differences are significant at $p < .05000$

Variable	Mean	Std.Dv.	N	Diff.	**Std.Dv. Diff.**	t	df	p	Confidence -95.000%	Confidence +95.000%
Control RAMP	-2.19388	2.939958								
INT RAMP	4.52265	4.577537	12	-6.71652	4.081428	-5.70063	11	0.000138	-9.30974	-4.12331

Table 2: t test results of ramp exercise

4.2.2 Maintained (steady state) exercise:

The 500 ms time window that had the same mean value as the overall average of the maintained exercise signal was selected for finding the change in conduction velocity due to chiropractic intervention. The iterative method used to find the conduction velocity from high density surface electromyography was the same as the ramp exercise.

The results, as shown in figure 20, showed how the intervention group had a greater change in conduction velocity as compared to the control group during the steady state exercise. The mean values of the changes in the conduction velocity were recorded for each subject with the error bars denoting the standard deviation due to the three attempts given to each subject for every recording set. The control group showed a steady pattern; the average percentage difference in the control group was 0.28%. Some values in the control group showed were negative, signifying the possible presence of fatigue in the subject due to which the conduction velocity may have slowed down. The intervention group showed a positive change in conduction velocity in each subject going up to 40% in some cases.

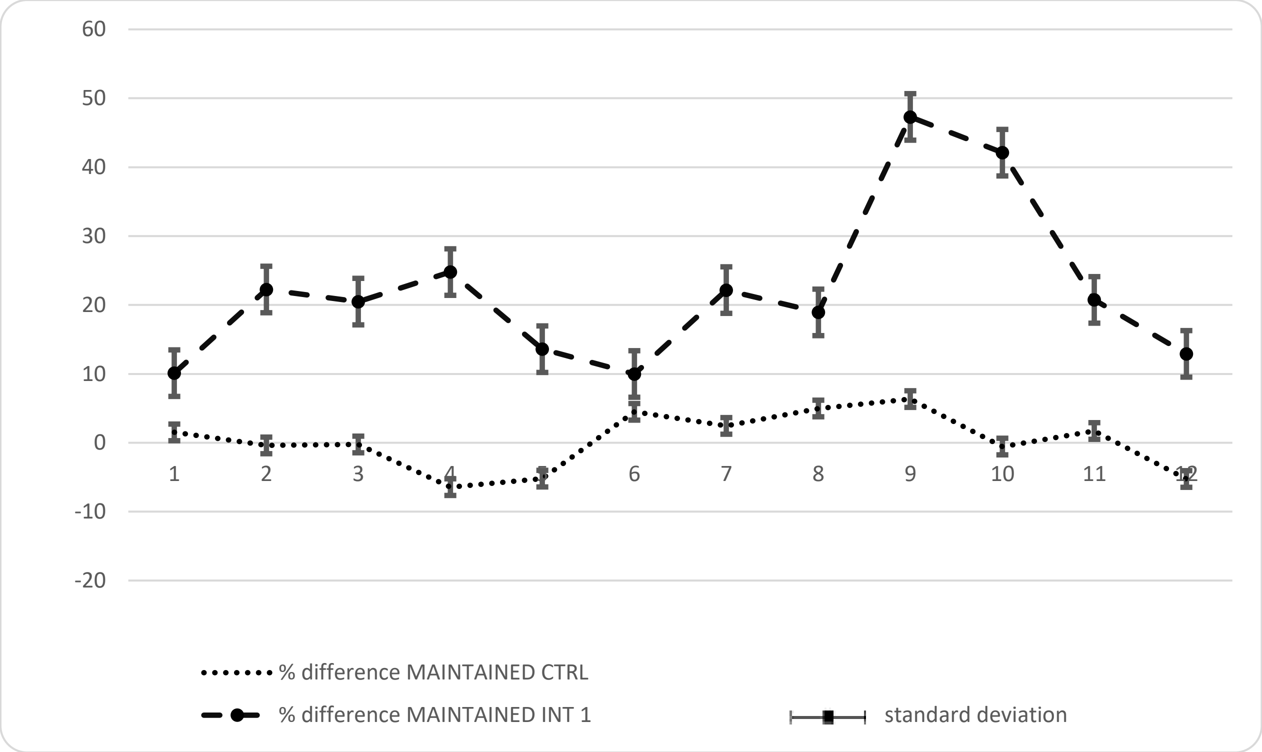
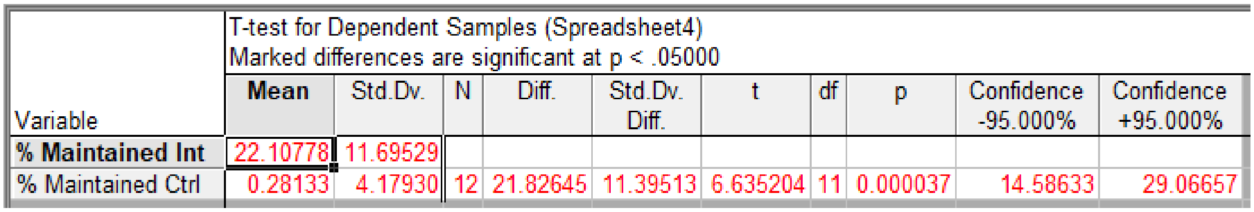


Figure 20: Graphical representation of the percentage change in the conduction velocity of the anterior tibialis muscle with and without chiropractic intervention during sustained contraction exercise

To further analyze the difference between the recorded values, a t test was conducted on the data of change in CV values in the maintained exercise. The value of α was set as 0.05 to minimize type 1 error and the value of p obtained was much less than 0.05 which points out that there is a significant impact of chiropractic intervention on MFCV since the two groups (control and intervention) are significantly different from one another. Table 3 illustrates this observation in detail.



T-test for Dependent Samples (Spreadsheet4)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
% Maintained Int	22.10778	11.69529								
% Maintained Ctrl	0.28133	4.17930	12	21.82645	11.39513	6.635204	11	0.000037	14.58633	29.06657

Table 3: t test results of the 10% MVC maintained value exercise denoting the effect of chiropractic intervention

4.3 Discussion:

Previous research indicates that there is a neurological connection between the spine and the muscles of the body [2], [29]. These studies were focused on exercises similar to the ones in this research being performed on the brachial biceps to understand if human reflexes were improved due to chiropractic intervention [14], [2]. These studies, however did not make use of HD sEMG as a tool, but instead, relied on either conventional 3 electrode configurations or used an array (1x13) of electrodes to measure the EMG signal produced by the muscle. Such studies faced the problem of not being able to attain the same results after the electrodes were taken off [30]. This was due to the chances of mistaken positioning of the sEMG electrode location over the muscle surface of the subject. Another problem was that it was essential to use the exact physiological center of the muscle in the conventional electrode configuration. Using a single point of measurement meant that there was a chance of losing important information from the same muscle. HD sEMG has been introduced a technology that provides information from different parts of the same muscle simultaneously. This will give a clearer picture about the muscle physiology and help understand the changes that the muscle undergoes during an exercise [3].

In this research, High Density surface electromyography (HD sEMG) was adopted was used to analyze the data collected from the anterior tibialis muscle before and after chiropractic intervention. The use of 64 channels to study the effects of chiropractic intervention, allowed improved ways to apply signal processing techniques on the data [31]. This further aided in getting more reliable calculations and also paved way to future applications of this research in different applications including: the use of image processing techniques on spatially distributed channels on the muscle to locate the motor units present on the muscle, allowing a better understanding of the muscle physiology [27]. The 12 subjects involved in the study were tasked to perform sustained isometric contraction and dynamic ramp exercise to validate the finding of each test. The amount of maximum force produced by the same muscle was also analyzed during this study to understand if chiropractic intervention led to an increase or decrease in the total force produced by the AT muscle.

The results indicate that during the ramp exercise, the conduction velocity improved by an average of 4.52 m/s (standard deviation of 4.577 m/s) in the intervention group while the control group experienced a decrease in the conduction velocity, by 4.22 m/s (standard deviation of 2.93 m/s) upon performing the same exercise. This difference in conduction velocity was then statistically tested to find out if this was enough of a difference in calculations to be considered as a vital change in conduction velocity due to a change in a parameter (in this case-chiropractic intervention). Using a sample of 12 subjects, the data was tested by first forming two groups, one representing the difference in the conduction velocity due to chiropractic intervention and the other (control group) representing the difference in the conduction velocity in these 12 subjects without chiropractic stimulation. The results of a bi-directional dependent Student’s test showed the value of p was significantly lower than 0.05, indicating the high significance of chiropractic intervention playing a part in this change of conduction velocity.

During Maintained (sustained) isometric contraction exercise, the conduction velocity increased by as much as 22.11 m/s (standard deviation of 11.69 m/s) in the intervention group, whereas the control group experienced an increase in the conduction velocity of only 0.28 m/s (standard deviation of 4.17 m/s). Like the ramp exercise, the results of this exercise were also compiled and statistically tested to find out chiropractic intervention played a role in the change in the AT muscle physiology. The results showed that chiropractic stimulation was indeed improving the conduction velocity in this muscle, as discussed in the results section.

Another statistically analysis was done on the force produced by the muscle prior to and after chiropractic intervention. The results of the t- test showed that not only does the conduction velocity in the muscle improve but the amount of maximum force that the muscle can produce (maximum voluntary contraction) is also increased by a statistically significant margin.

In this study, the anterior tibialis muscle was the anatomical focus of the experiment. The exercises performed involved sustained as well as dynamic contractions being carried out by this muscle in a controlled environment. The results demonstrate how the tissue composition of the AT muscle adapts to increase the amount of force produced by the muscle, while performing the same task after chiropractic intervention. A possible explanation of this behavior is that the muscle sublets the force to be produced into motor units spatially scattered on the muscle, thereby, diversifying the load on the muscle and improving the amount of force produced by it. This diversifying effect can be studied by adopting image processing techniques on the topographical maps attained from this research.

Furthermore, this study validates the findings of past studies that focused on the reflex time of brachial muscle after chiropractic stimulation [14]. The results from this research, indicate an improved conduction velocity in the anterior tibialis muscle. The same data can be used to apply new signal processing techniques to get a clearer picture of the human muscle functionality.

An inference for the results observed in this study is that chiropractic intervention uses spinal manipulation to stimulate the neurological pathways that connect the Central Nervous System to the AT muscle. Once the spine experiences mechanical stimulation, the neurons running from the spine to other parts of the body are influenced such that there is a change in the ionic concentration around the neurons after the intervention. It leads to an improved neurological pathway with a faster and possibly stronger current passing through the axon. This phenomenon is yet to be tested using an invasive electrode mesh that can demonstrate how the neurons behave. So far, conduction velocity has been calculated using signal processing means including correlation and ML method. There is still room for improvement by adopting spatial processing methods adopted from EEG analysis as well as image processing techniques since HD sEMG allows the muscle to be viewed as an image.

The present study is limited to the effect of chiropractic intervention on the conduction velocity and force produced by the AT muscle. The research can be further expanded to learn the spatial distribution of the motor units found on the muscle and to identify the nerve endings present inside the muscle. This is possible in accordance with previous researches that identified motor units as spatial units where the EMG activity reaches the highest point fastest during an exercise [18]. Instantaneous in a single muscle fiber can also not be recorded via. HD sEMG since they are too minute an activity to merge to the surface of the skin to be measured by the electrodes present. This proves that HD sEMG is more effective than the conventional surface electrode methods but invasive electrode matrices are required in case of more precise measurements of data [5].

4.4 Conclusion:

It is clear from the results that due to chiropractic intervention, there is a change in the neurological pathways that control the conduction velocity of the anterior tibialis muscle. The muscle ends up producing more force and the subject can respond faster to a stimulus considering the higher conduction velocity. It is possible that the nerves leading to the AT muscle are stimulated during the chiropractic intervention which leads to a more efficient response from the body the next time a task is performed. The control group demonstrates that these results do not indicate that the brain involvement in this process. Keeping the topographical mapping results in mind, it can be inferred that the muscle divides the load amongst more fibers to allow more force to be produced within the same span of time. Spinal stimulation enhances this ability thereby leading to a higher conduction velocity in the muscle fibers and a greater force being produced while performing the same task. The use of HD sEMG ensures that the readings are reliable and paves way for new methods of signal processing that can be adopted.

This study not only substantiates the effectiveness of chiropractic intervention but also encourages the use of HD sEMG for future studies involved in surface electromyography. The significance of this research can reflect in ergonomics, where new equipment designs can be made keeping the muscle physiology in mind. Another aspect for future applications is training athletes by keeping the anatomical and physiological features of their targeted muscle under consideration using HD sEMG. The results also prove that chiropractic intervention can be used a means to improve the target muscle’s conduction velocity and output force.

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