

To the Graduate Council

I am submitting herewith a thesis written by Harini Mangavelli entitled “Analysis of Electrical Activity of the Core Muscles Exposed to Whole-Body Vibrations While Driving a Tractor Trailer Using Electromyography device.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

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(Original signatures are on file with official student records.)

**Analysis of Electrical Activity of the Core Muscles Exposed to
Whole-Body Vibrations While Driving a Tractor Trailer Using
Electromyography device**

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Harini Mangavelli
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DEDICATION

I would like to dedicate this thesis to my parents, for being a big support for me all through my ups and downs and for inspiring me to complete my masters. My dream to pursue higher education would not have been possible without their support.

ACKNOWLEDGEMENTS

I sincerely thank my major professor Dr. Jack Wasserman whose boundless guidance, encouragement helped me in completing this thesis. My thesis was almost impossible without his support. I would like to thank members of my thesis committee, Dr. John Landes and Dr. J. A. M. Boulet for their assistance during my thesis.

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ABSTRACT

Lower back disorders are observed to be the most significant problem for most of the industrial workers who operate commercial vehicles. A person sitting can have 40% higher load on the lumbar spine than when standing. Human core muscles related to spinal movement respond to rapid potential motions related to external acceleration inputs of vibration in order to control body posture, the increased muscle tension can result in muscle fatigue. The over use of muscles, vibration exposure combined with dehydration of spine and long term seating can lead to lower back pain and axial discomfort to the drivers. Electromyography (EMG) is a technique used to monitor and analyze the electrical activation of the muscle.

It has been found that the human spine has a natural frequency of 4-8Hz for natural upper body motion caused by curvature motion for the human spine. Trucks have historically produced the critical frequency which resulted in spinal problems for drivers. The purpose of air-ride seats is to reduce the critical frequency amplitudes. Muscular tension can move the natural frequencies to higher level to evaluate the response of the muscle to the expanded acceleration levels in the range of the spinal natural frequency.

A Flex Comp Infinity device, Sonosens® monitor and accelerometers are mounted on the driver of the tractor trailer to collect EMG, ultrasound and acceleration data, respectively. Three testing trials are performed to examine the EMG data, which is correlated with the ultrasonic data and acceleration data collected during the tests. Standard data was collected on the driver using the standard commercial long hall tractor trailer on normal roads.

The main purpose of the current research is to collect and analyze the physiological activity of the Erector spinae, Gluteus medius and Rectus abdominis muscles that relate to the lower back disorders. Present thesis work also examines spinal motions of the human body when exposed to whole-body vibrations.

The study results show that the Erector spinae muscle activity is higher than that of Rectus abdominis and Gluteus medius muscles. Also the muscle fatigue on all the core muscles is observed to occur after 1hr 40 mins to 2 hr, and lasts for nearly 10 mins. The EMG results are compared to the acceleration and ultrasonic data, which were also collected during the test. It is observed that approximately 75% of the ultrasonic results and 60% of acceleration data correlate with EMG results. More accurate results can be expected if more tests are carried out. This research is highly useful to carry out further investigation in the areas of whole body vibration and the muscular response to reduce the level of excitation.

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1. GENERAL INTRODUCTION

1.1 Background

Today, human beings are highly exposed to vibrations that are induced mechanically in regular day-to-day life. However, the exposure to these vibrations increased rapidly due to the industrial revolution and new technology. Industrial workers are highly exposed to the mechanical vibrations which give rise to musculo-skeletal disorders. According to Donald Wasserman, around 8-10 million industrial workers are exposed to occupational vibrations [31]. According to the U.S. Bureau of Labor Statistics, 2004, an estimated six million occupational workers are exposed to whole body vibration contributing to spinal problems, and more than one million workers are subjected to segmental vibrations [49]. Lower back disorders are the most significant problems for many drivers operating commercial vehicles. According to the studies of Magnusson, et al. [57, 58] on truck and bus drivers of Sweden and USA, American drivers are highly exposed to vibrations and about 50% of drivers are significantly affected by lower back pain when compared to drivers in Sweden. Hence the long term exposure to whole body vibrations is a serious threat for truck drivers in the United States. Lower back disorders and discomfort to the driver are mainly due to the long term vibration exposure, long time seating, driving at natural frequencies, muscle fatigue and dehydration of spine. The human body, like any other mechanical structure has sets of natural frequencies that result in high displacement when those frequencies are applied to the body. Muscle fatigue occurs due to the overuse of muscles while supporting the spinal column to reduce spinal motions when exposed to external vibration inputs. It is observed that 80% of drivers are susceptible to back problems and surgeries in their 30's because they do not use air ride seats. The air ride

seat acts as a spring-mass-damper system with a resonant frequency of 4Hz. It is also observed that the load on the spine is 30% greater when seated than when standing. Hence long term seating results in a high load on the spine and so in back disorders. Dehydration of the spine is a serious threat to the driver when getting older as the water in the spine does not restore in their sleep at night. The response of muscles to whole body vibrations also depends on various factors such as road type, type of driver, vehicle type, driving speeds and environmental conditions.

The aim of this research is to study the long term effects of whole body vibrations on the human body by analyzing the physiological activity of core muscles that relate to lower back disorders. Three testing bouts are carried out using the same driver while driving same long haul standard commercial tractor trailer. An electromyography device has been mounted non-invasively on the driver's body. Electromyography is the technique used to record and analyze the electrical activity of muscles when exposed to whole body vibrations. The fatigue of Erector Spinae muscles, Gluteus muscle and Rectus abdominis muscles is examined. The EMG data is correlated with that of the ultrasonic device data and ISO 2631 filtered acceleration data which are also collected during the course of the testing.

1.2 Types of Vibrations

Human beings are mostly affected by vibrations at work due to operation of hand held tools such as grinders, hammers and vehicles such as trucks, tractors, bulldozers, etc.

The two types of occupational vibrations that are generally observed are

- Hand-arm Vibrations or Segmental Vibrations
- Whole Body Vibrations

Segmental vibrations: These are the vibrations that are transmitted from hand tools affecting the upper part of the human body. These vibrations generally affect pneumatic, gasoline, electrical and hydraulic powered hand-tool operators [31]. These vibrations result in muscle disorders, circulatory disorders, neurological disorders, bone disorders, joint disorders and nervous system disorders [38]. The most significant effect due to these vibrations is vascular disorders known as vibration-induced white finger. When the human body is exposed to vibration between approximately 10-50 Hz, bone and joint disorders like deformity of bones of the hand, osteoarthritis, cysts and vacuoles are observed [38][39].

Whole-body vibrations: These are the vibrations that are transmitted from head-to-toe and which generally affect the drivers of buses, trucks, heavy duty equipment and operators of railroad locomotives, cranes, fork-lifts, etc. [31] Measuring and evaluating the whole-body vibrations is observed to be very difficult and costly, hence not much research is carried out in this area [45]. In fact, whole-body vibrations are more dangerous than that of the segmental vibrations as the vibrations enter the human body through many paths such as the spine [43]. Table 1 shows a few occupational vibrations and the sources of exposure.

Table 1: Examples of Occupational Vibration Exposure

Industry	Type of Vibration	Common source of Vibration
Agriculture	Whole body	Tractor operation
Boiler making	Hand-arm	Pneumatic tools
Construction	Whole body, Hand-arm	Heavy equipment vehicles, Pneumatic tools, Jackhammers
Diamond Cutting	Hand-arm	Pneumatic drills, Vibrating hand tools
Forestry	Whole body, Hand-arm	Tractors, chain saws
Foundries	Hand-arm	Vibrating cleavers
Lumbar	Hand-arm	Chain saws
Furniture manufacture	Hand-arm	Pneumatic chisels
Iron and steel	Hand-arm	Vibrating hand tools
Machine tools	Hand-arm	Vibrating hand tools
Mining	Whole body, Hand-arm	Vehicle operation, Rock drills
Riveting	Hand-arm	Hand tools
Rubber	Hand-arm	Pneumatic stripping tools
Sheet metal	Hand-arm	Stamping Equipment
Ship yards	Hand-arm	Pneumatic hand tools
Shoe-making	Hand-arm	Pounding machine
Stone dressing	Hand-arm	Pneumatic hand tools
Textile	Hand-arm	Sewing machines, Looms
Transportation	Whole body	Vehicles

Source: http://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_intro.html

1.3 Long and short term effects of whole-body vibrations on the human body

Poor posture of the driver; poor seat design and exposure to high vibration are some of the reasons for lower back pain. More than 130 field studies were conducted since 1950 on long-term exposure to whole-body vibrations that emphasized the danger of lower back pain, acute herniated lumbar disc and degeneration of lumbar spine segments. It is observed that the exposure to whole-body vibrations also leads to biochemical changes in gastric secretions, enzyme levels, blood count, uric acid, endocrines, etc. [46]

Long term affects: There is a high risk of spinal disorder and lower back discomfort in people exposed to long-term whole-body vibrations [47] [46], [48]. The highly effected regions reported are the lumbar part of the vertebral column and the thoracic region. The other effects of long term vibration exposure are headache, irritability, dizziness, etc. There is a high risk of abnormalities in the function of reproductive organs of women due to the long-term exposure to vibrations. This results in menstrual disturbances, miscarriages, etc. [47]

Short term affects: The most frequently observed short term effects of whole-body vibrations are discomfort, activity interference, physiological and neuromuscular changes, and nervous system changes. Apart from all the above, the major effects are headache, abdominal pain, chest pain, etc. Discomfort is caused by many factors such as direction of vibration, vibration contact with the human body, environment, etc. Activity interference includes the ability of vision and manual control. Fatigue is also caused due to the whole body vibrations however it is not supported scientifically. Physiological changes include increased heart rate; these reactions depend on vibration axis, magnitude and type of subject [47]. Vestibular functional changes are observed due to the short term

exposure to whole body vibrations. It is also observed that hearing is also slightly affected. Table 2 shown below explains few long term and short term effects of whole body vibrations.

Table 2: Major Short term and Long term effects of WBV

Long term effects	Short term effects
Degenerative spinal changes	Head ache, Discomfort
Lumbar scoliosis	Chest pain
Disc disease	Abdomen pain
Disorders of gastro intestinal systems	Nausea
Herniated discs	Loss of balance

Source: <http://chppm-www.apgea.army.mil/documents/FACT/65-022-0503.pdf>

1.4 Electromyography device

Electromyography (EMG) is a technique used to record and analyze the physiological activity of muscles. It is sometimes called myoelectric activity as it is the study of muscular electric signals. The electromyography device which was chosen to record the activity is called Flex-comp EMG machine. Flex-comp EMG machine is capable of recording and displaying the raw data, median frequency, RMS frequency and mean frequency. This machine proved to be very useful as it is compact, easy to use and does not cause any disturbance to the driver from his daily routine. The equipment was used to collect the data for long term without any interruption and the data was processed using Matlab. A compact flash drive was used for remote storage and the data was retrieved faster than it could have been with any other device. This device provided a noninvasive method of data acquisition of data from different core muscles. The device produced no side effects, no discomforts and no allergies on the driver.

1.5 Scope of work

The present research is aimed at carrying out three testing bouts to examine the long term effects of WBV on the human body. It is observed from the previous work carried out by many researchers that the lumbar spine is more affected by the whole-body vibrations than any other segment of the spine. The activity of core muscles that relates to lower back disorders is investigated by collecting the data using electromyography. The present work answers a few important questions regarding the reasons for discomfort to the drivers and various possible ways to reduce them. When is the fatigue taking place on core muscles and what steps can be taken to restore the muscle activity? What is the spinal motion pattern when the human body is exposed to whole-body vibrations?

Muscle fatigue is an important phenomenon observed when the muscle reacts to vibrations and tries to reduce the spinal motion. The EMG data is correlated with that of the ultra sonic data and ISO 2631 filtered acceleration data collected during the course of testing.

This project shared the resources of Commercial Vehicles Group, Research and development division, Columbus with financial assistance from Dr. Wasserman, The University of Tennessee. This project deals with the vibration and biomechanical analysis carried out performing various tests on a tractor trailer driver. This extensive research is the basis for increased understanding of various biomedical influences on truck drivers due to long term exposure to whole-body vibrations.

2. LITERATURE SURVEY

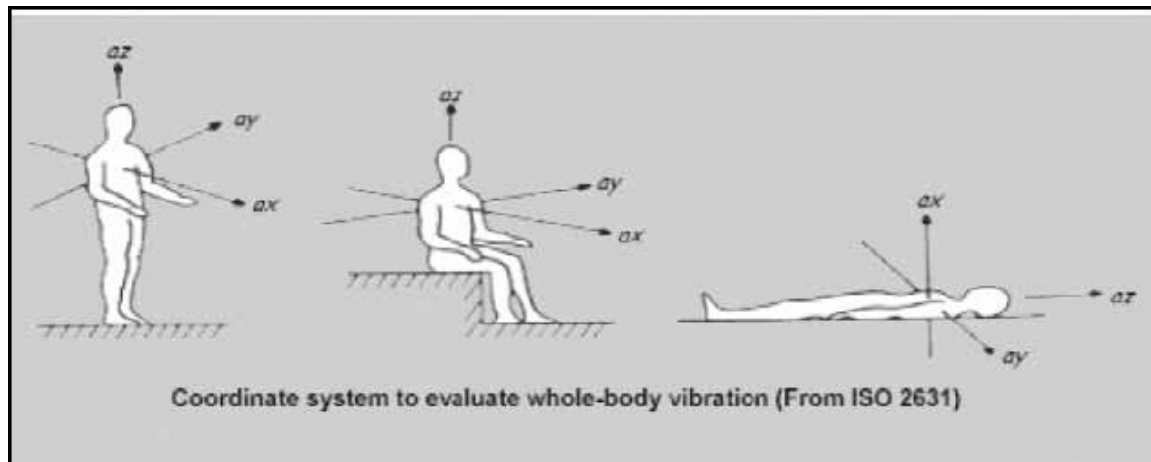
2.1 Whole-Body Vibrations

Whole-body vibrations (WBV) are universally experienced by operators of buses, locomotives, trucks, cars, buses, cranes, bulldozers, helicopters, farm vehicles and other vibrating equipment. WBV are also called head to toe vibration; it does not target a specific part of the body. Exposure to WBV has many adverse effects, most commonly lower back discomfort due to the degeneration of intervertebral discs and disc buckling. These effects are commonly found among the drivers when exposed to vibration regularly for a long term period. Another common effect is muscle fatigue, which is caused when the muscles react to vibrations in order to support the spinal column. Literature shows that the magnitude of vibration transmitted to the human spine is greatest at resonant frequencies from 4.5 to 5.5Hz and from 9.4Hz to 13.1 Hz.

Whole-body vibrations result in kidney disorders, high blood pressure and reproductive disorders in both women and men. In addition to issues with health, WBV exposure adversely affects the comfort level which results in poor operator performance. There are other factors influencing WBV exposure such as road type, body weight of driver, vehicle type and other environmental factors. Rough roads produce significant shock and rotational motion at higher levels causing discomfort and motion sickness. The effects of WBV are mainly due to the awkward postures of the driver in the seat and are largely due to the rocking of pelvis.

2.2 Measuring WBV

Figure 2.1: Coordinate system to evaluate whole-body vibration



SOURCE: (From ISO 2631)

The effect of whole-body vibration on the human body is based on the period of vibration exposure, frequency and acceleration of vibration. In order to measure and evaluate the whole-body vibrations, International Standard 2631 has been publicized. The limitation of this standard is that it is not assessed below the frequency of 80Hz. Most commonly the musculoskeletal disorders are caused by frequencies below 80Hz which implies that the standard is inadequate. These standards are applicable only to persons who are normally fit and not for people with disabilities.

Whole-body vibrations are measured in the X, Y and Z coordinate system given by ISO 2631 and illustrated in Figure 2.1 The resultant of acceleration in longitudinal (X axis) and transverse directions (Y and Z axes) is the vector sum of a_x , a_y , a_z . Based on the resultant acceleration value and the vibration exposure time an acceleration limit can be identified. Using ISO standards, one can determine if the acceleration is in the “caution zone.”

2.3 WBV Standards

International Standard (ISO 2631): International standard ISO 2631 was prepared in 1978 and republished in 1985 to give guidance about human exposure to whole-body vibrations and also to evaluate the data gained from research in this area. This standard is not only useful in the assessment of existing findings but also helps in evaluation of new findings. ISO 2631 gives the limits of vibration exposure in the range of 1-80Hz. These limits were chosen to insure comfort, working efficiency and safety or health. ISO limits are specified in terms of acceleration, frequency, time and direction of vibration. ISO 2631 gives separate limits for the vibration in transverse and longitudinal directions. The magnitude of vibration is described in terms of root mean square (RMS) of acceleration in m/s^2 and on two frequency weightings which are defined on a logarithmic graph of acceleration versus frequency in time intervals of 1 min to 24 hr. The measurement of vibration is done using transducers, amplifying equipment, a recorder and an RMS rectifying device. There are three methods of evaluation of vibration.

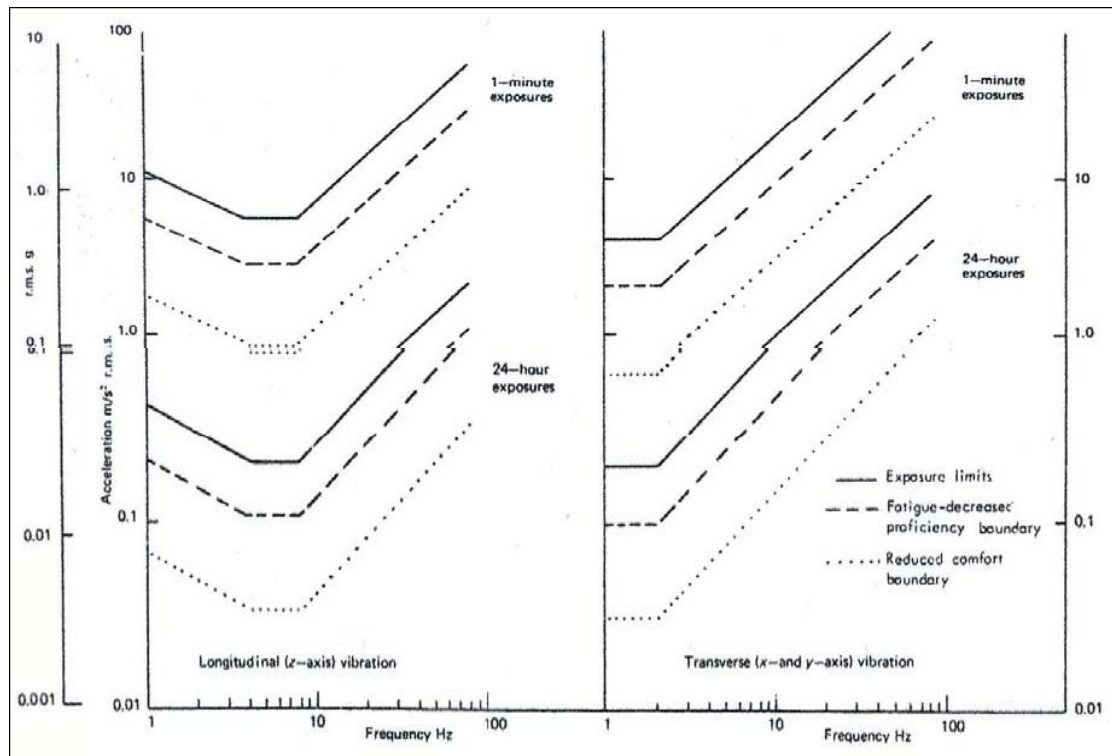
- Fatigue decreased proficiency boundary aimed at preserving working efficiency
- Exposure limit aimed at preserving health or safety
- Reduced comfort boundary aimed at preserving comfort.

In the year 1997, a revised ISO standard was published making a few additions to the previous version. It specifically suggested the type and positions of the equipment to be used, methods to be followed to evaluate the data, the directions of measurement etc. This standard relies on methods for assessing the vibration effects on health, comfort, perception and motion sickness abandoning the time dependent boundaries [50]. The frequency ranges of concern for vibration exposure are given as 0.5 to 80Hz for human

comfort and 0.1 to 0.5Hz for motion sickness. The caution zone established in ISO 2631/1-1997 is shown below. A vibration exposure value that falls in the caution zone is likely to be considered a health risk. According to Griffin, ISO 2631(1997) reflects “muddle and absence of agreement” rather than an identification of areas of consensus based on scientific evidence [50]. ISO 2631 explains only about human exposure to vibrations of frequencies up to 80Hz. This is an important aspect of ISO 2631, as many people are exposed to vibration frequencies less than 80Hz, while few of them are exposed to vibrations that are more than 80Hz. ISO recognized the exposure to spinal vibrations above 0.5 m/s^2 as injurious to the drivers. A company can be prosecuted if a driver is exposed to spinal vibration level around 1.5 m/s^2 .

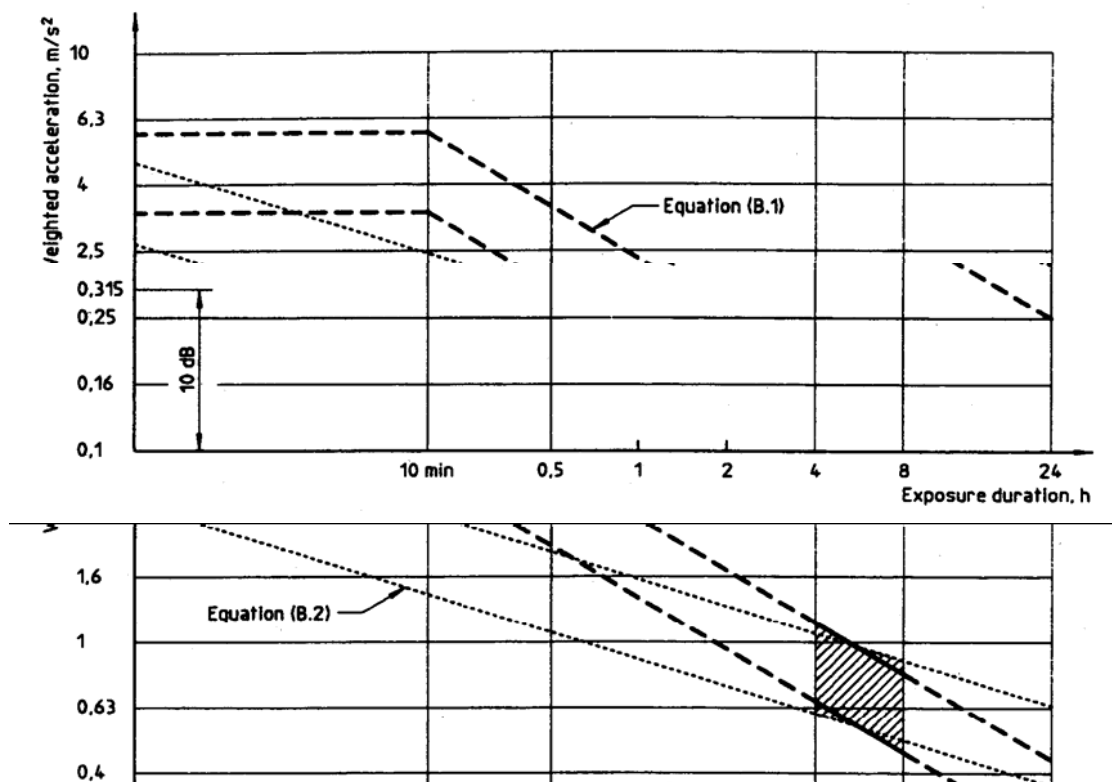
Figures 2.2 and 2.3 below show the boundary set out in ISO 2631/1-1985 for vibration exposure for 1 min and 24 hr, and health guidance caution zones according to ISO-2631/1(1997).

Figure 2.2: Boundaries set out in ISO 2631/1-1985 for human exposure to mechanical vibration for 1 minute and 24 hours.



Source: <http://dspace.dsto.defence.gov.au/dspace/bitstream/1947/4336/1/DSTO-TR-1756.pdf>

Figure 2.3: Health guidance caution zone from ISO 2631/1 (1997)

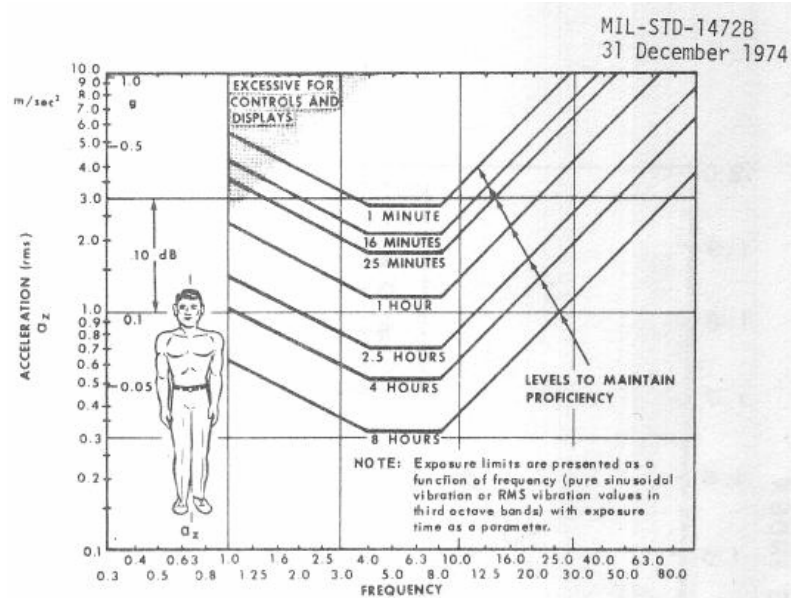


Source: <http://dSPACE.dsto.defence.gov.au/dSPACE/bitstream/1947/4336/1/DSTO-TR-1756.pdf>

American Standards (ANSI):

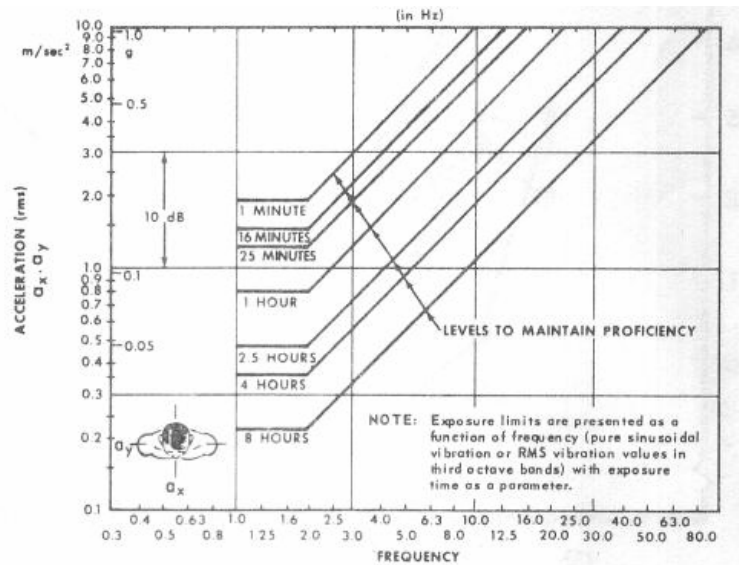
These standards are used in the United States for assessing whole-body vibrations. The ANSI standard 3.18 is taken from ISO 2631(1985) and ANSI 2000 is taken from ISO 2631(1997). Figure 2.4 below explains the established limits of acceptable exposure to whole-body vibrations. The U-shaped curve shows the acceleration limits as a function of frequency in the Z axis. Figure 2.5 below gives the limits of exposure of WBV in X and Y axes.

Figure 2.4: FDP boundary-Z axis



Source: [51]

Figure 2.5: FDP boundary-X&Y axes



Source: [51]

2.4 Reduction of Whole body vibrations exposure:

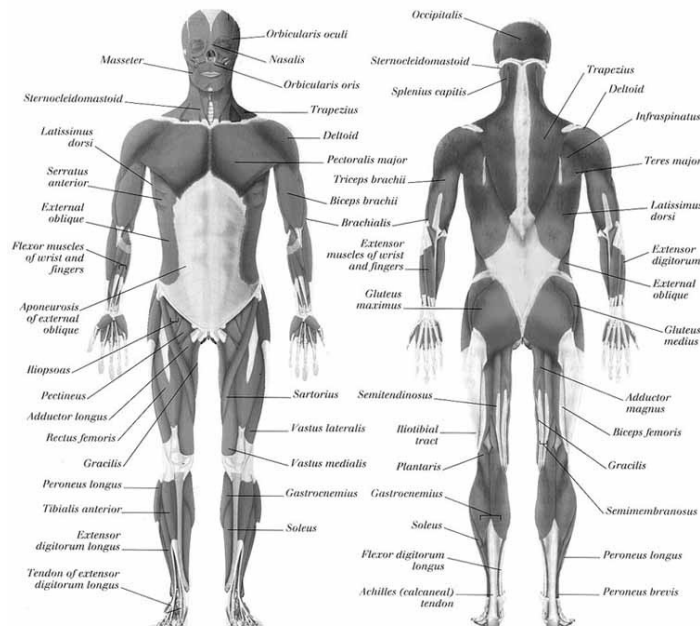
The following are the steps to be taken to considerably reduce the adverse effects of WBV.

- Try to avoid bad seating postures.
- The seat position has to be adjusted correctly for good support and hand controls.
- The speed of the vehicle should be maintained correctly in order to avoid bumps and jolts.
- Try to avoid rough and uneven roads.
- Vehicle suspension has to be maintained properly.
- Try to avoid long-term exposure to vibrations and it is suggested to allow for breaks.
- Use parts which are less worn (for example: tires).
- Have regular health checkups and follow safety procedures.

3. MUSCLE ACTIVITY

3.1 Anatomy of Muscles

Figure 3.1: Anatomy of Muscles

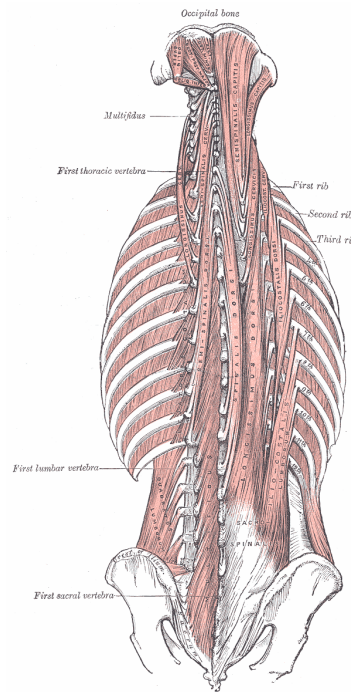


Source: http://www.davidlnelson.md/images/muscle_anatomy.jpg

Figure 3.1 shows anatomy of human muscles. The core muscles are shown in Figures 3.2, 3.3, 3.4 and their relation to spinal motion is explained below.

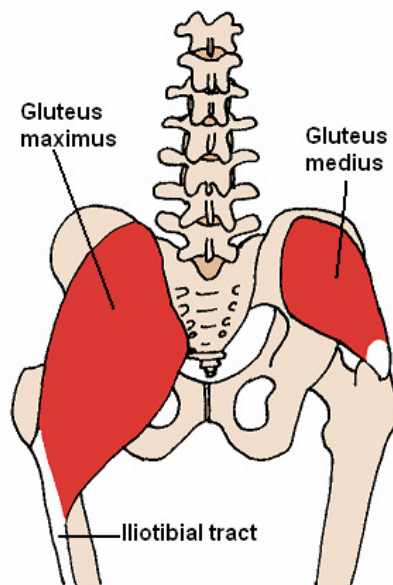
Erector spinae: These are the bundle of muscles that are extended in the thoracic and cervical regions. These muscles lie on the side of the vertebral column at different sizes and structures. Erector spinae muscles arise from a thick tendon attached to the medial crest of the sacrum. These muscles are larger in size in the lumbar region and gradually diminish as they ascend to vertebrae and ribs. The muscle splits in the upper lumbar region to iliocostalis, longissimus ad spinalis (lateral, intermediate and medial columns, respectively). The main function of these muscles is extension of the spine and trunk back.

Figure 3.2: Erector spinae



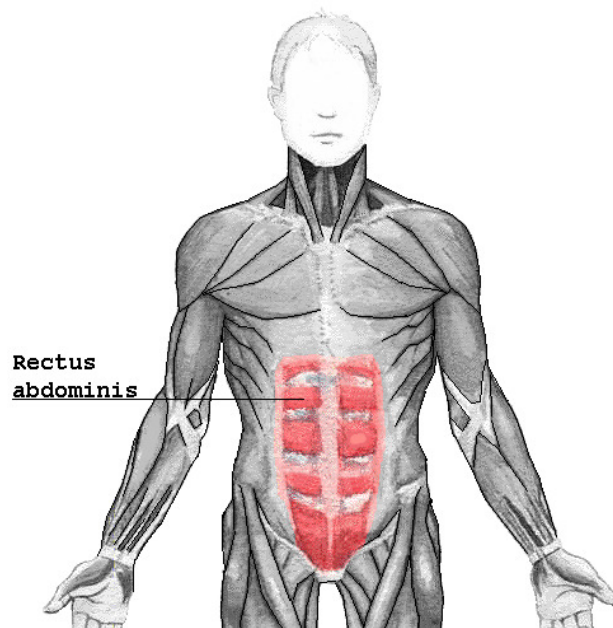
Source: <http://upload.wikimedia.org/wikipedia/commons/9/90/Gray389.png>

Figure 3.3: Gluteus Medius



Source: <http://upload.wikimedia.org/wikipedia/commons/9/90/Gray389.png>

Figure 3.4: Rectus abdominis



Source:http://upload.wikimedia.org/wikipedia/commons/9/95/Rectus_abdominis.png

Gluteus Medius muscle: This is a thick, broad, radiating muscle that is located at the outer surface of the pelvis. It arises from the ileum between the iliac crest, posterior gluteal line and anterior gluteal line and also from gluteal aponeurosis. It helps in abduction of the hip and rotation of the thigh.

Rectus abdominis (abs): This is a long flat muscle that extends on the whole length of human abdomen. The main function of this muscle is flexing of the lumbar spine. It is attached to the crest of the pubis at the lateral side and is connected to the ligaments covering the symphysis pubis. Rectus abdominis controls tilting of pelvis and curvature of the lower spine.

3.2 Lower Back Musculoskeletal Disorders

Musculoskeletal disorders include low back pain, joint and strain injuries. It is very important to prevent back disorders which are the major ill health disorder at work. There are many factors that affect the low-back disorder such as 1. Lifting 2. Awkward postures 3. WBV 4 Static work postures 5. Heavy physical work. Most of the studies reveal that there is a strong exposure response relationship between low-back disorders and whole-body vibrations. It is also observed that the whole-body vibrations when combined with other work factors result in increased back disorder. The effect of whole-body vibrations also depends on the type of vehicle used, road type, vehicle load, etc. Experimental results suggest that exposure to whole-body vibration results in fatigue of the para spinal muscles and ligaments, disc fiber strain, lumbar disc fiber strain, intradiscal pressure increase, disc herniation and micro fractures in vertebral end plates [53]. The present thesis focuses on the lower back muscular disorders due to whole body vibrations.

3.3 Muscle Activity Using EMG Technique

The present research is carried out to see the muscular activity due to the exposure to whole-body vibration. An electromyography device is connected at different muscle locations and tested on a normal subject. The data collected is analyzed in a noninvasive manner and the results show stimulation in neuromuscular activity. The electromyography pattern changes reveal whether the muscle is activated as a result of exposure to whole-body vibrations. Muscle force, length of the muscle, velocity of contraction, muscle fatigue, individual skin resistance and electrode placement are the factors on which EMG output depends [54]. It is shown in the literature that the application of mechanical vibrations to muscle or tendon stimulate sensory receptors.

Due to these stimulations, α -neurons are activated which results in reflex muscle contractions. Human muscle has a tendency to respond to the vibrations thus trying to support the spinal cord which results in muscle fatigue. Hence, experimental data and analysis of EMG data reveals that the EMG data for all vibrating conditions is greater when compared to the non-vibrating condition.

4. MATERIALS AND METHODS

4.1 Flex-Comp Infinity System for Collecting EMG Data

The Flex-Comp Infinity system is manufactured by Thought Technology, Ltd. and used for EMG data acquisition. The machine is calibrated internally and is activated by the user in order to obtain a high-quality signal. The machine is used for many applications such as research, physiotherapy, physiology, primary care, etc. The Flex-Comp machine is compact, handy, accurate, and sensitive and is very easy to use in all situations. It is capable of storing large and complex data and is also used to process and analyze the high-resolution data. However, for more accuracy Matlab is the software used to analyze the data. Figure 4.1 shows Flex-Comp Infinity system used to collect the electromyographic data.

Figure 4.1: Flex- Comp Infinity System



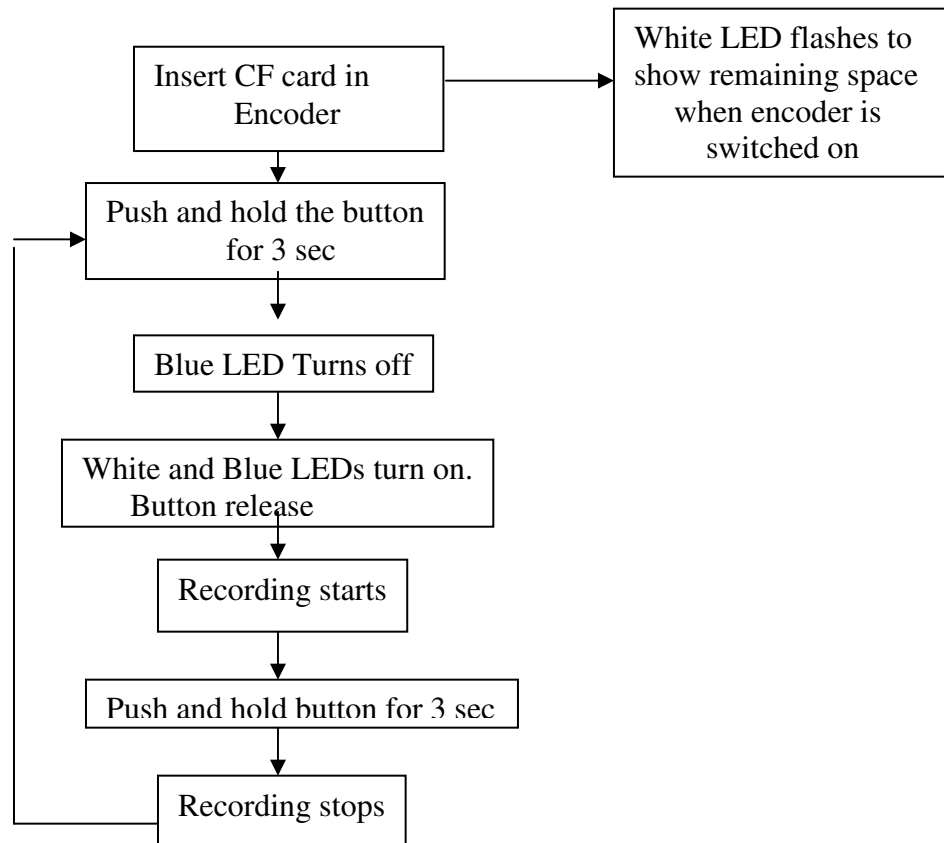
Source: Flex - Comp Infinity system manual

4.2 Working Principle

The Flex-Comp Infinity includes the encoder unit, USB interface unit, fiber optic cable and four alkaline “AA” batteries. The encoder samples the signals coming in, then digitizes, encodes and transmits the data through USB interface unit. The USB interface unit is connected to the USB port of the computer. It converts the data that from the encoder to USB format. A compact flash card inserted in the encoder is used as the data storage device. Before use, the compact flash card is to be formatted by connecting to the PC. The data acquisition procedure is shown in the figure 4.2.1 below.

4.2.1 EMG Data Acquisition Procedure

Figure 4.2: Flow chart of the data acquisition procedure



Source: Flex-Comp Infinity software manual

4.2.2 Application on to the driver

The Flex-Comp Infinity system consists of four sensors which were non-invasively positioned onto the various core muscles of the subject. Two electrodes were placed on the erector spinae muscle; one is taped on gluteus medius muscle and one on the rectus abdominis. The electrodes were of disposable type because reusable electrodes cause cross skin infection. Even if they are sterilized, it is recommended to employ gas sterilization which is expensive. The electrodes were taped on the subject using stick-on tapes provided by the manufacturer. The driver reported no allergies or infection due to the tape. The subject was comfortable with the testing, except that he experienced a little pain while pulling the tapes out from the skin. A questionnaire was filled while the subject was answering various questions related to testing. Figures 4.3, 4.4, 4.5 below show the application of the EMG device on the subject, the type of the seat used and the type of truck used by the driver.

Figure 4.3: Application of EMG on subject



4.3 Seat type

Figure 4.4: Standard Commercial Vehicle Seat Model 2000 used for test



The seat used for the testing is manufactured by National Seating in Vonore, Tennessee. The seat shown is a high-back, air-ride with parallelogram base design. However, all the data was collected in the suspension locked condition of the seat. The seat has a compact packaging design with several footprint capabilities. The seat has fore-aft, recline and cushion slide, front cushion adjuster and rear cushion adjuster options. The seat also has adjustable armrests, 3 - stage lumbar and 2- stage bolsters. The shock absorber in combination with the air spring provides the necessary ride comfort for the driver. The fore-aft isolation is achieved using a chugger located in the seat lower frame.

4.4 Truck type

Figure 4.5: Peterbilt made tractor-trailer used for the testing



The tractor-trailer used for the testing was a 1998 Peterbilt 379. The truck carried a load of approximately 20,000lbs for all the three tests.

4.5 Driver Data

The subject was asked to answer a few questions before carrying out the tests. The following are the details.

SGender: Male

Age: 31 yrs old

Weight: 185 lbs

Height: 5 ft 9 in

Body Mass Index: 27.3 (BMI > 25 is more likely to cause errors due to motion of skin during movement)

The subject was suffering with mild back pain since an accident that occurred in 1998. The driver had no surgeries or injuries on his body. He had been driving the tractor-trailer for about 12 years. The subject was quite comfortable with all the equipment mounted on his body. The testing did not affect his normal routine except that he had a little pain while removing the device due to the tapes.

4.6 Accelerometers and Seat Pad

The triaxial capacitive accelerometer used for the testing is of model Number 3703D1FD20G. The sensitivity of the instrument is 100mV/g; range of measurement is ± 20 g pk (from calibration sheet). Three accelerometers were mounted in the cab of the truck. One accelerometer was fixed at the base of the passenger seat, another at the base of the driver's seat and the third at the base of the gear shift. The data from all the three accelerometers was fed into recorder. The data from the recorder was used for subsequent evaluation.

The seat-pad accelerometer used for the testing was of the model number 356B41. The sensitivity of the seat pad is 100mV/g, range of measurement is ± 10 g pk (obtained from calibration sheet). As shown in the figure the seat pad containing triaxial accelerometer was attached on to the driver's seat. The seat pad was taped to the seat and the driver sat on the seat pad. Figure 4.6 shows the seat pad containing triaxial accelerometer used for the tests. The data from the seat pad accelerometer was also fed to the recorder and the Human Vibration Meter (HVM) discussed below. The reading from the HVM was collected every 5 min and that data was correlated with EMG and ultrasonic data. Figure 4.7 shows the HVM device used for the test.

Figure 4.6: Seat Pad containing triaxial accelerometer



4.7 HVM 100

Figure 4.7: Human Vibration Meter



Source: <http://www.lardav.com/HVM100.htm>

Human Vibration Meter, manufactured by Larsen Davis is a hand-held light weight instrument used for measuring human exposure to vibration. It performs the relevant calculations and provides results on an LCD display. This is capable of measuring acceleration in X, Y, Z axes simultaneously for about 200hrs of time. The HVM was set up for WBV with 60 sec averaging and a storage interval of 5 minutes. The acceleration readings from the seat pad in the Z direction are also taken for every 5 min during testing. The acceleration readings taken from the HVM were used to correlate the EMG and ultrasonic data.

4.8 Ultrasonic device

A graduate student named Gretchen Hinton used an ultrasonic device to study the movements of the driver's body segments. The movements of the spinal column and posture profiles of driver were measured to analyze the comfort of the driver during long periods of driving. The data has been captured from the ultrasonic device and correlated with EMG data.

5. PRELIMINARY TEST REPORT

Many preliminary tests were carried out to get an idea of the equipment set up and its data recording capability. The basic testing was done in order to improve and simplify the process of data acquisition. Four preliminary testing trials were done on the same seat with different subjects. The subject with low BMI and with no body complications was considered as a best fit to carry out the actual tests. The subject used for the final preliminary test was used for all the three actual tests. The driver was very cooperative and enthusiastic to take part in the testing. He reported no major problems in participating as it does not disturb his routine job schedule. The following are the few conclusions drawn from preliminary testing which were helpful to increase the accuracy of the data collected.

5.1.1 Preliminary Test 1

This is the basic test performed to prepare the checklist of the accessories needed for the equipment set up. This test was helpful to get versed in the process of data collection. All the equipment was plugged into the simulator provided by National Seating, Vonore, Tennessee. The subject used for this test was a graduate student from the University of Tennessee, Knoxville.

5.1.2 Preliminary Test 2

This testing was aimed at assessing the comfort level of the driver with the device. The subject chosen for the test was a 55 year old male. His height was 5 ft 5 in and his weight was 210 lb. His calculated BMI was 34.9. He stated that he had been a tractor-trailer driver for 33 years. The testing was carried out on a tractor-trailer equipped similarly to the simulator in the previous test. The driver had no physical abnormalities or surgeries

but had been experiencing intermittent back pain for years. He reported no inconvenience caused because of the equipment only that it was painful while taking the tapes off his body. EMG data was not obtained in this test as there were some problem with the sensor's connection with the encoder. Setting up the equipment for this test took approximately 3 hours. Hence, care was taken for proper EMG set up and also to reduce the set up time.

5.1.3 Preliminary Test 3

This test was performed to select one driver from the three drivers available for actual testing. The driver with least BMI and health problems was preferred. The driver for this test was a 50 year old male. His height was 5 ft 8in, his weight was 240 lb and his BMI was 36.5 (calculated using the standard BMI equation). He had experience in driving tractor-trailers for about 25 years. The subject had no physical abnormalities, surgeries or back pains. The test procedure, test equipment and seat were similar to the previous test. The subject had minimal discomfort from the device. He had a little discomfort due to the pressure of the sensors when his back interacted with the seat. The driver stated that the device was quite comfortable and did not disturb his normal work routine.

The posture of the driver was observed, which showed that the lumbar region was neutral, the cervical region was dorsal and thoracic region was more dorsal. The movement of the lumbar spine was static during the whole test. The ultrasound recorded had no complications, but the EMG data still needed some filtering. Figure 5.1 shows the application of the EMG device on the driver for preliminary test 3.

Figure 5.1: EMG application on subject for preliminary test 3



5.1.4 Preliminary Test 4

The driver used for this test was the best fit for the actual tests. The driver for this test was a 31 year old male. His height was 5 ft 9 in, his weight was 185 lb and his BMI calculated as 27.3. A BMI value of less than 25 is more likely to avoid errors in data collection. Hence, this subject was used for all the actual tests. The driver reported back pain because of an accident he had in 1998. The driver was very comfortable with the devices attached on him. No data was analyzed as the sensors came off the driver's skin during the test and so provided incomplete data. Greater care was taken in the actual test in order to avoid such complications. The truck, seat and the testing procedure were the same in all the tests.

6. RESULTS AND DISCUSSION

Data Analysis: The electromyographic data obtained from the Flex-Comp Infinity encoder was downloaded into the software called Biograph Infinity provided by the manufacturer. Biograph Infinity software program was used for processing and analysis of the data collected using the Flex-Comp Infinity system. Using the Biograph Infinity software permitted large amounts of data to be processed. The raw data was displayed in text format in the form of tables for the required period of time. The raw data files were processed and loaded in the text format which was later converted to Excel format. Further analysis was performed using Matlab software.

FlexPro is the software developed by Weisand GmbH & Co. KG which was used to convert large amounts of data into Matlab files. The Excel file processed using Biograph Infinity software was imported into FlexPro's object database using many binary formats. With this software, the Matlab files for 20 min intervals were generated from the binary formats. A Matlab code was written to read the data from the data file and to calculate the mean frequency, RMS value. The frequency distribution for most of the muscles ranges from 0-400 Hz, except for the masseter muscle where it reaches to 600Hz. RMS value of the signal measures the amplitude, which is the square root of the average power of the signal. The raw signal determines the time of activation of the muscle. RMS and ARV values represent the degree of activation and the force produced by the muscle. The motive of the present research is to find the rate of muscle fatigue, which is determined by mean frequency or median frequency. Mean frequency is widely used to represent muscle fatigue due to its high accuracy. There are a few possible reasons, such as interference of the signal with movement artifacts or cross talk of other

muscles, due to which the EMG signal is sometimes less reliable. However, proper care was taken to collect the best data by minimizing the above mentioned factors. Technical support was received from the manufacturer's representative in order to best utilize the equipment. The first and last 10 min of the data were not considered for analysis of the signals as the driver took a few minutes to settle in the seat.

Results: The mean frequency vs time graphs obtained from the Matlab code for all the three tests are presented below. The X-axis in all the graphs represents the time and the Y-axis represents the mean frequency of muscle activity. Each graph is plotted with four subplots where the first and second subplots represent the mean frequency of the right and left erector spinae muscle activity, respectively; the third subplot represents the mean frequency of the gluteus medius muscle activity; and the fourth subplot represents the mean frequency of the rectus abdominis activity.

6.1 Test 1

Figures 6.1-1a to 6.1-9a represent the RMS value of muscle activity for test 1.

Figures 6.1-1b to 6.1-9b represent the mean frequency of muscle activity for test 1.

6.2 Test 2:

Figures 6.2-1a to 6.2-10a represent the RMS value of muscle activity for test 2.

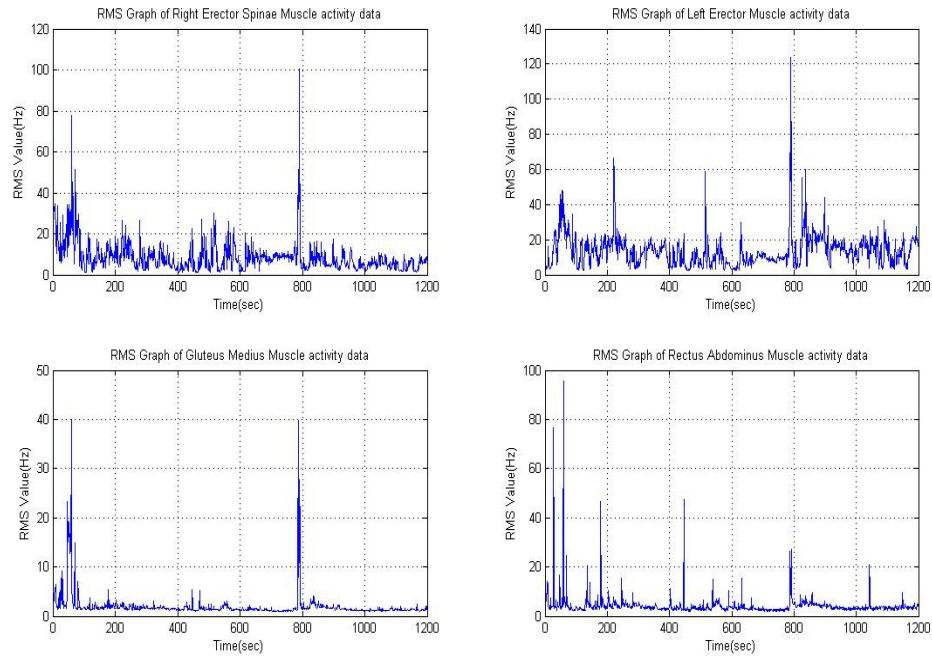
Figures 6.2-1b to 6.1-10b represent the mean frequency of muscle activity for test 2.

6.3 Test 3:

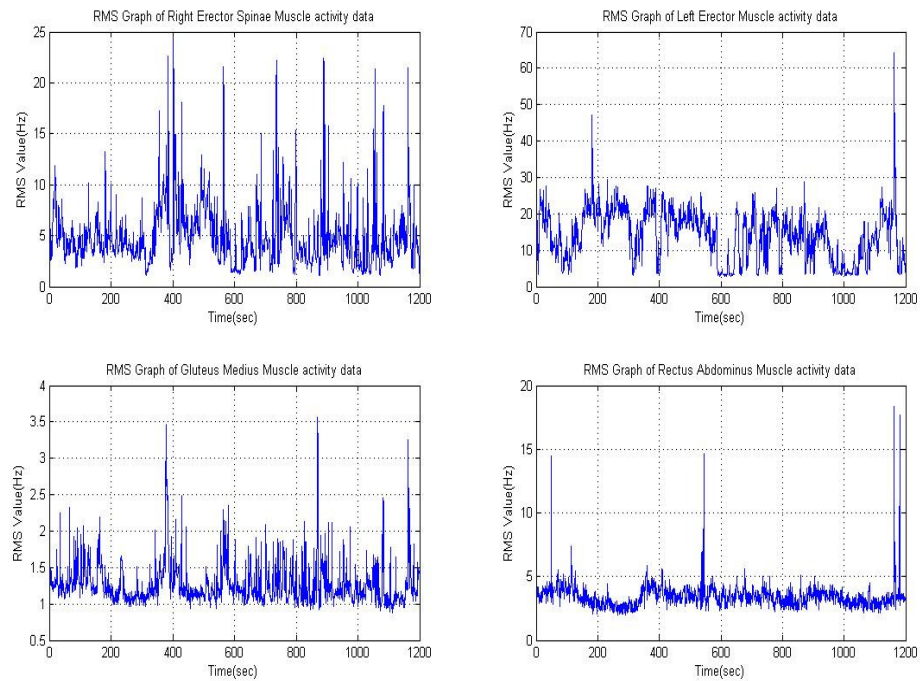
Figures 6.3-1a to 6.3-9a represent the RMS value of muscle activity for test 3.

Figures 6.3-1b to 6.3-9b represent the mean frequency of muscle activity for test 3.

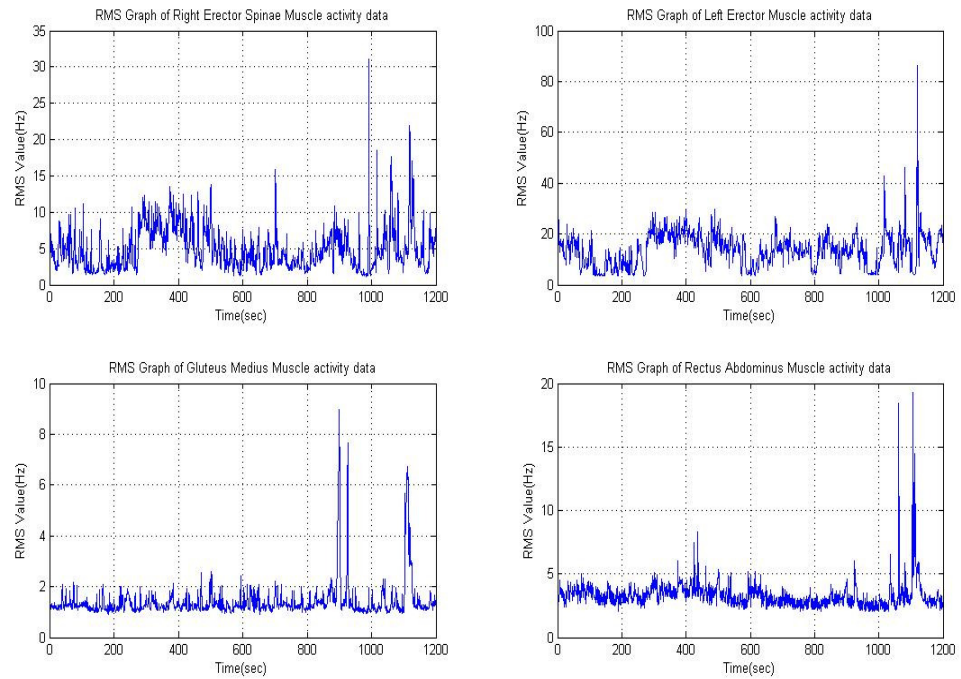
6.1-1a: RMS value graph of four channels during interval 00:00 to 00:20



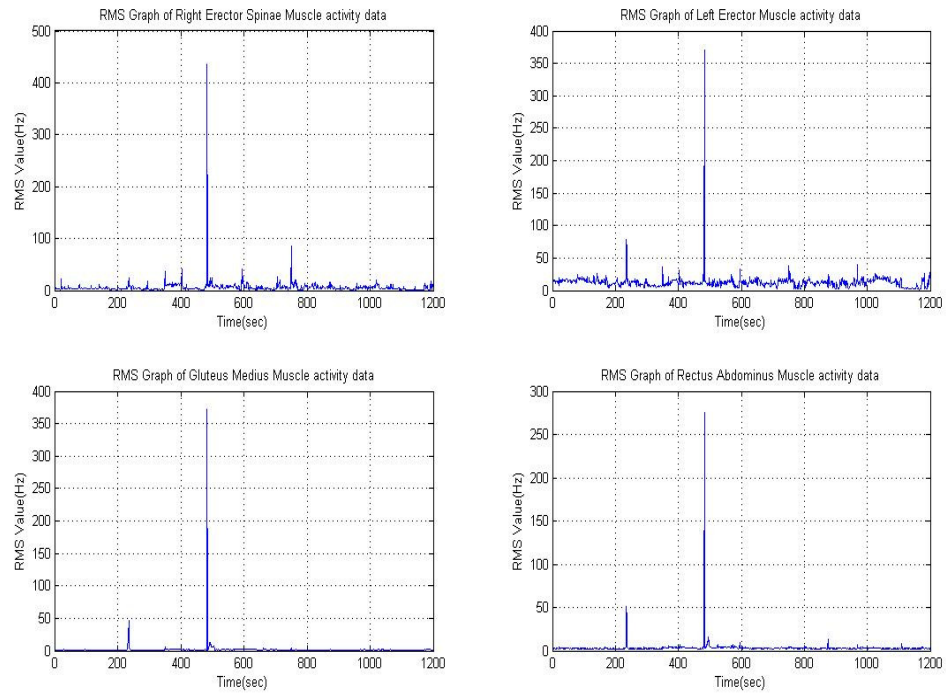
6.1-2a: RMS value graph of four channels during interval 00:20 to 00:40



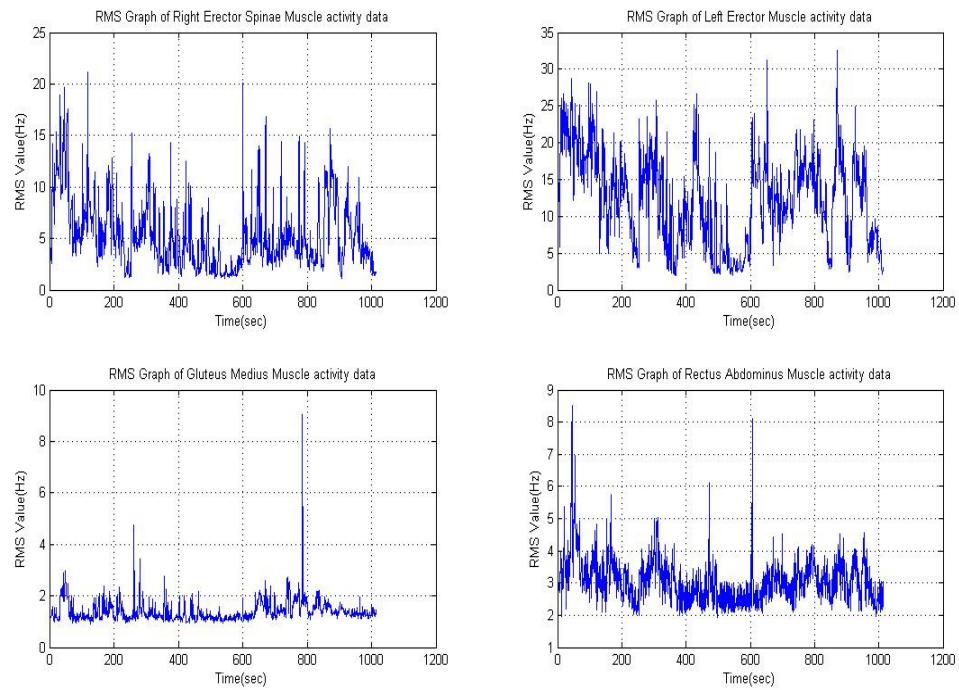
6.1-3a: RMS value graph of four channels during interval 00:40 to 00:60



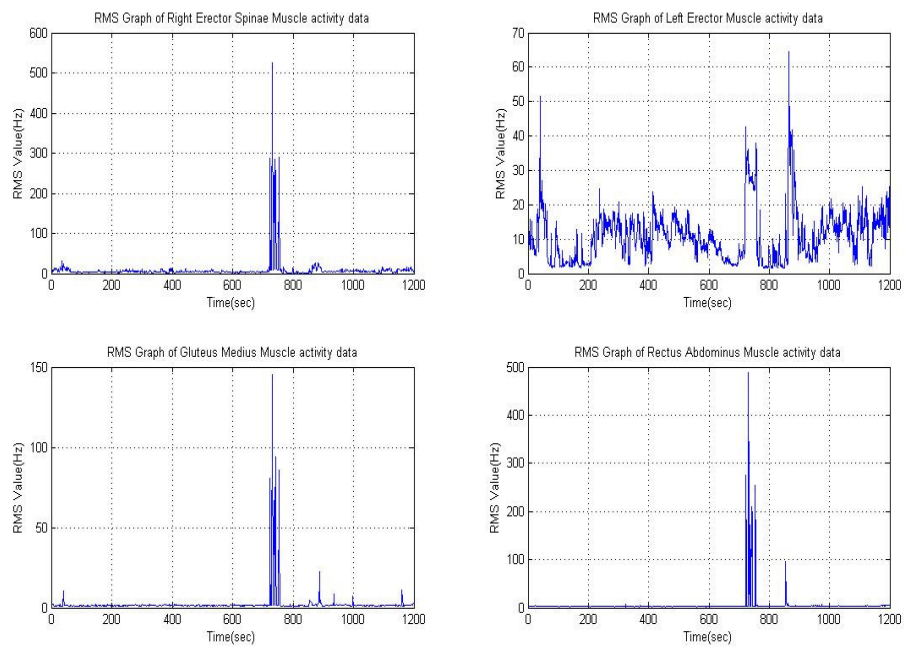
6.1-4a: RMS value graph of four channels during interval 00:60 to 00:80



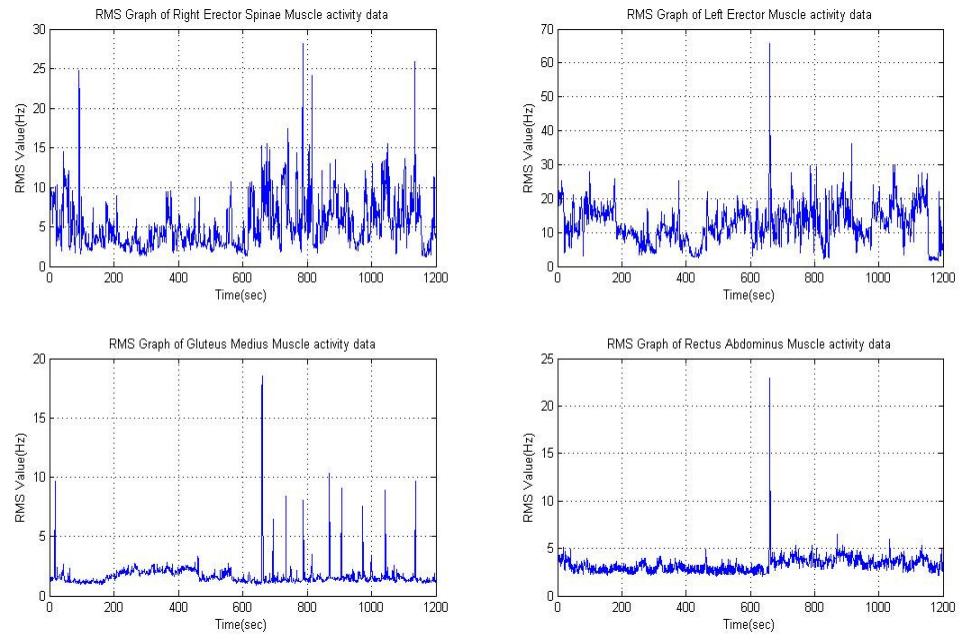
6.1-5a: RMS value graph of four channels during interval 00:80 to 01:00



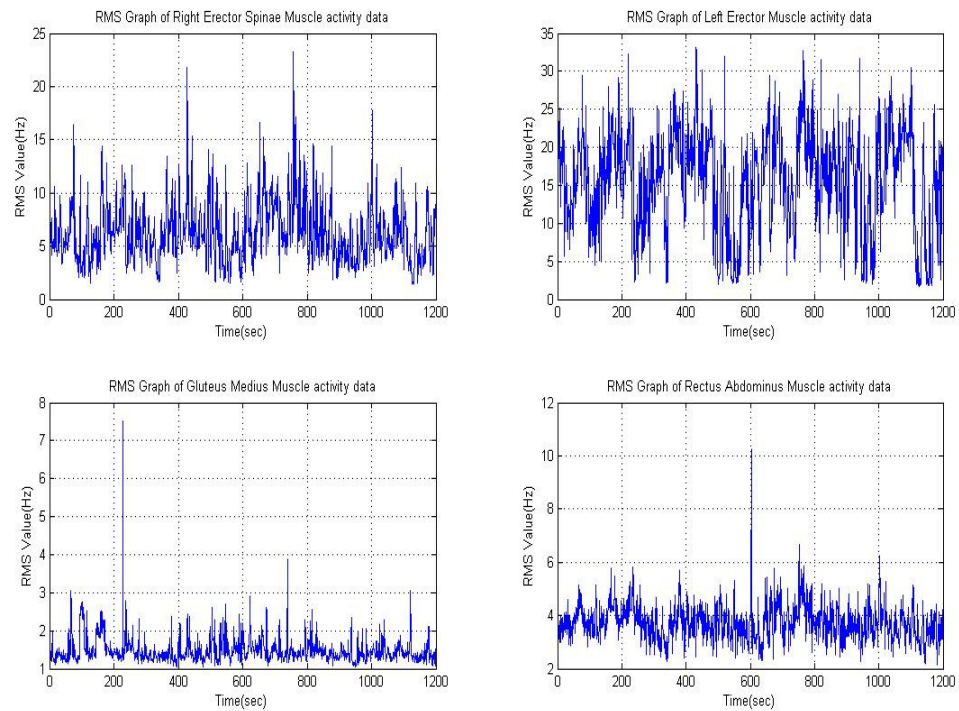
6.1-6a: RMS value graph of four channels during interval 01:00 to 01:20



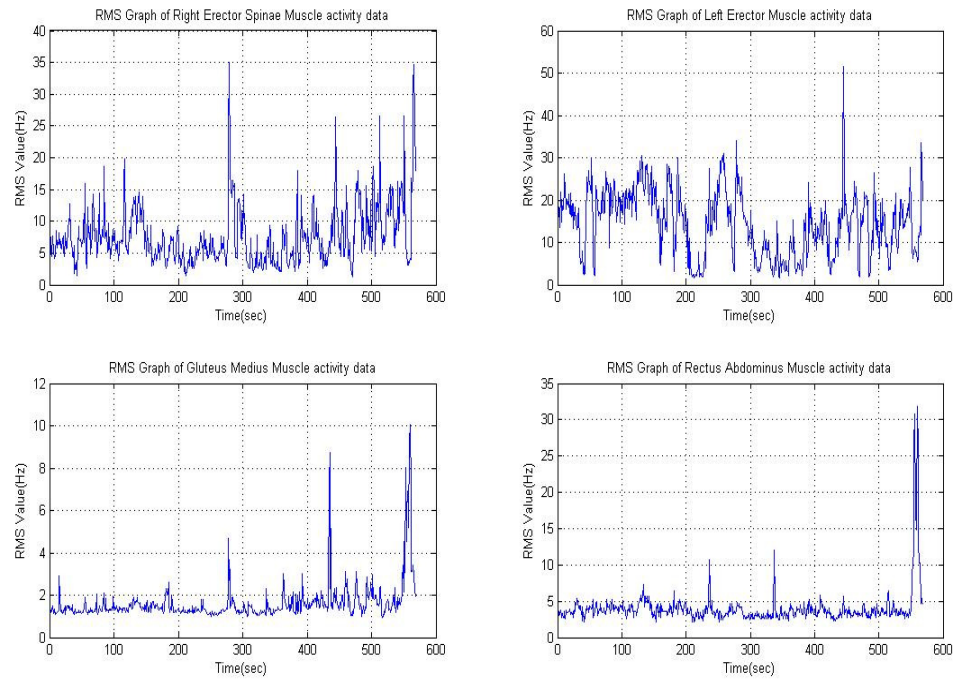
6.1-7a: RMS value graph of four channels during interval 01:20 to 01:40



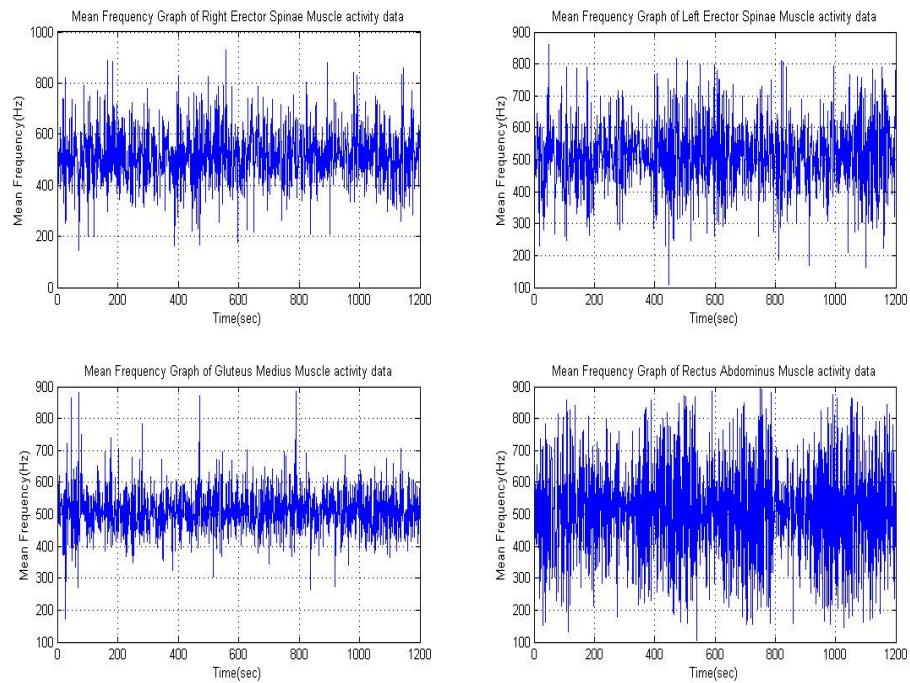
6.1-8a: RMS value graph of four channels during interval 01:40 to 01:60



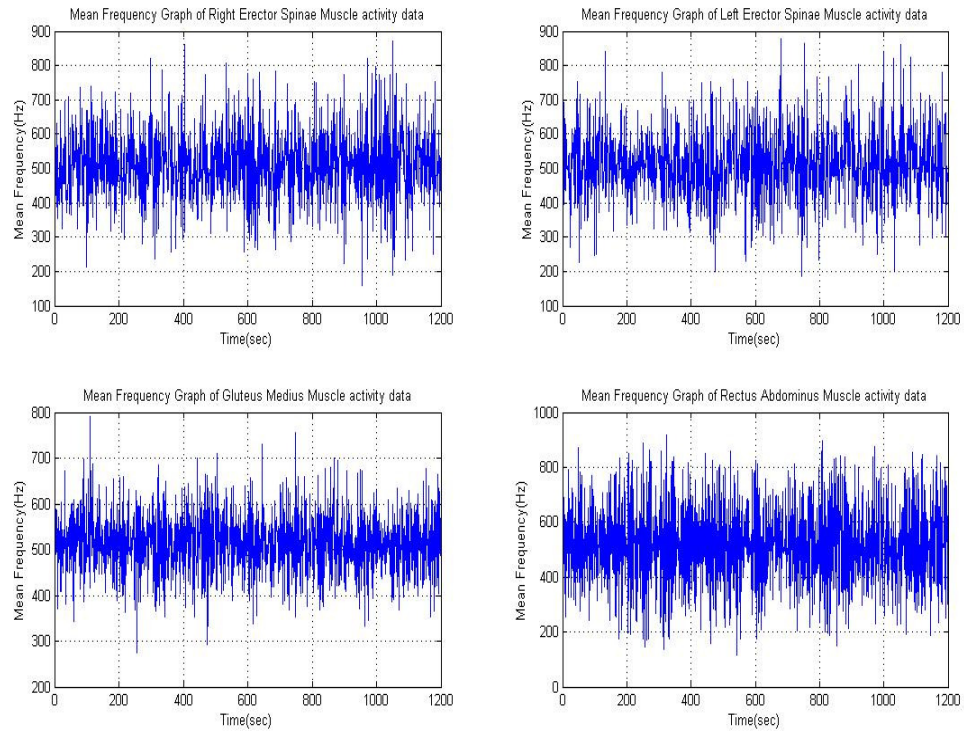
6.1-9a: RMS value graph of four channels during interval 01:60 to 01:80



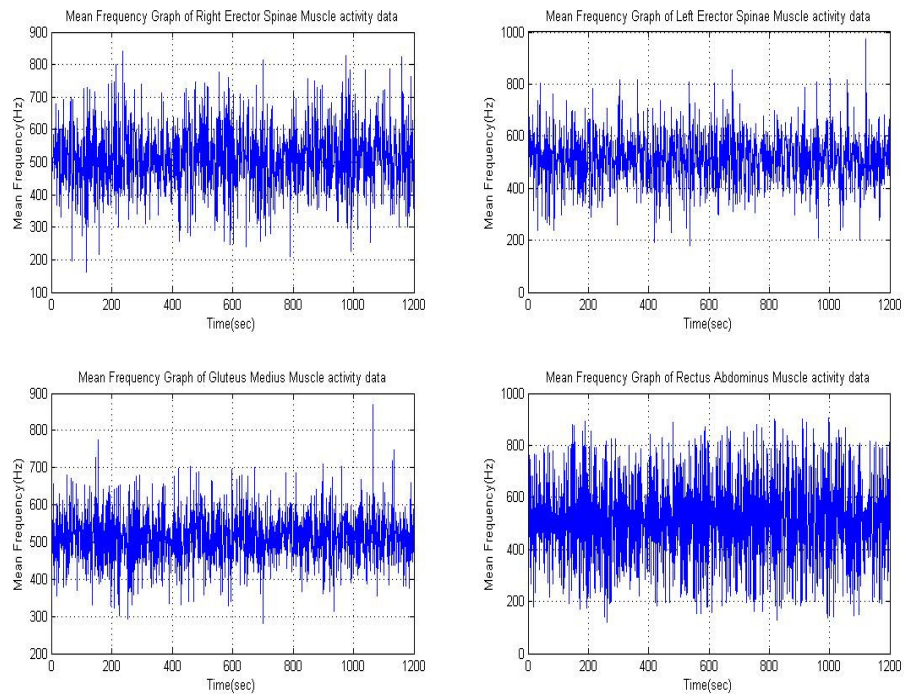
6.1-1b: Mean Frequency graph of four channels during interval 00:00 to 00:20



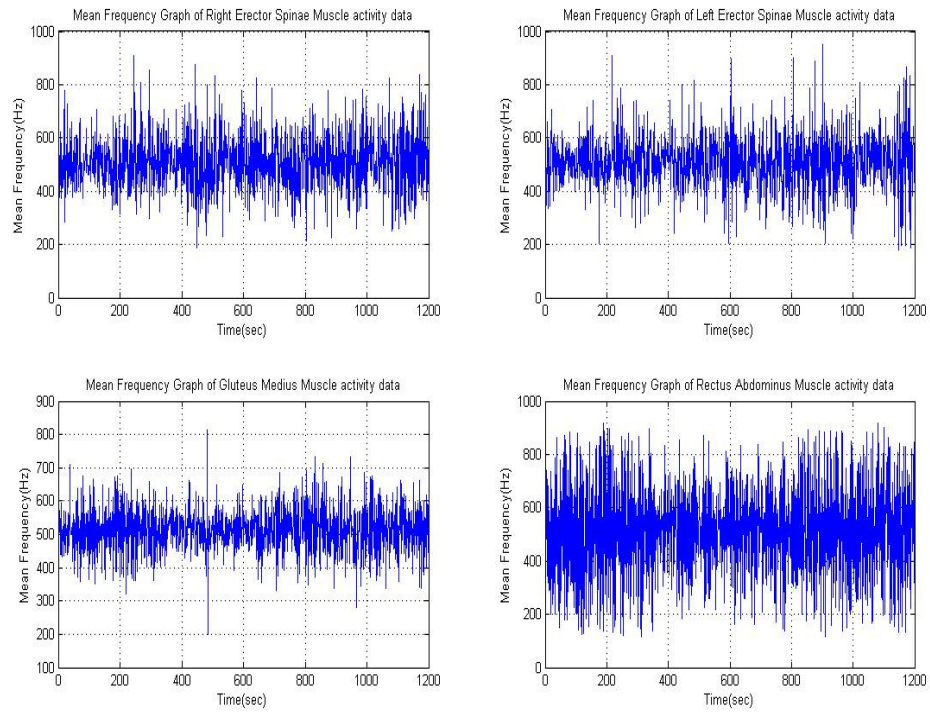
6.1-2b: Mean Frequency graph of four channels during interval 00:20 to 00:40



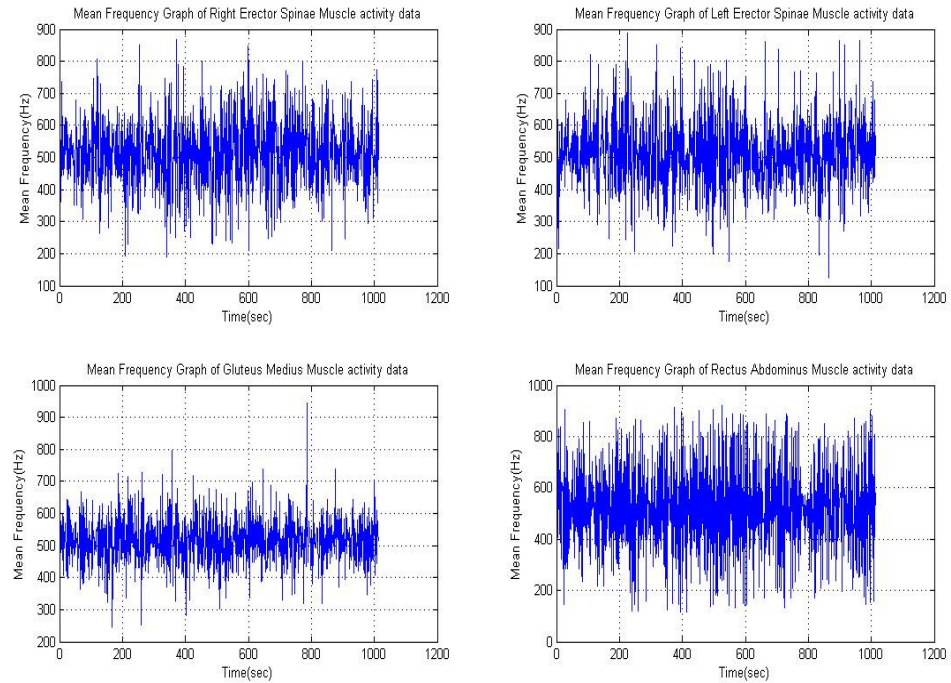
6.1-3b: Mean Frequency graph of four channels during interval 00:40 to 00:60



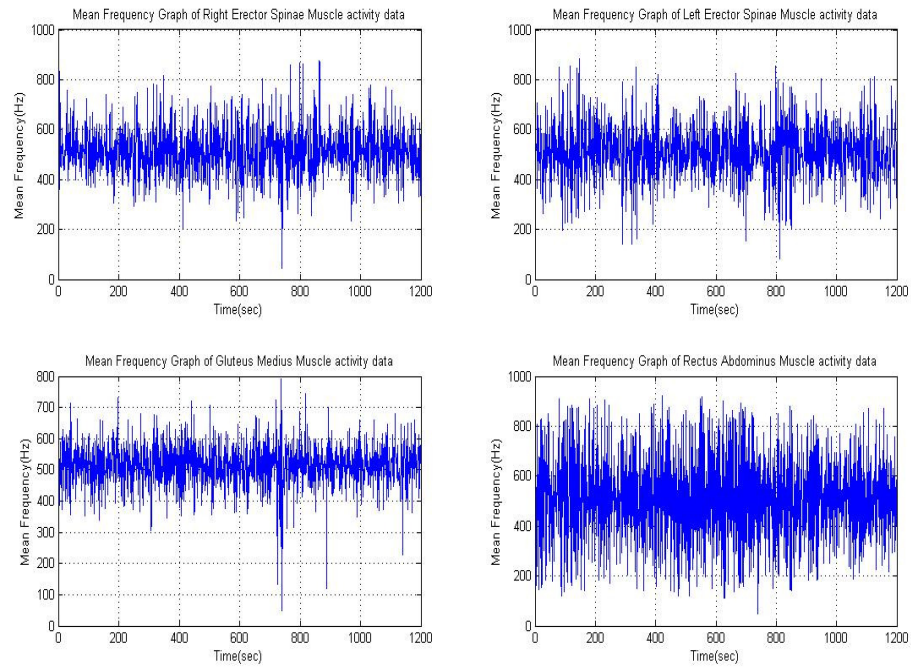
6.1-4b: Mean Frequency graph of four channels during interval 00:60 to 00:80



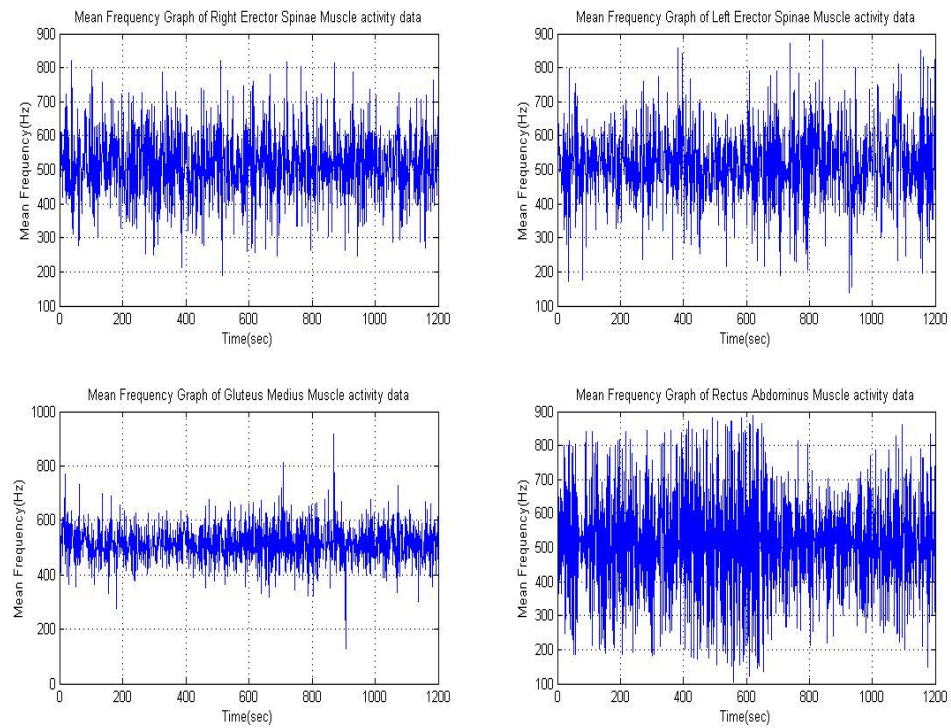
6.1-5b: Mean Frequency graph of four channels during interval 00:80 to 01:00



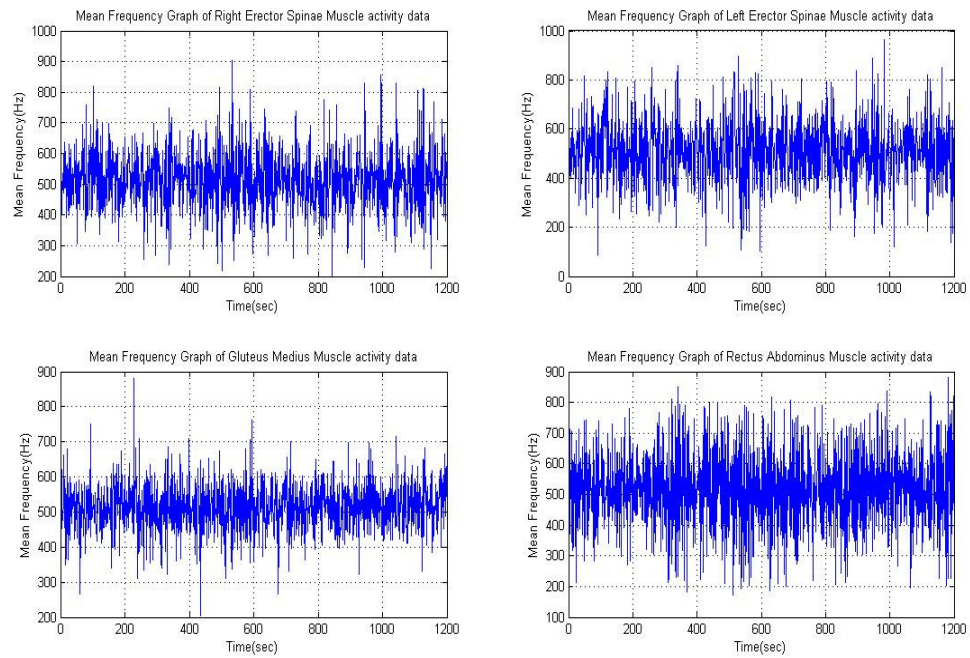
6.1-6b: Mean Frequency graph of four channels during interval 01:00 to 01:20



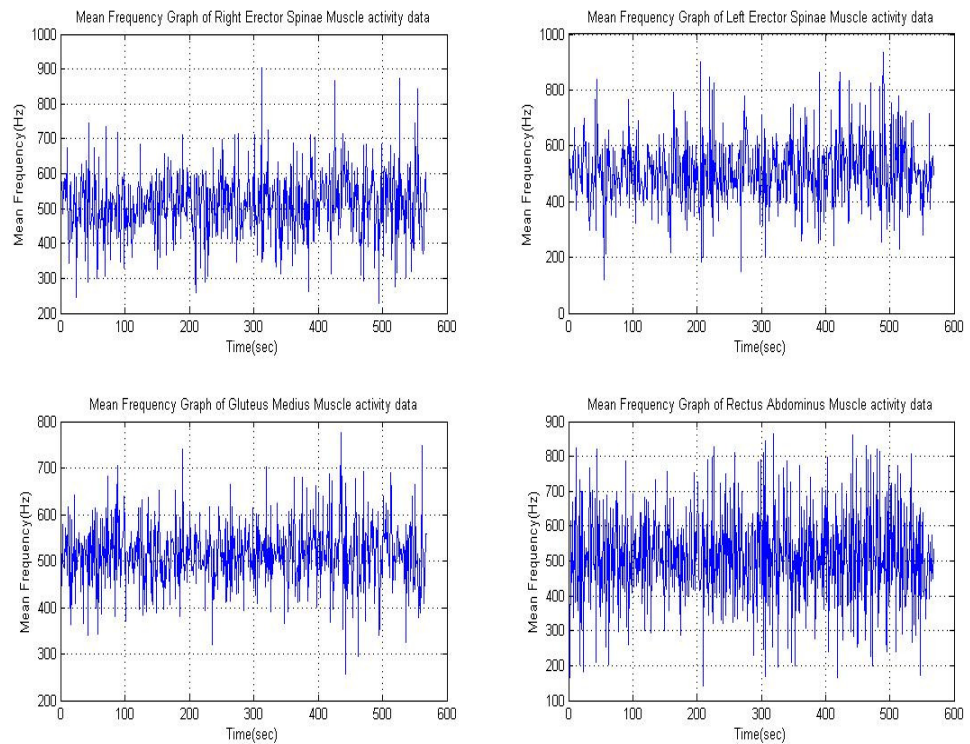
6.1-7b: Mean Frequency graph of four channels during interval 01:20 to 01:40



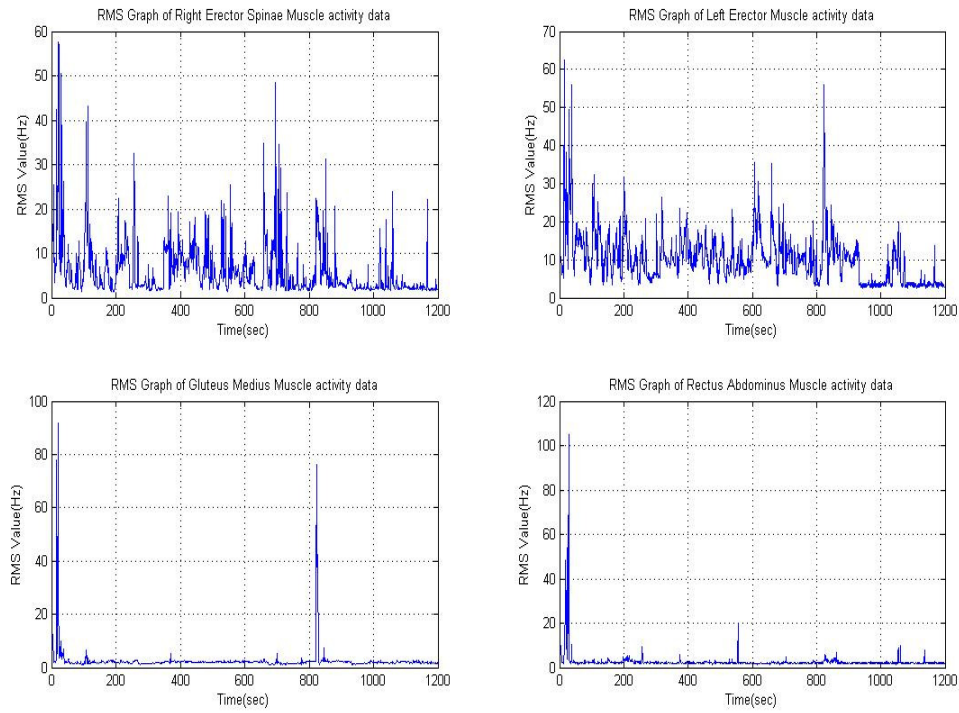
6.1-8b: Mean Frequency graph of four channels during interval 01:40 to 01:60



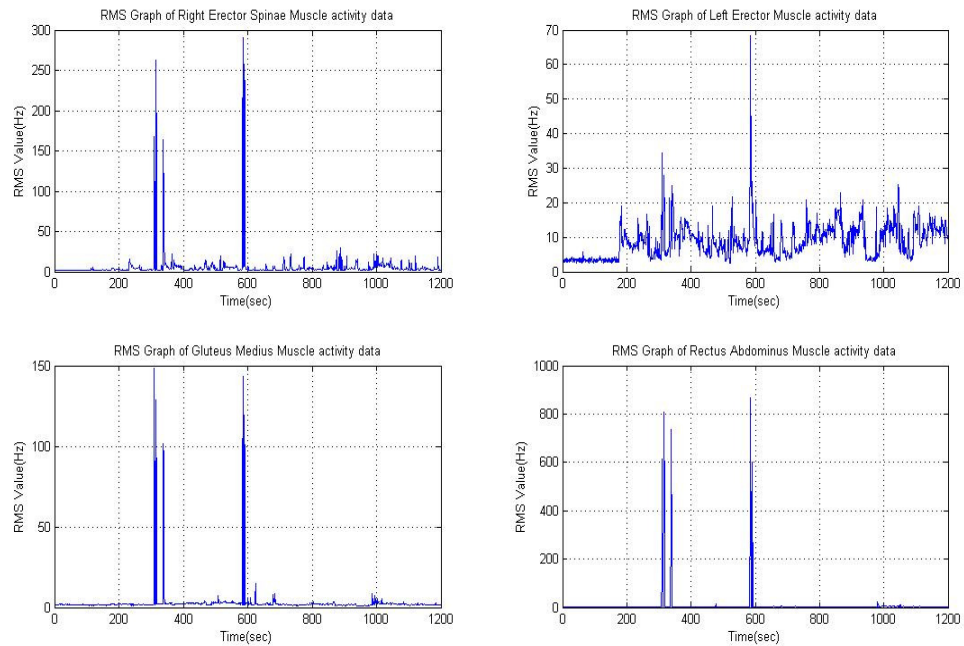
6.1-9b: Mean Frequency graph of four channels during interval 01:60 to 01:70



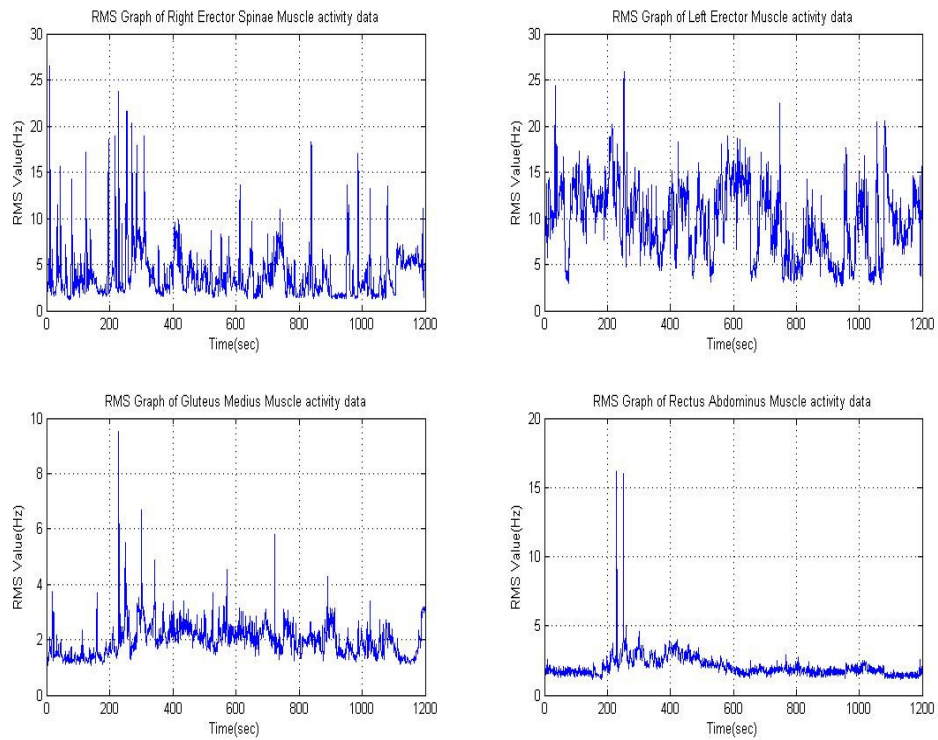
6.2-1a: RMS Frequency graph of four channels during interval 00:00 to 00:20



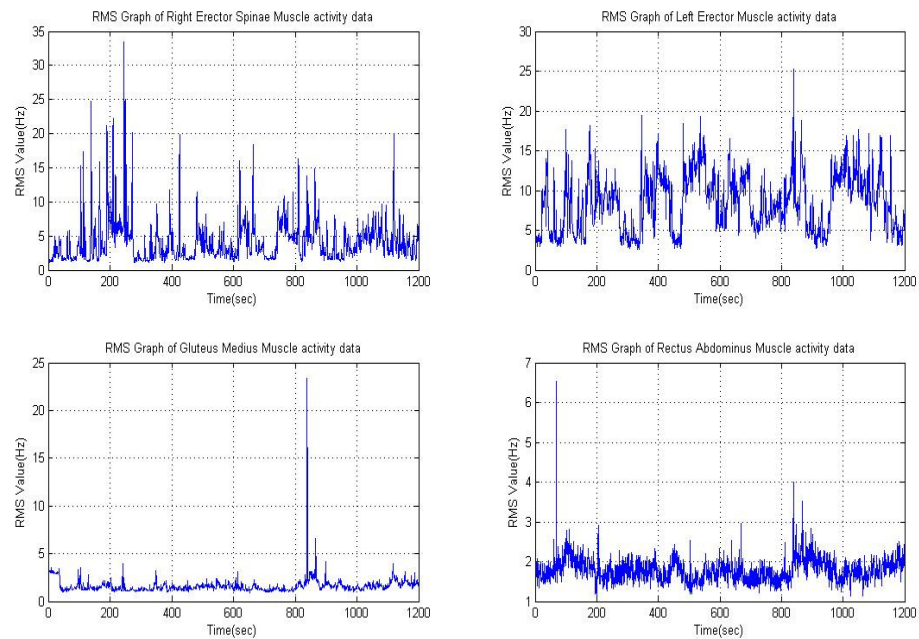
6.2-2a: RMS Frequency graph of four channels during interval 00:20 to 00:40



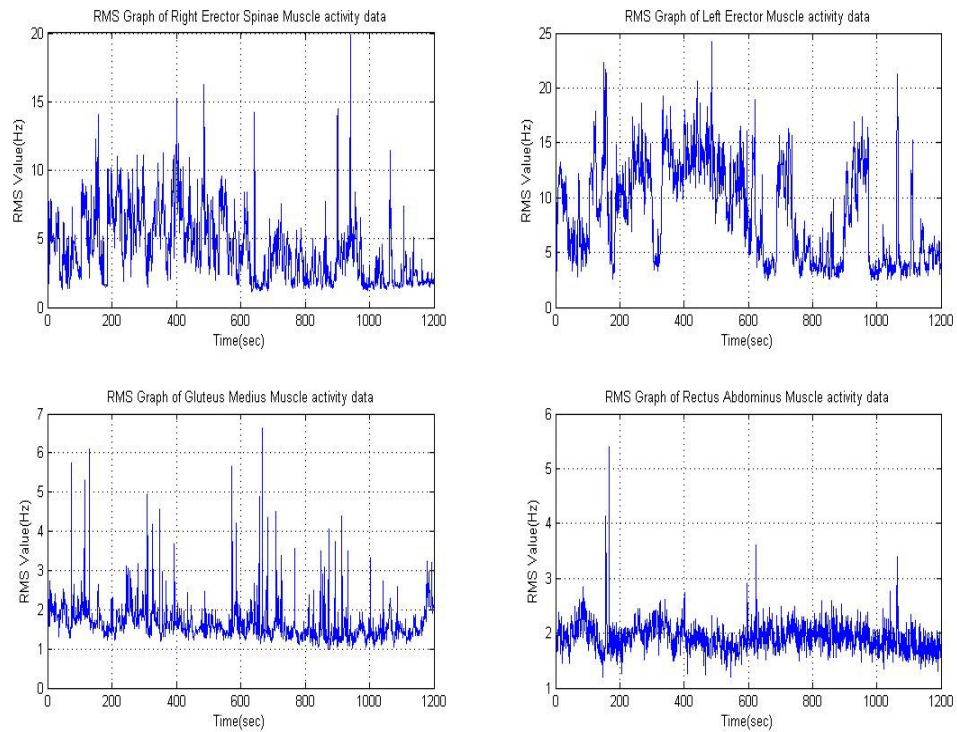
6.2-3a: RMS Frequency graph of four channels during interval 00:40 to 00:60



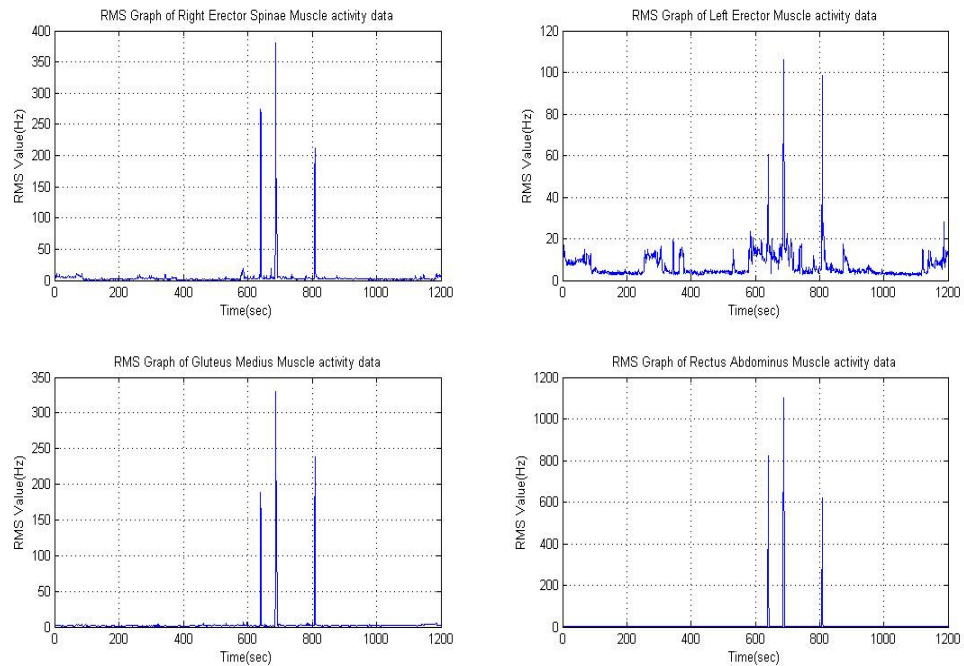
6.2-4a: RMS Frequency graph of four channels during interval 00:60 to 01:20



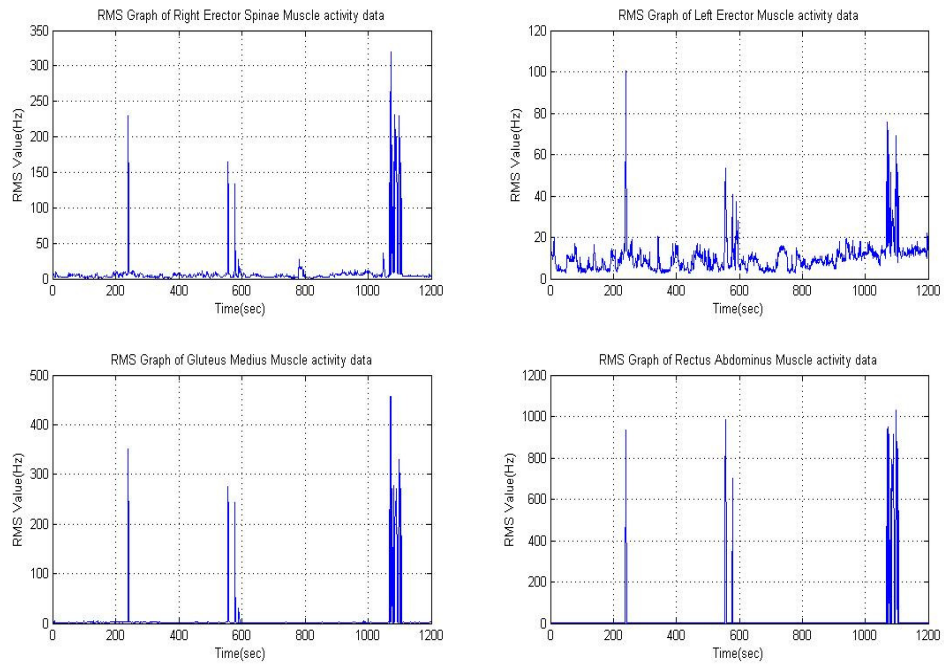
6.2-5a: RMS Frequency graph of four channels during interval 01:20 to 01:40



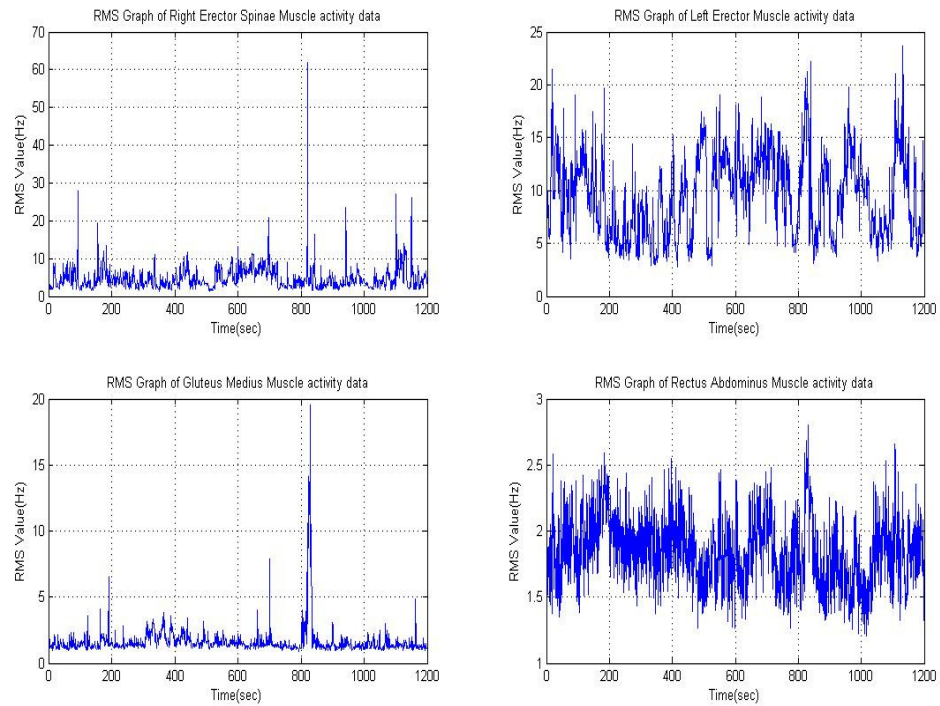
6.2-6a: RMS Frequency graph of four channels during interval 01:40 to 01:60



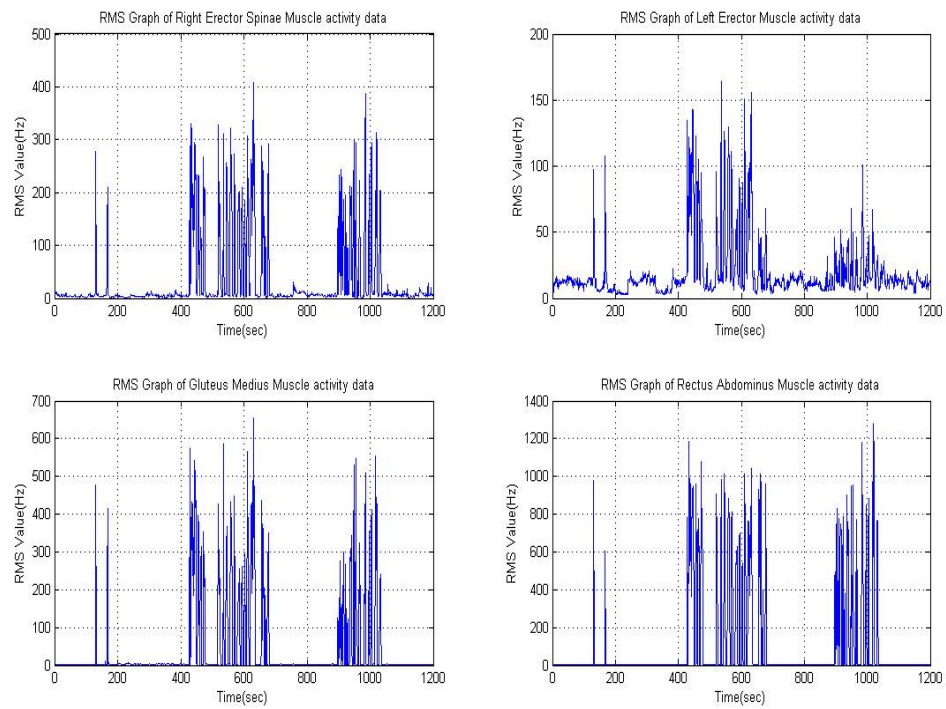
6.2-7a: RMS Frequency graph of four channels during interval 02:00 to 02:20



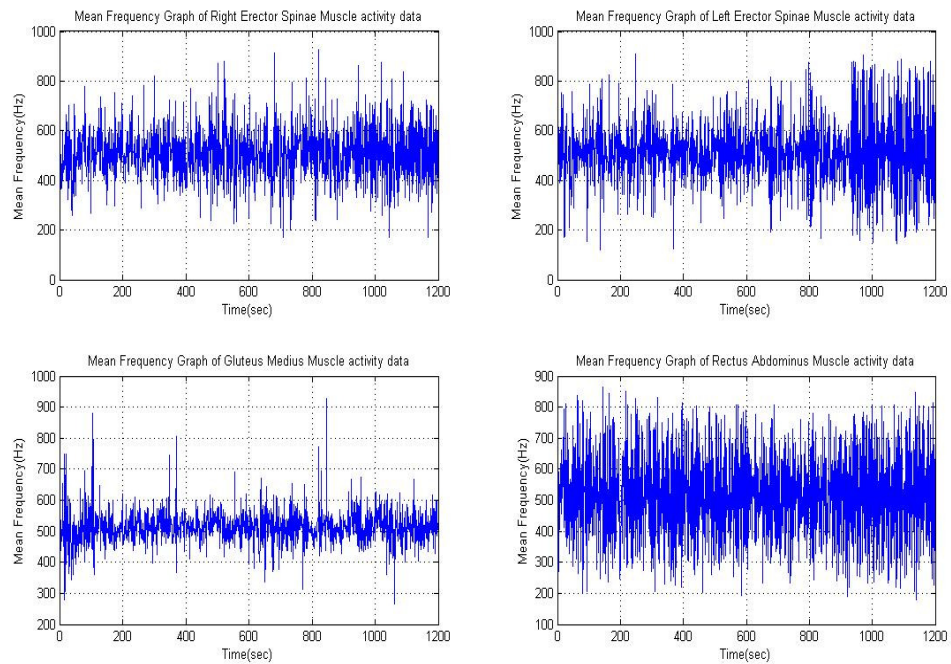
6.2-8a: RMS Frequency graph of four channels during interval 02:20 to 02:40



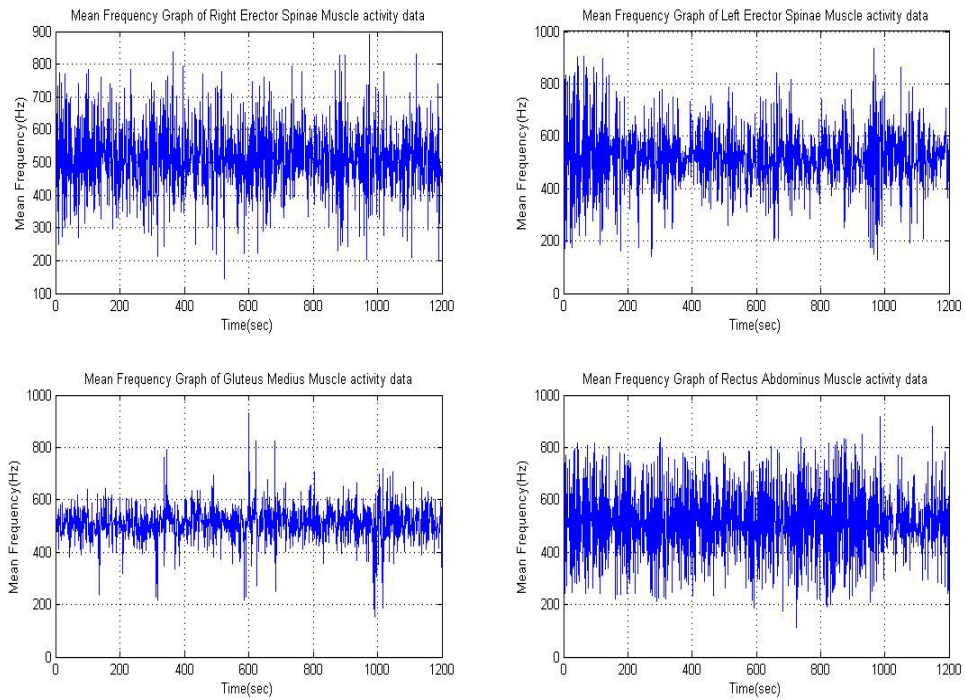
6.2-9a: RMS Frequency graph of four channels during interval 02:40 to 02:60



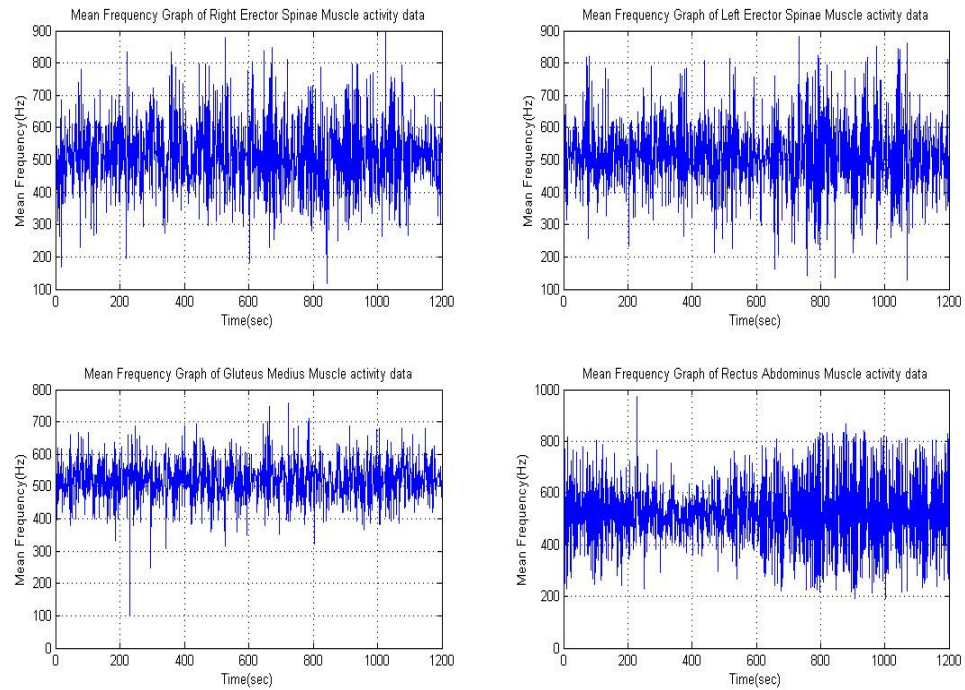
6.2-1b: Mean Frequency graph of four channels during interval 00:00 to 00:20



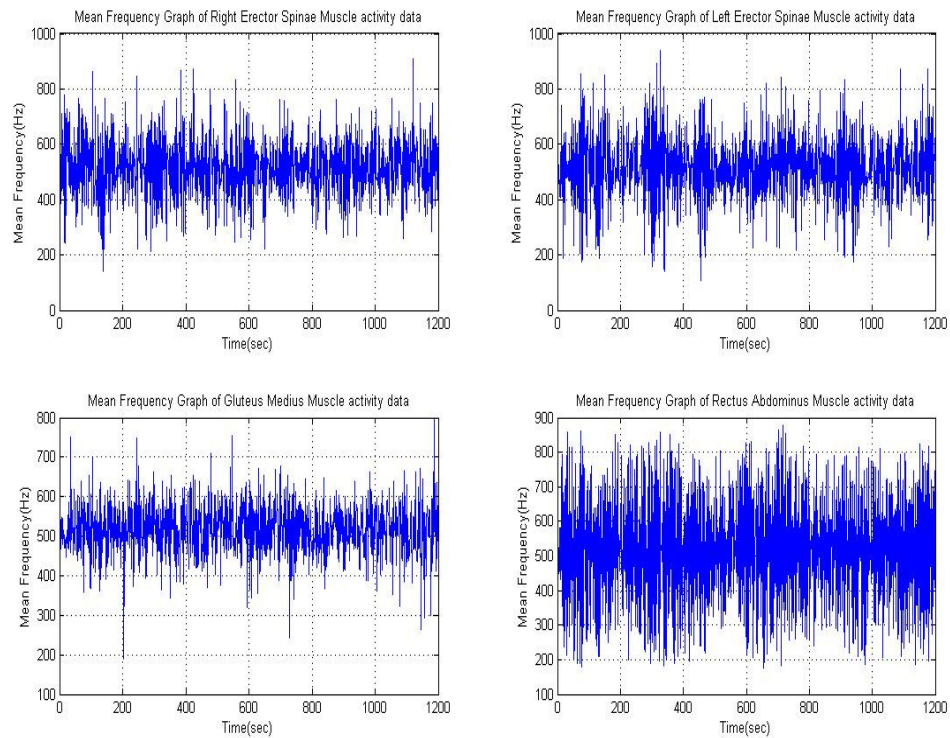
6.2-2b: Mean Frequency graph of four channels during interval 00:20 to 00:40



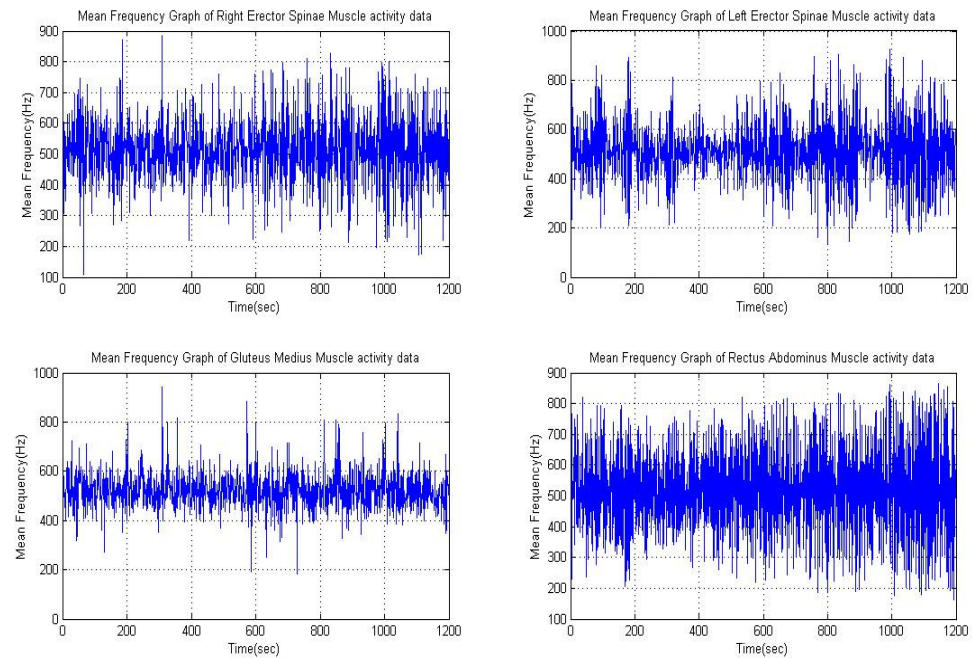
6.2-3b: Mean Frequency graph of four channels during interval 00:40 to 00:60



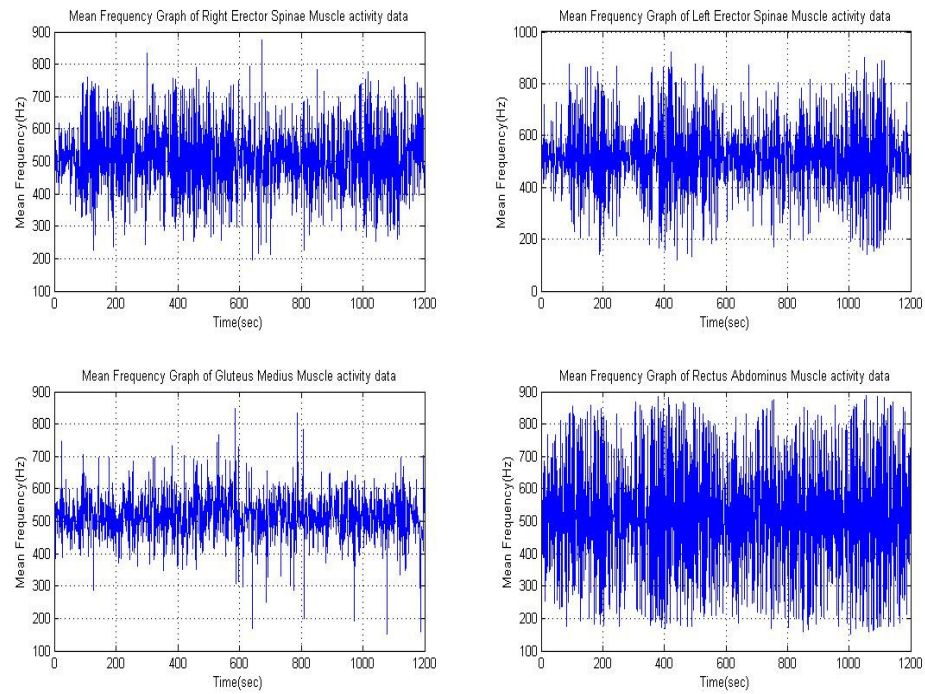
6.2-4b: Mean Frequency graph of four channels during interval 00:60 to 00:80



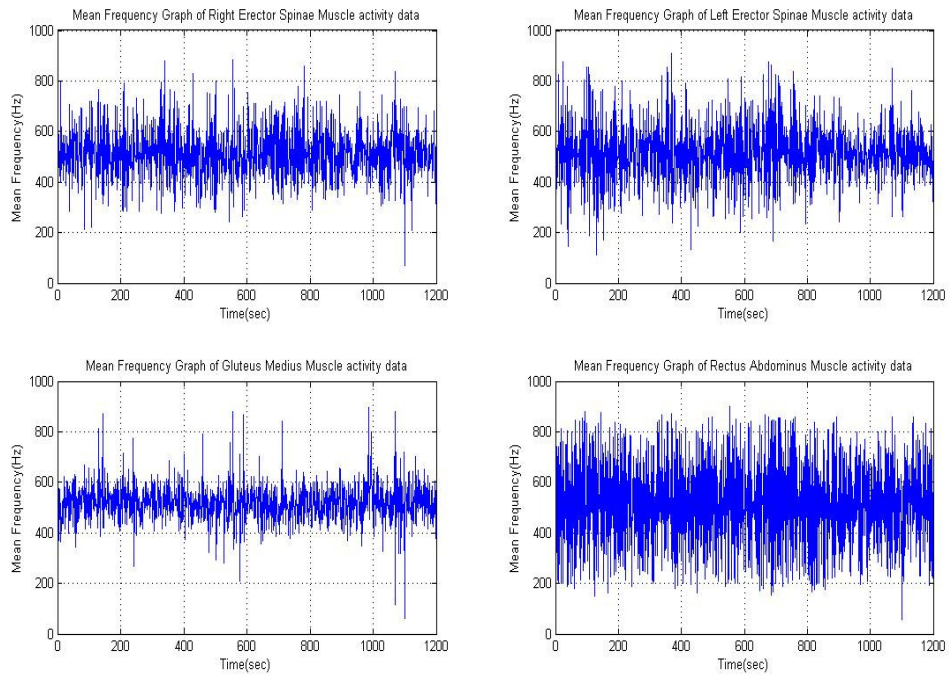
6.2-5b: Mean Frequency graph of four channels during interval 00:80 to 01:00



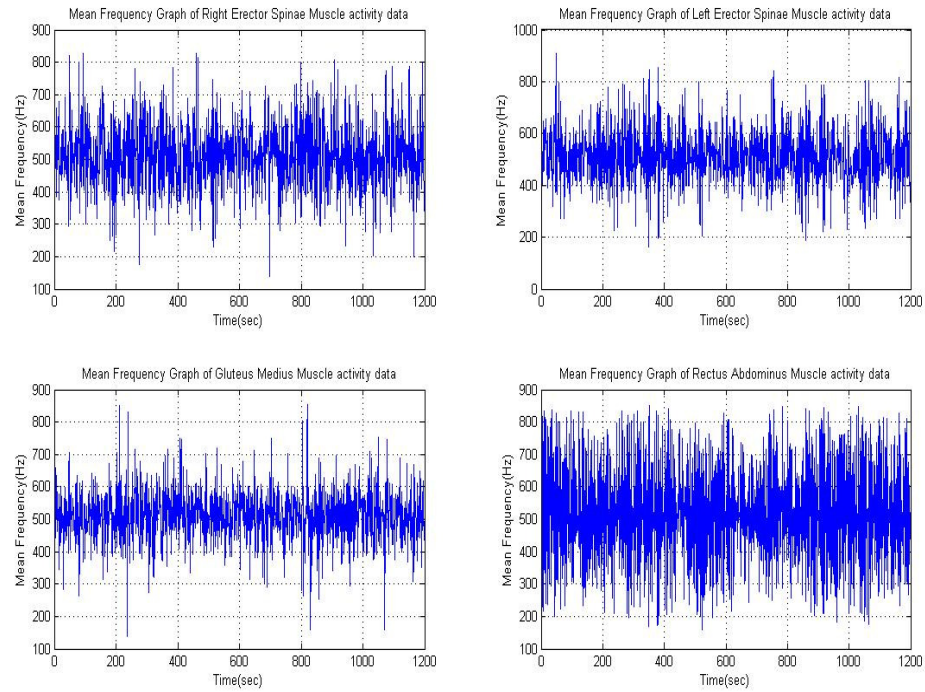
6.2-6b: Mean Frequency graph of four channels during interval 01:00 to 01:20



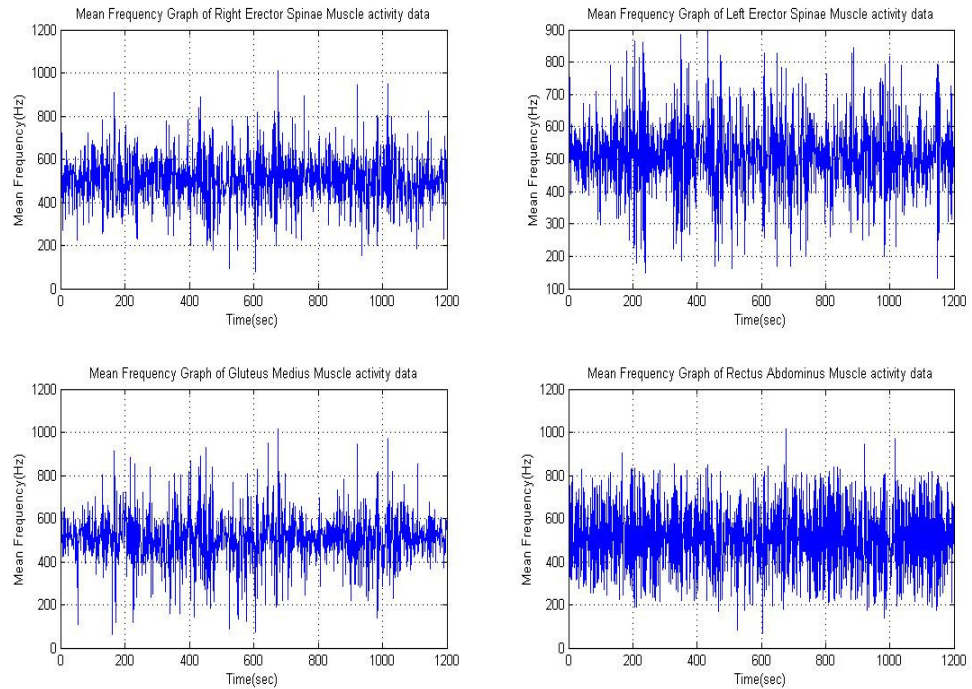
6.2-7b: Mean Frequency graph of four channels during interval 01:20 to 01:40



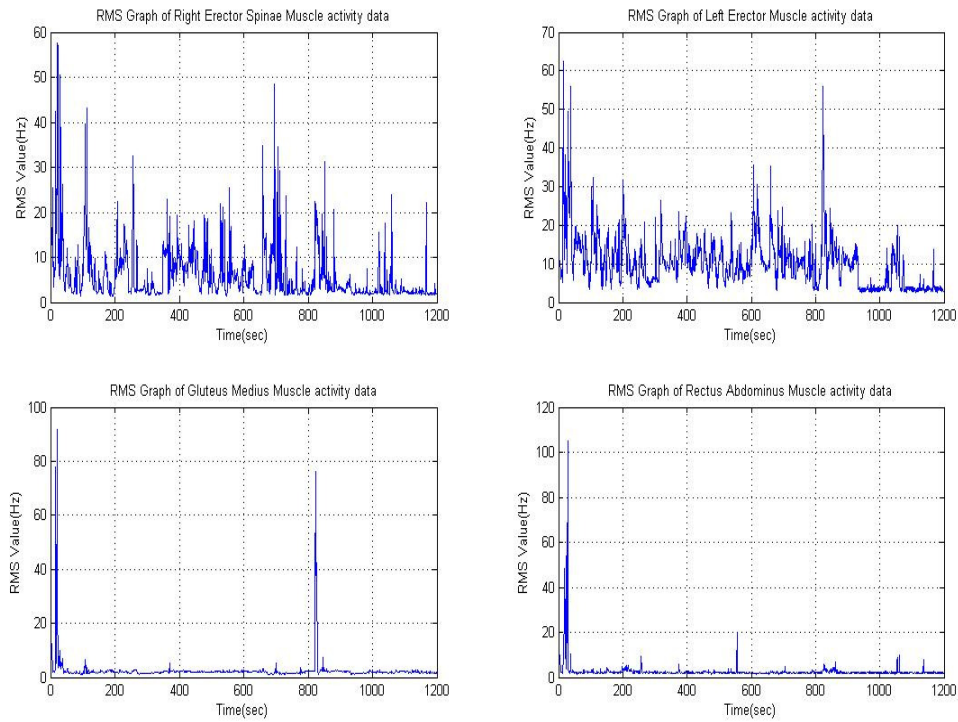
6.2-8b: Mean Frequency graph of four channels during interval 01:40 to 01:60



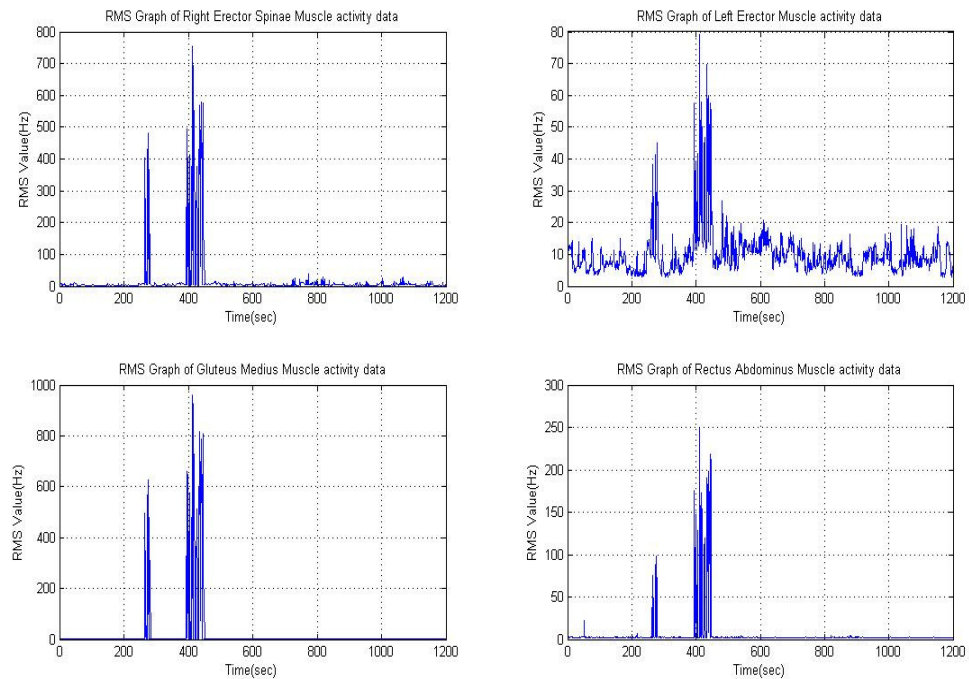
6.2-9b: Mean Frequency graph of four channels during interval 01:60 to 01:80



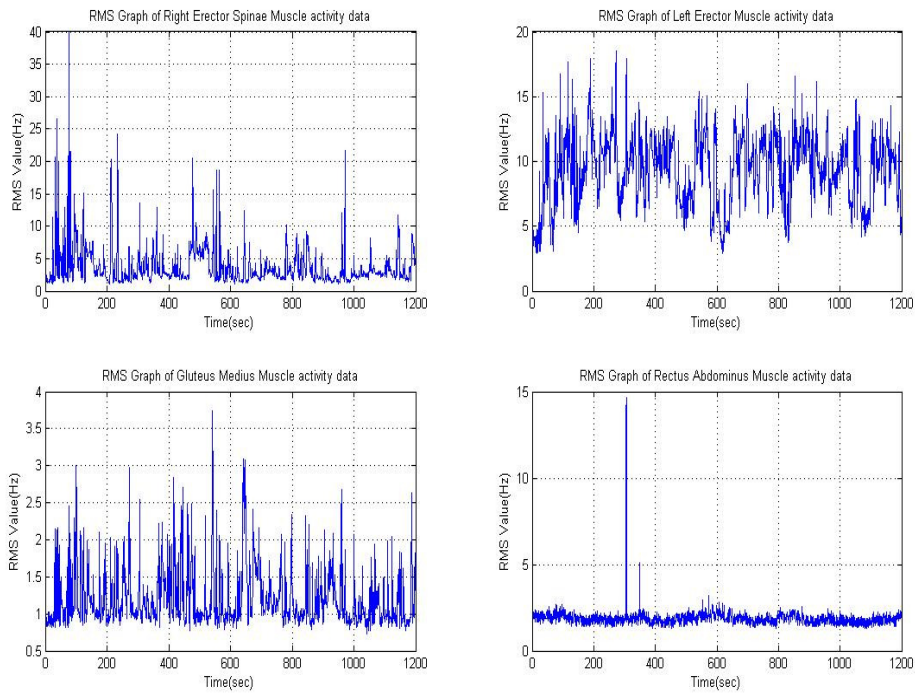
6.3-1a: RMS Frequency graph of four channels during interval 00:00 to 00:20



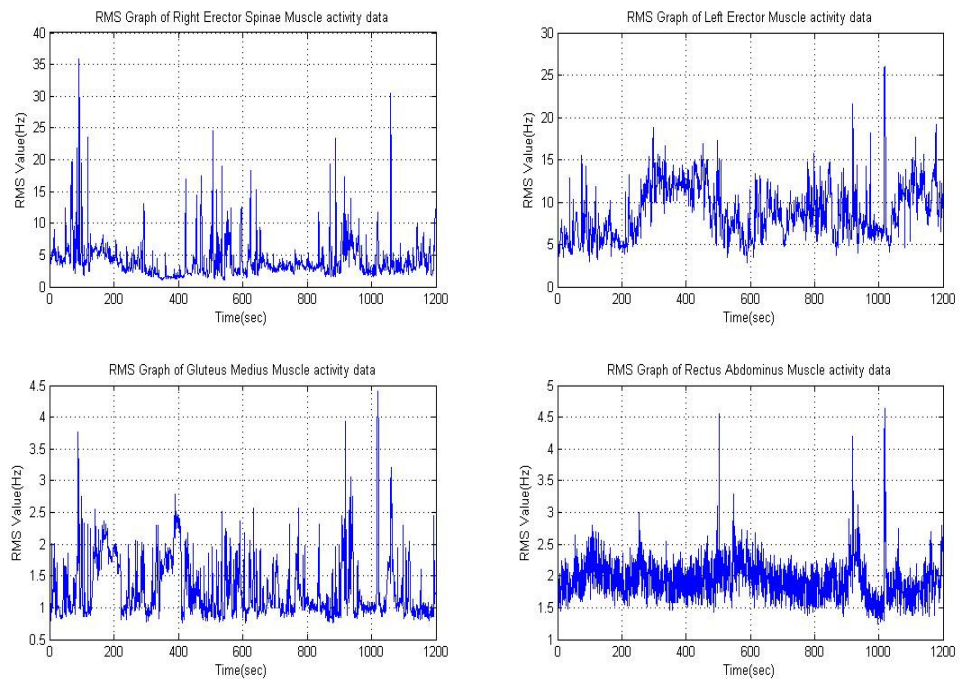
6.3-2a: RMS Frequency graph of four channels during interval 00:20 to 00:40



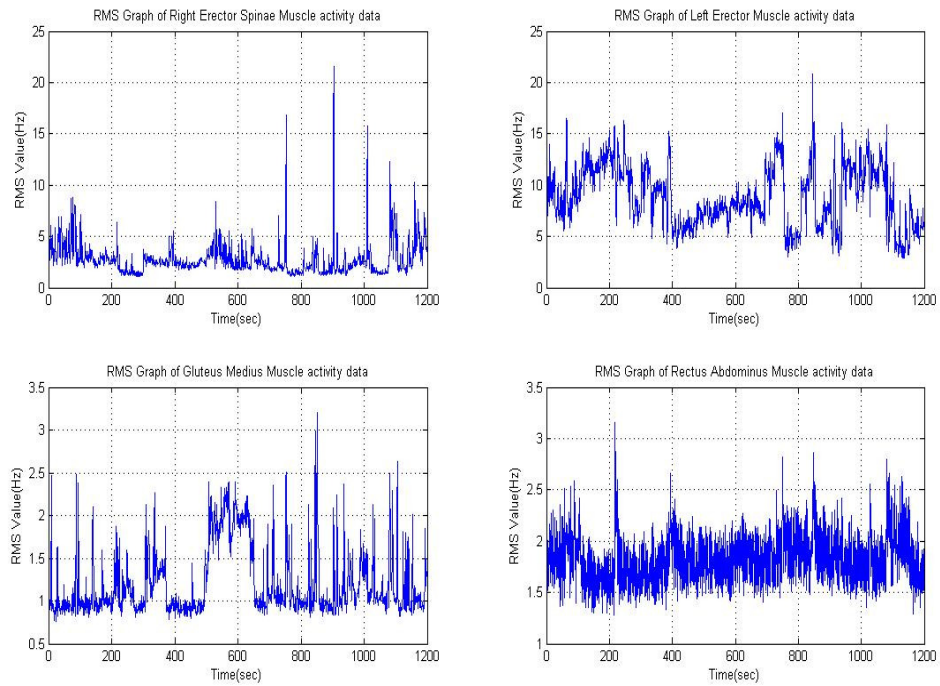
6.3-3a: RMS Frequency graph of four channels during interval 00:40 to 00:60



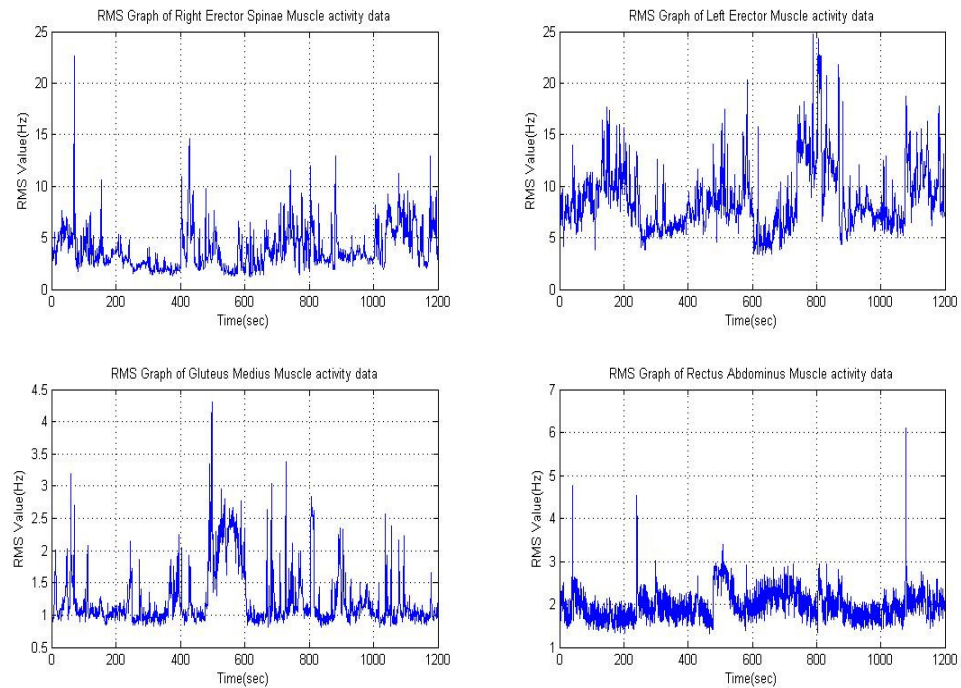
6.3-4a: RMS Frequency graph of four channels during interval 01:00 to 01:20



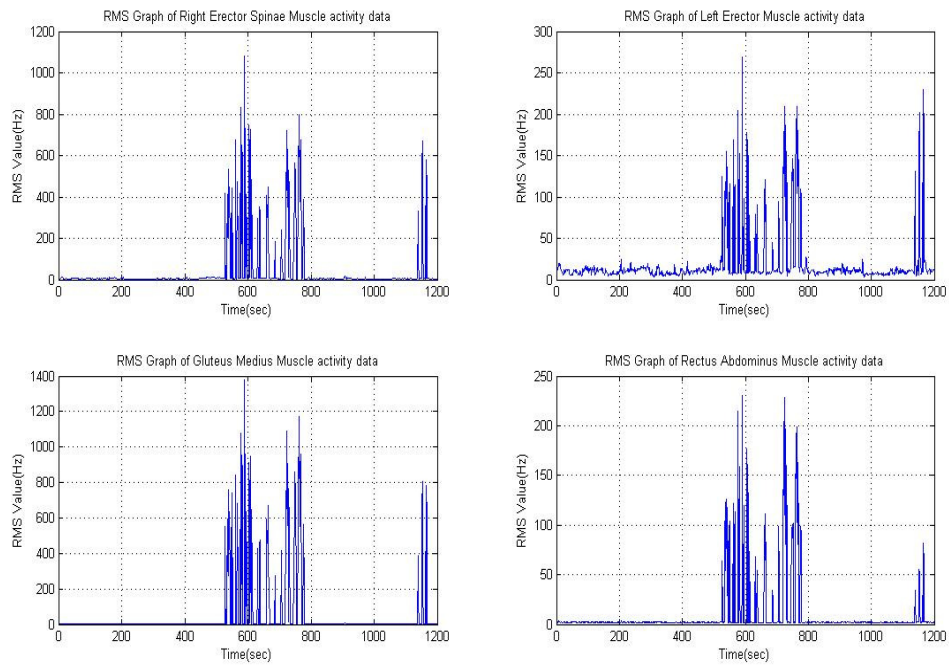
6.3-5a: RMS Frequency graph of four channels during interval 01:20 to 01:40



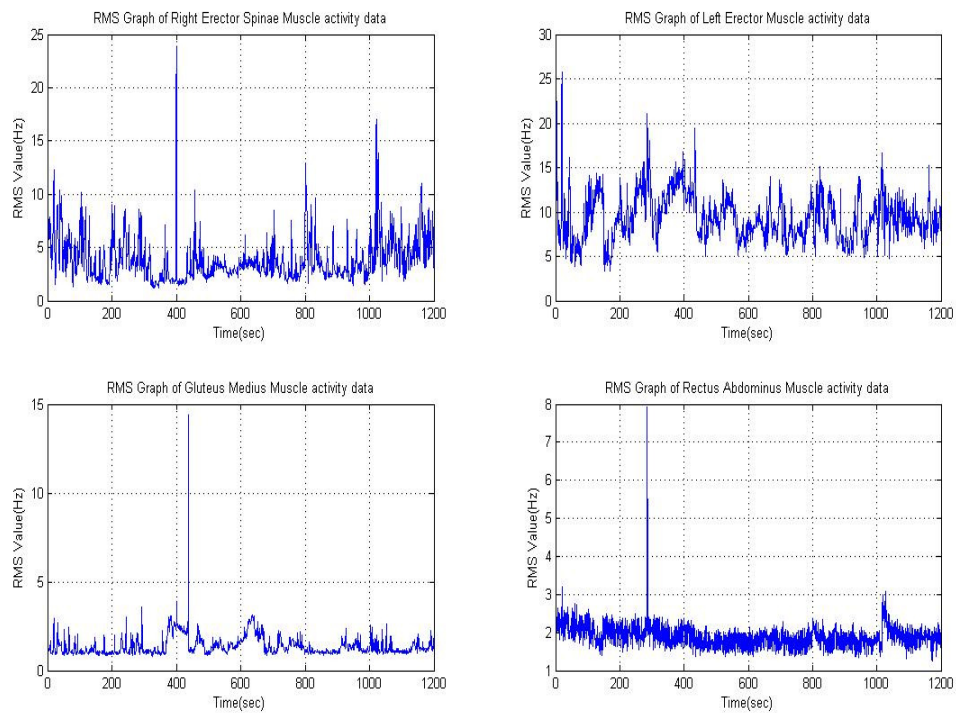
6.3-6a: RMS Frequency graph of four channels during interval 01:40 to 01:60



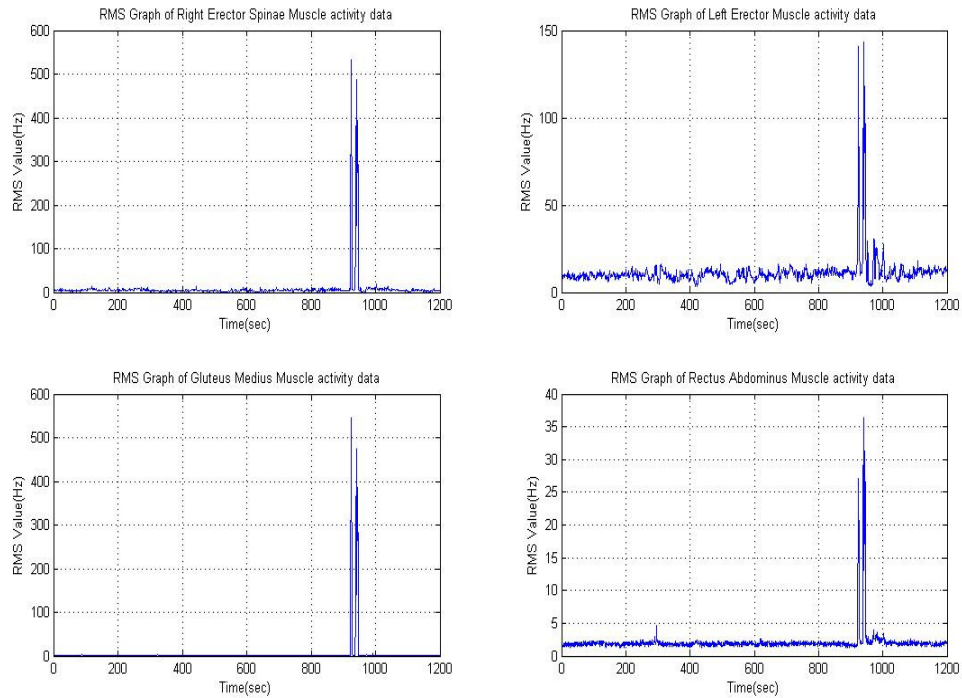
6.3-7a: RMS Frequency graph of four channels during interval 02:00 to 02:20



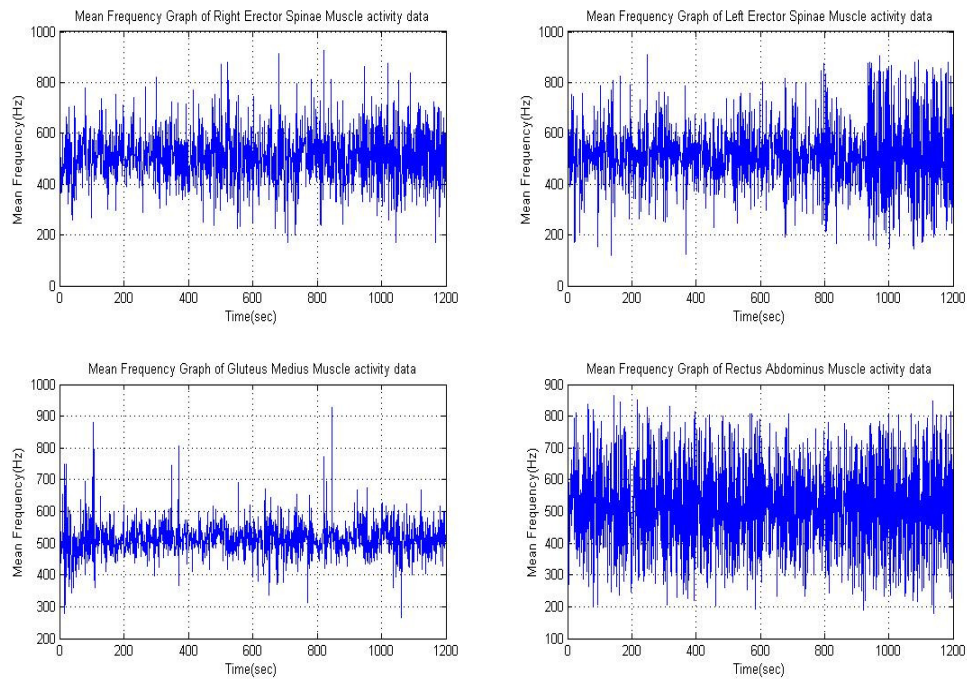
6.3-8a: RMS Frequency graph of four channels during interval 02:20 to 02:40



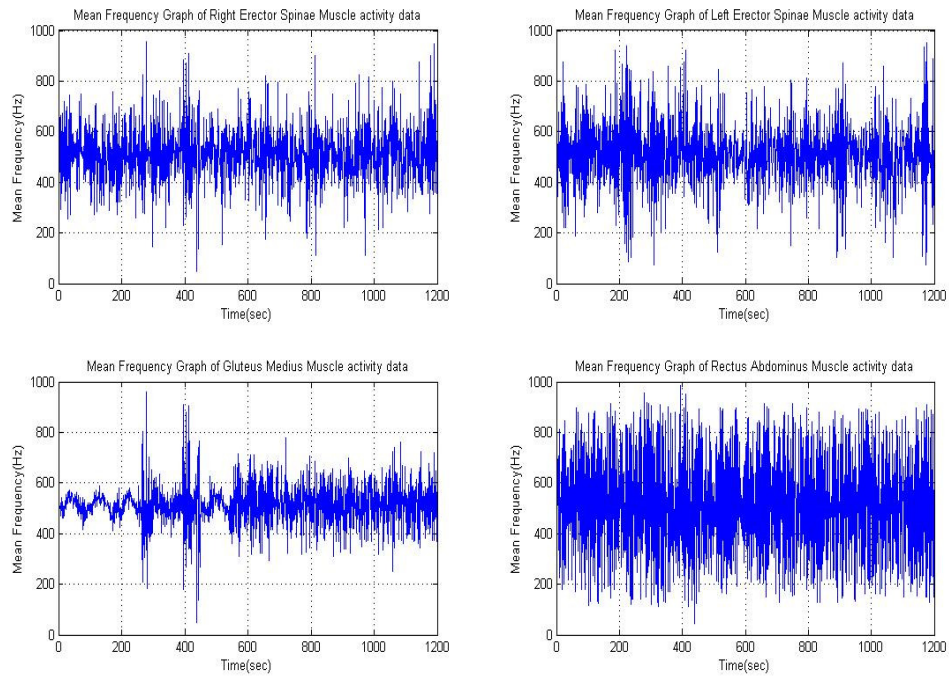
6.3-9a: RMS Frequency graph of four channels during interval 02:40 to 02:60



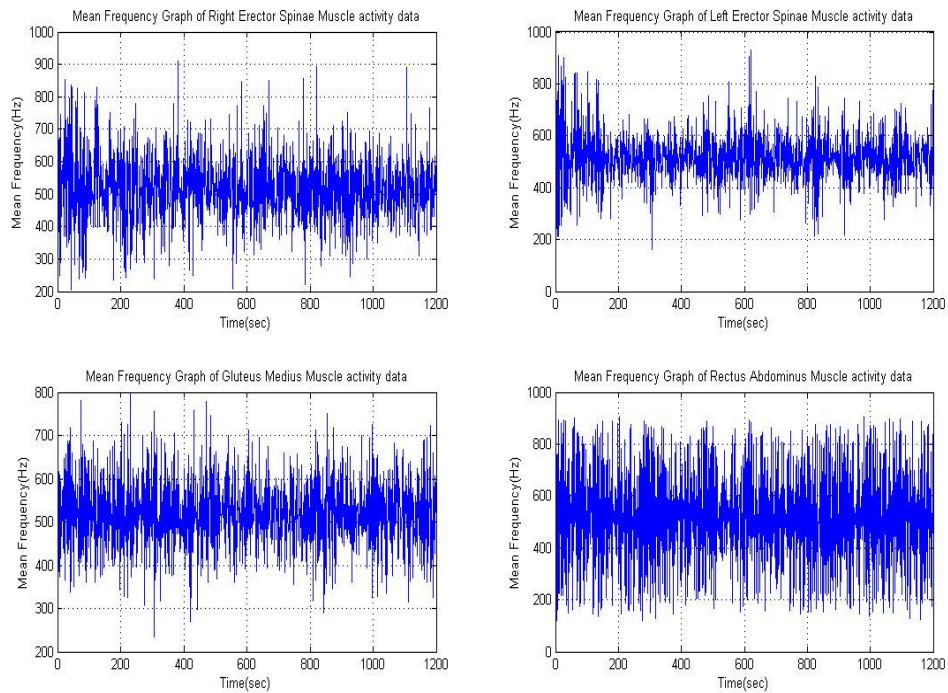
6.3-1b: Mean Frequency graph of four channels during interval 00:00 to 00:20



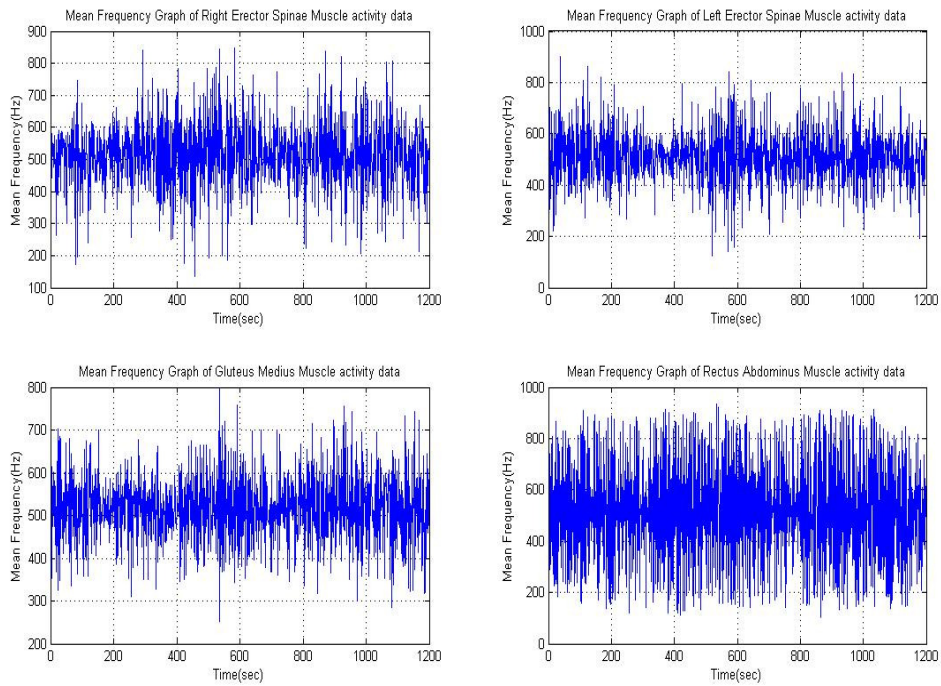
6.3-2b: Mean Frequency graph of four channels during interval 00:20 to 00:40



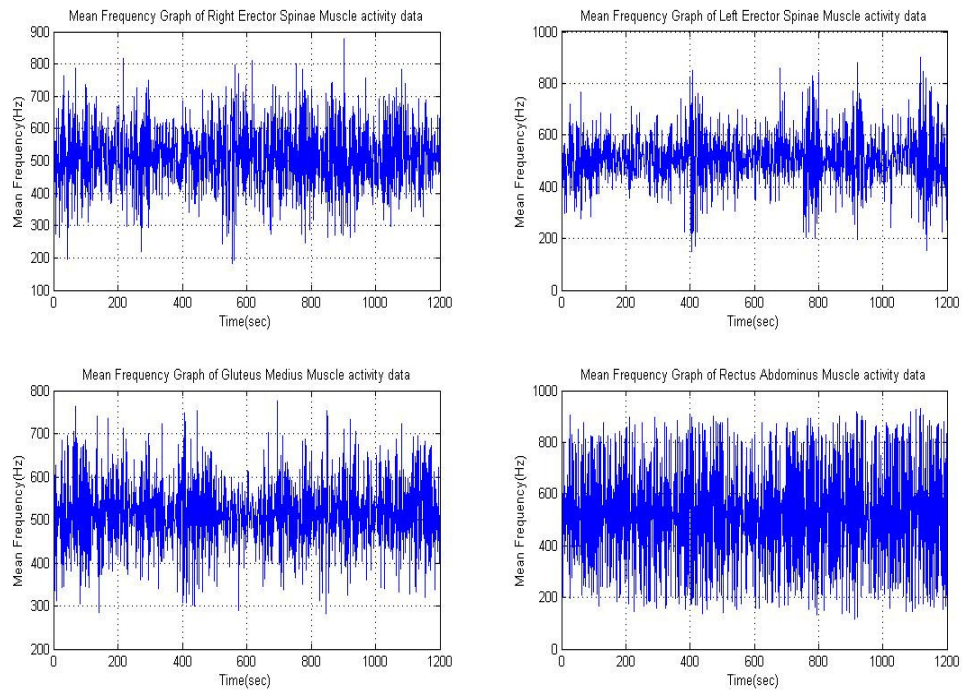
6.3-3b: Mean Frequency graph of four channels during interval 00:40 to 00:60



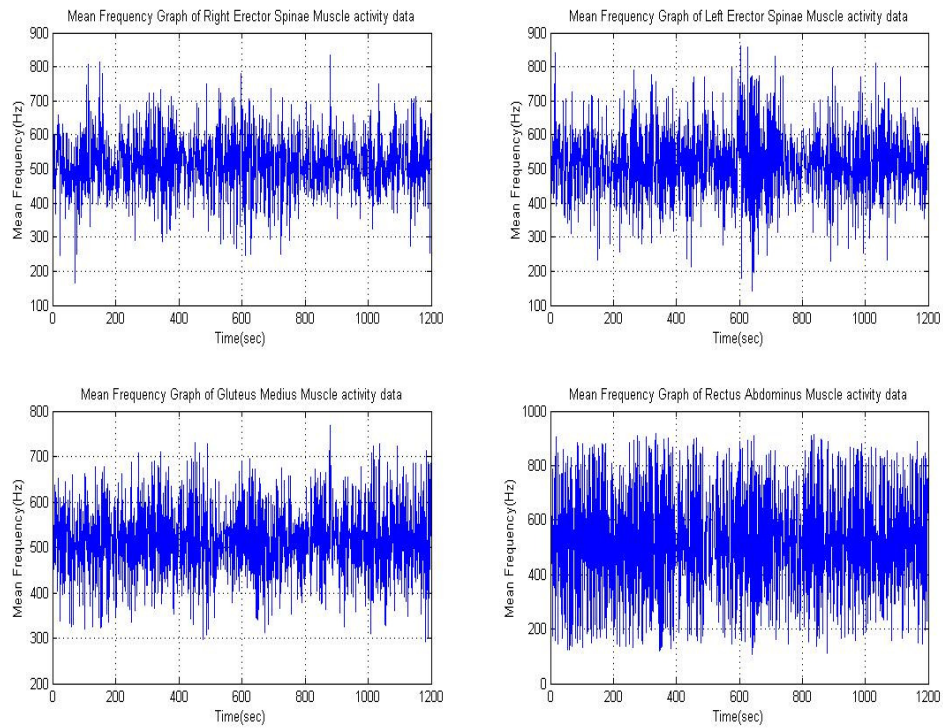
6.3-4b: Mean Frequency graph of four channels during interval 00:60 to 01:20



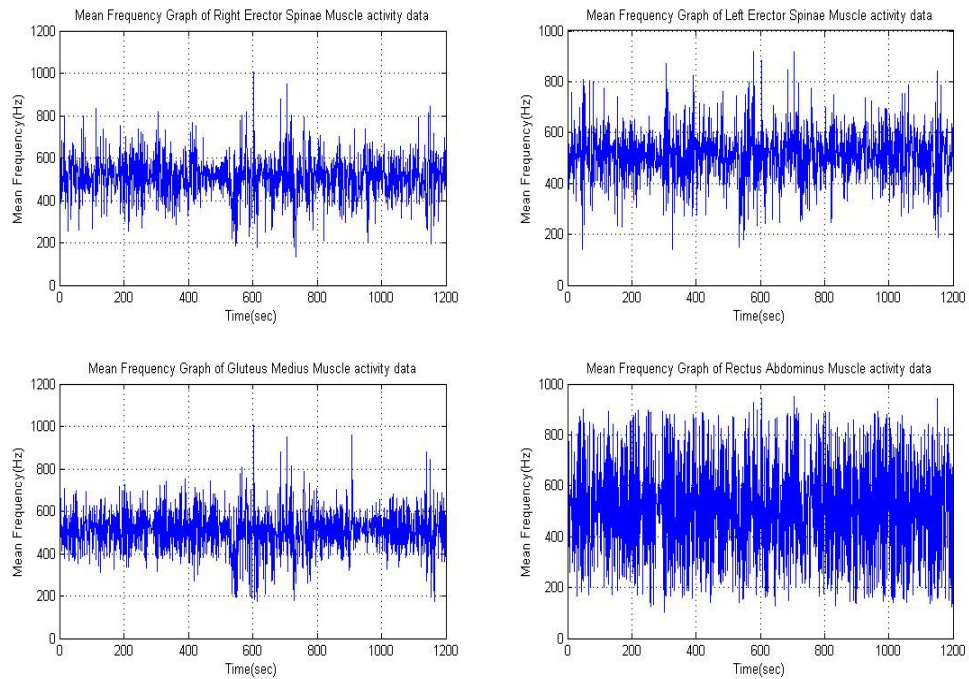
6.3-5b: Mean Frequency graph of four channels during interval 01:20 to 01:40



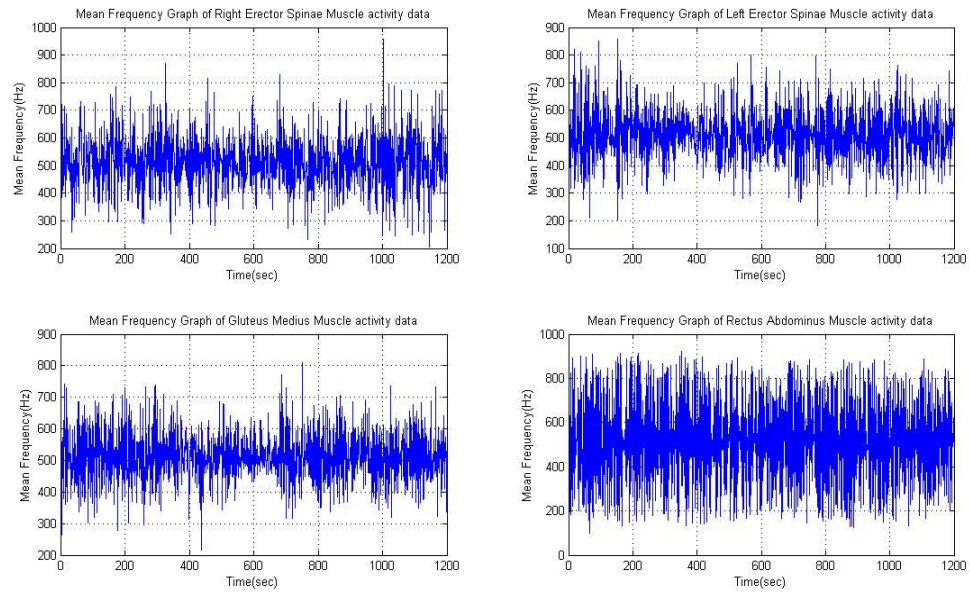
6.3-6b: Mean Frequency graph of four channels during interval 01:40 to 02:00



6.3-7b: Mean Frequency graph of four channels during interval 02:00 to 02:20



6.3-8b: Mean Frequency graph of four channels during interval 02:20 to 02:40



6.3-9b: Mean Frequency graph of four channels during interval 02:40 to 02:60

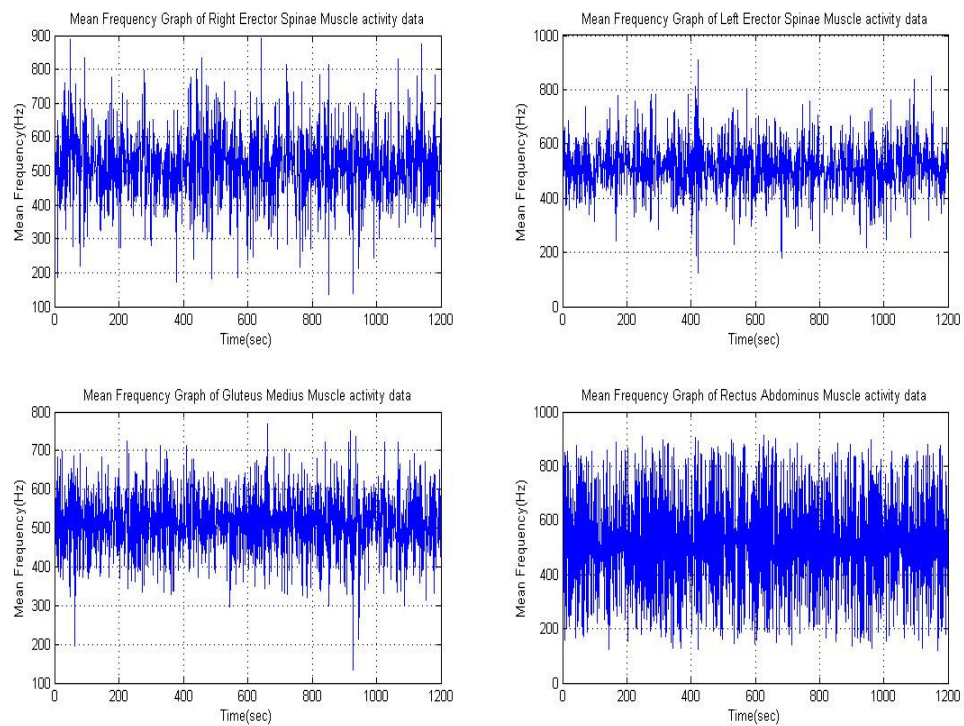


Figure 6.4-1: Comparison of Mean frequencies vs Time for test 1

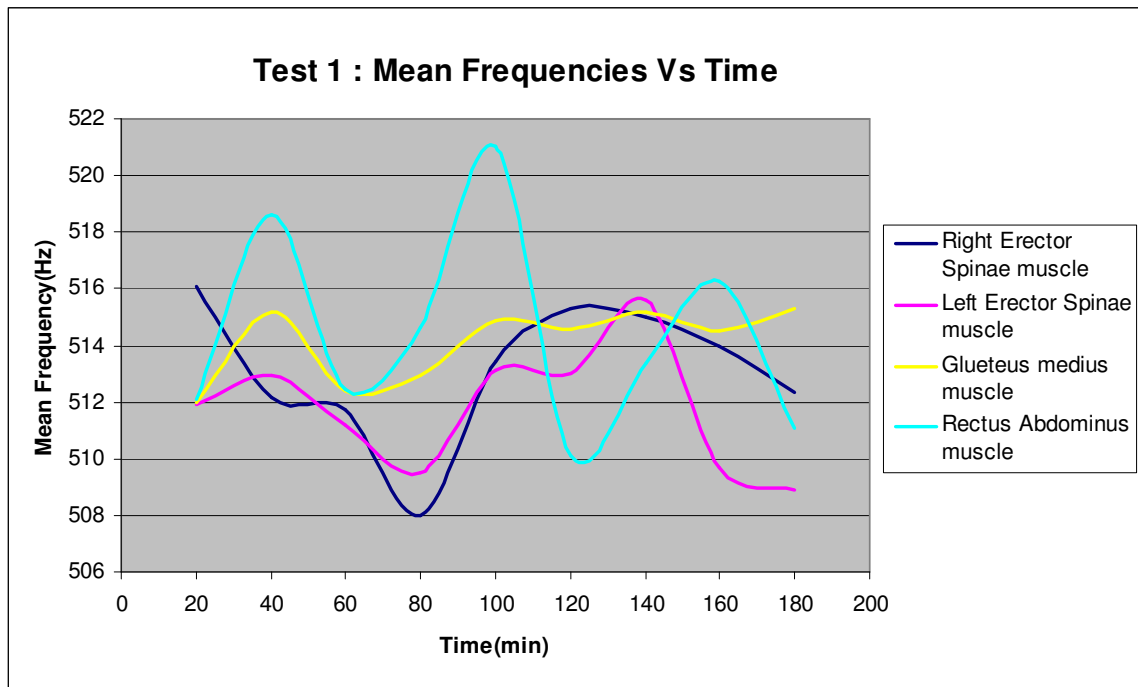


Figure 6.4-2: Comparison of Mean frequencies vs Time for test 2

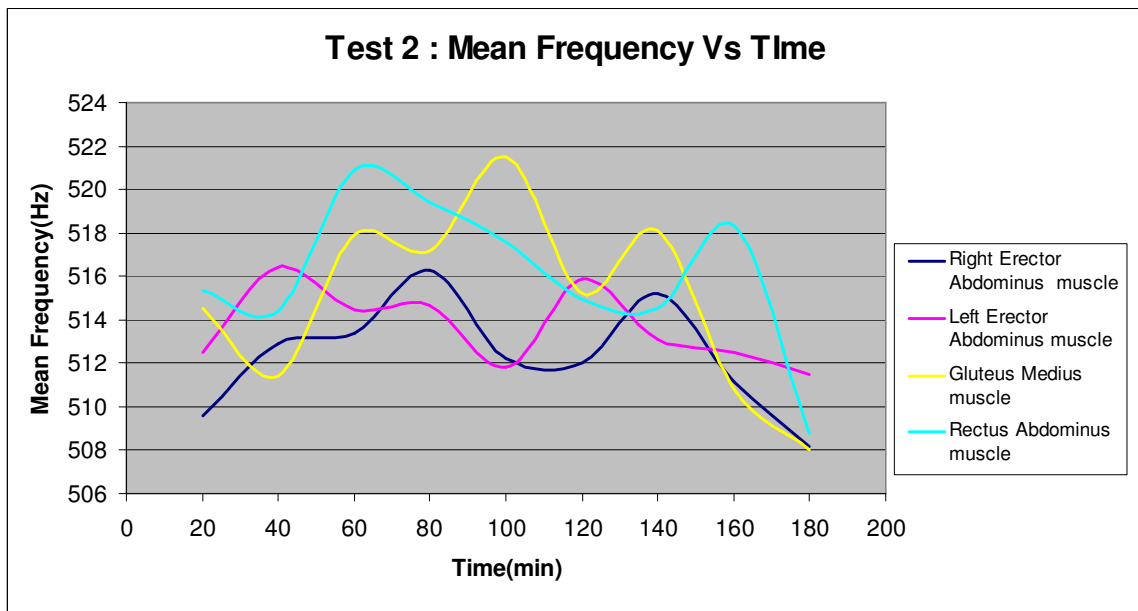
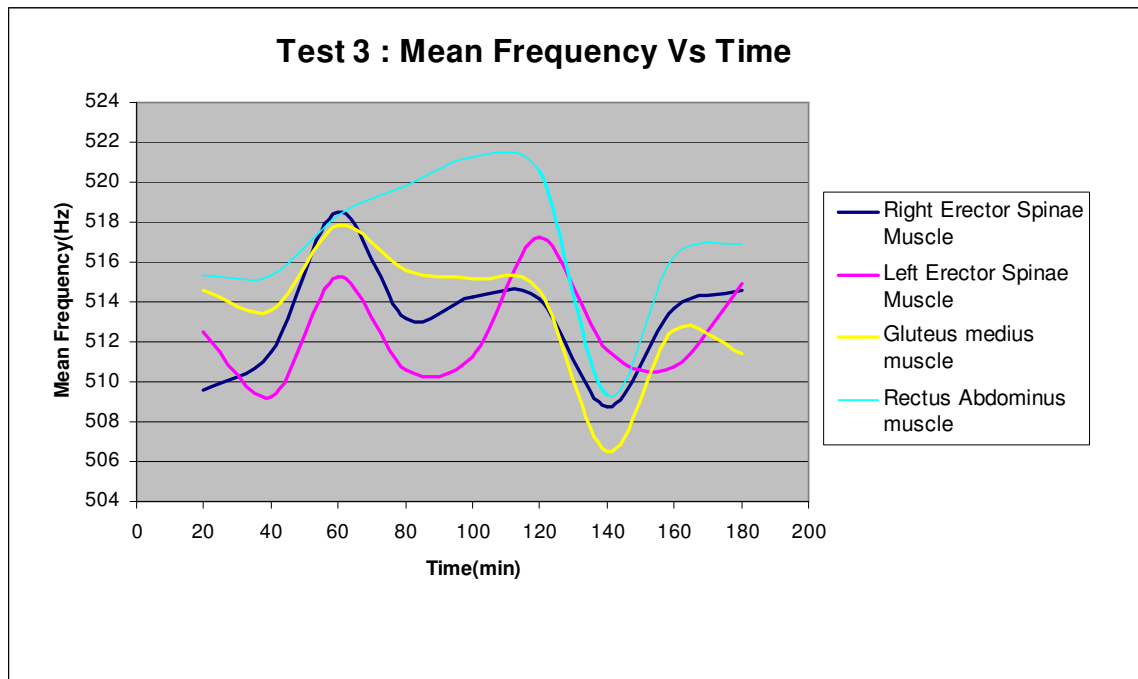


Figure 6.4-3: Comparison of Mean frequencies vs Time for test 3



Figures 6.4-1, 6.4-2, and 6.4-3 above are a comparison of muscle fatigue of the core muscles drawn in Excel considering their respective mean frequency values.

6.4 Flow chart: A spreadsheet for all the three tests was prepared in order to compare and correlate the results of EMG data with that of acceleration data and ultrasonic data results. Tables 3, 4, and 5 below show the time elapsed during the test for the ultrasonic results, which are the movement of the lumbar region, four channels of electromyographic data, and acceleration values from Human Vibration Meter.

6.5 Correlation of EMG data with Acceleration data and Ultrasonic data obtained by calculating the RMS value

Table 3: Flow chart of spinal movements, acceleration and EMG of Test 1

Time	Frontal	Torsional	Sagittal	Ch 1	Ch 2	Ch 3	Ch 4	Az
0								
1								
2								
3								
4								
5								0.405
6								
7								
8								
9	Start	Start	Start					
10								0.618
11								
12	Increased Motion	Increased motion	Some increased motion	Max	Max	Max	Max	
13		Lg posture change to L		Max	Max	Max	Max	
14			Very static until 0:58					
15								0.508
16								
17								
18								
19								
20								0.48
21								
22								
23					yes			
24								
25								0.463
26				yes		yes		
27							yes	

28								
29								
30		Increasing motion						0.572
31								
32								
33		Lg motion inc						
34				yes		yes		
35								0.892
36								
37								
38				Max	Max	Max	Max	
39								
40								0.66
41								
42								
43								
44								
45								0.437
46								
47								
48								
49								
50								0.46
51								
52								
53								
54								
55								0.227
56	Increased motion	Posture change towards N with inc motion		Yes	Yes	Yes	Yes	
57				Yes	Yes	Yes	Yes	
58			Increased motion	Yes	Yes	Yes	Yes	
59				Yes	Yes	Yes	Yes	
1								0.356

1.01								
1.02								
1.03								
1.04								
1.05	Posture change	Posture change						0.259
	to N	to N						
1.06	Increased	with inc	Posture change					
	Motion	motion	towards Flexed					
1.07								
1.08	Posture change			Max	Max	Max	Max	
	to L							
1.09	Posture change		Posture change	Yes	Yes	Yes	Yes	
	to N		towards N					
1.1			Lg inc					0.547
			in motion					
1.11			Posture change					
			towards Flexed					
1.12								
1.13								
1.14	Decreasing posture	Posture change						
	to L	towards L						
1.15								0.446
1.16		Lg inc						
		in motion						
1.17								
1.18								
1.19								
1.2								0.574
1.21				Yes	Yes	No	Yes	
1.22				Yes	Yes	No	Yes	
1.23								
1.24								
1.25								0.323

1.26				Yes	Yes	No	No	
1.27								
1.28								
1.29								
1.3				Yes	No	No	Yes	0.473
1.31								
1.32				Yes	Yes	Yes	Yes	
1.33				Yes	Yes	Yes	Yes	
1.34								
1.35								0.184
1.36								
1.37								
1.38								
1.39								
1.4								0.37
1.41								
1.42								
1.43								
1.44								
1.45	Posture	Posture	small inc					0.624
	towards N	towards N	in motion					
1.46	Increased	Increased						
	motion	motion		Max	Max	Max	Max	
1.47								
1.48				Max	Max	Max	Max	
1.49								
1.5								0.5
1.51								
1.52								
1.53								
1.54								
1.55								0.295
1.56	Increased			No	Yes	No	No	
	motion							
1.57								
1.58								
1.59								
2	Posture		Lg inc					0.407
	towards N		in motion					

2.01	Increased			Yes	No	No	No	
	Motion							
2.02								
2.03			Very static					
			to END					
2.04								
2.05								0.418
2.06								
2.07								
2.08								
2.09								
2.1								0.388
2.11				Yes	Yes	Yes	Yes	
2.12								
2.13		Inc motion						
2.14				Max	Max	Max	Max	
2.15								0.446
2.16	Increased	Lg inc						
	motion	in motion						
2.17	Posture to			Max	No	No	No	
	R of N							
2.18								
2.19								
2.2	Static and							0.428
	close to N							
2.21	until END			Yes	Yes	No	No	
2.22								
2.23								
2.24								
2.25				Yes	Max	Max	No	0.522
2.26								
2.27				Yes	Yes	Yes	Yes	
2.28								
2.29								
2.3								0.352
2.31								
2.32				Yes	Yes	No	Yes	
2.33								

2.34								
2.35								0.373
2.36				Yes	Yes	No	No	
2.37								
2.38								
2.39								
2.4								0.48
2.41								
2.42								
2.43								
2.44				Yes	Yes	Yes	Yes	
2.45								

Table 4: Flow chart of Spinal movements, acceleration and EMG for Test 2

Time	Frontal	Torsional	Sagittal	Ch 1	Ch 2	Ch 3	Ch4	Az
0								
1								
2								
3								
4								
5								
6								
7								
8								
9	Start	Start	Start					
10	Still settling in	Still settling in	Still settling in					
11								
12								
13				Yes	Yes	Yes	Yes	
14								
15								
16								
17			Motion trend					
			to inc Flex					
18								
19								
20								0.234
21								
22		Increased motion						
23		Posture change towards L						
24								
25	Posture change towards N	Posture change to N	Motion trend towards N	Max	Yes	Max	Max	0.347
26		Increased	Inc in					

		motion	motion			
27			Motion trend			
			to inc Flex			
28			until 0:43			
29	Posture change	Posture change				
	L of N and	from R of N				
30	back to N	to L of N		Max	Max	Max
31						
32						
33						
34						
35						0.34
36						
37						
38						
39						
40						0.297
41						
42						
43		Posture change	Posture change			
		towards N	towards N			
44	Increased movement	Increased motion	Very large inc in motion	yes	yes	yes
45	Posture change slightly to L	Very static until 1:05		yes	yes	yes
46						
47						
48						
49						
50						0.372
51						
52	Posture					

	change						
	more to L						
53			Max	Max	Max	Max	
54							
55							0.177
56							
57	Movement inc,						
	Posture						
58	moves back						
	towards N						
59							
1							0.237
1.01							
1.02							
1.03							
1.04							
1.05		Posture becomes	Yes	Yes	Yes	Yes	0.289
		progressively					
1.06		more L of N.					
1.07							
1.08							
1.09							
1.1							0.252
1.11							
1.12							
1.13	Movement inc,		Posture change				
	Posture		towards N				
1.14	moves back		Increased	yes	yes	yes	yes
	towards N		Motion				
1.15	Motion trend		Motion trend	yes	yes	yes	yes
			towards inc				
	towards L		Flexed				
1.16				Yes	Yes	Yes	Yes

1.17	Very static						
	posture						
1.18	until 2:00						
1.19							
1.2							0.288
1.21							
1.22							
1.23					Yes	Yes	
1.24							
1.25							0.25
1.26							
1.27							
1.28							
1.29							
1.3							0.316
1.31				Yes	Yes	Yes	Yes
1.32							
1.33							
1.34							
1.35							0.319
1.36			Posture change	Yes	Yes	Yes	Yes
			to more Flexed				
1.37							
1.38							
1.39		Posture change		Yes	Yese	Yes	Yes
		towards N					
1.4		Increased		Max	Max	Max	Max
		movement					
1.41							
1.42							
1.43							
1.44		Becomes much more					
		more to L of N					
1.45		until 1:59					0.199

1.46						
1.47						
1.48						
1.49						
1.5						0.362
1.51				Yes	Yes	Yes
1.52				Yes	Yes	Yes
1.53				Yes	Yes	Yes
1.54						
1.55						0.339
1.56						
1.57						
1.58		Posture goes to N				
1.59	Increased movement	Increased movement	Increased motion			
2				yes	yes	yes
2.01	Posture goes to N			Yes	Yes	Yes
2.02		Posture returns to L of N				
2.03		quite quickly.				
2.04						
2.05		Posture static and to L of N				0.975
2.06		until 2:30				
2.07						
2.08						
2.09	Increased movement @ N		Increased motion	yes	yes	yes
2.1	Movement trend to L					0.399
2.11			Motion trend toward Flexed	yes	yes	yes
2.12						

2.13						
2.14	Movement trend					
	back to N					
2.15						0.174
2.16						
2.17						
2.18						
2.19			Static			
2.2			Yes Yes Yes	Yes		0.347
2.21						
2.22						
2.23			No static			
2.24						
2.25						0.487
2.26						
2.27						
2.28		Posture changes				
		back to N				
2.29		Increased				
		motion				
2.3			Yes Yes Yes	Yes		0.307
2.31						
2.32						
2.33						
2.34						
2.35						0.538
2.36			Yes Yes Yes	Yes		
2.37						
2.38						
2.39						
2.4						0.425
2.41						
2.42		Posture moves to				
		to L and stays				
2.43						
2.44						

2.45					0.316
2.46					
2.47			Increased	yes yes yes	
			motion		
2.48	Motion trend				
	towards L				
2.49					
2.5	Posture change				
	back to N				

Table 5: Flow chart of Spinal movements, acceleration and EMG for Test 3

Time	Frontal	Torsional	Sagittal	Ch 1	Ch 2	Ch 3	Ch 4	Az
0								
1								
2								
3								
4								
5								0.372
6								
7								
8								
9	Start	Start	Start					
10								0.361
11	Posture from	Increased						
	L of N	motion						
12	to R of N			max	max	max	max	
13	Inc Motion	Posture		max	max	max	max	
		change to R						
14								
15								0.43
16								
17								
18		Posture						
		gradually						
19		towards N						
20								0.437
21	Posture		Posture					
	gradually to L		gradually					
22	of N		flexed	Yes	Yes	Yes	Yes	
23		Lg posture						
		change to R						
24								
25				Max	Max	Max	Max	0.445
26	Stays L of N			Max	Max	Max	Max	
	until 1:14							
27			Very static	Max	Max	Max	Max	
			until 1:12					

28								
29								
30						0.342		
31								
32								
33								
34		Increased						
		motion						
35						0.312		
36								
37								
38								
39								
40						0.267		
41								
42				Yes	Yes	Yes	Yes	
43								
44								
45								0.359
46								
47								
48								
49								
50								0.459
51				Yes	Yes	Yes	Yes	
52								
53								
54								
55								0.43
56								
57								
58		Posture						
		change						
		to R						
59		Lg inc						
		motion						
1								0.405
1.01				Yes	No	Yes	No	
1.02								

1.03							
1.04							
1.05							0.367
1.06							
1.07							
1.08							
1.09							
1.1							0.376
1.11							
1.12	Posture moves	Increased	Lg increase				
	to N	motion	of motion				
1.13			Very static	Yes	Yes	Yes	Yes
			until 1:48				
1.14							
1.15							0.33
1.16							
1.17	Increased			Max	Max	Max	Max
	motion						
1.18	Posture change	Posture change					
	R to N	towards N					
1.19		Increased					
		motion					
1.2							0.322
1.21							
1.22				Yes	Yes	Yes	Yes
1.23				Yes	Yes	Yes	Yes
1.24							
1.25							0.347
1.26							
1.27	Posture change			No	Yes	Yes	No
	N to L						
1.28	and back to N						
1.29							
1.3		Increased					0.343
		motion					
1.31	Posture moves to						

1.32	to L of N							
1.33				Yes	Yes	Yes	Yes	
1.34								
1.35		Increased						0.383
		motion		Max	Max	Max	Max	
1.36	Remains L							
	of N until							
1.37	2:04							
1.38		Very static						
		to 2:04						
1.39								
1.4								0.391
1.41								
1.42				Yes	Yes	Yes	Yes	
1.43								
1.44								
1.45								0.341
1.46								
1.47								
1.48			Increased					
			motion					
1.49				Yes	Yes	Yes	No	
1.5								0.361
1.51								
1.52								
1.53				Yes	Yes	Yes	No	
1.54								
1.55								0.381
1.56								
1.57								
1.58				No	Yes	Yes	Yes	
1.59								
2								0.375
2.01								
2.02								
2.03	Posture from							
	L to N							
2.04		Sm posture						
2.05		change to R	Increased					0.397

2.06	Posture from		motion				
	N to L						
2.07				Max	Max	Max	Max
2.08			Increased	Max	Max	Max	Max
			motion	Max	Max	Max	Max
2.09				Max	Max	Max	Max
2.1	Relatively static		Increased	Max	Max	Max	Max
	until end		motion				0.77
2.11			Posture becomes	Max	Max	Max	Max
			more flexed				
2.12				Max	Max	Max	Max
2.13				Max	Max	Max	Max
2.14							
2.15			Increased				0.396
			motion				
2.16				Yes	Yes	Yes	Yes
2.17			Very static				
2.18			until end.				
2.19							
2.2							0.45
2.21							
2.22				Yes	Yes	Yes	Yes
2.23				Yes	Yes	Yes	Yes
2.24							
2.25							0.351
2.26							
2.27							
2.28							
2.29							
2.3							0.378
2.31		Posture					
		change to R					
2.32		Increased					
		motion					
2.33							
2.34							
2.35							0.439

2.36								
2.37								
2.38								
2.39		Posture change						
		towards N						
2.4		Lg increase						0.476
		of motion						
2.41								
2.42								
2.43				Yes	Yes	Yes	Yes	
2.44								
2.45								0.474
2.46								
2.47								
2.48								
2.49								
2.5				Yes	Yes	Yes	Yes	0.448

Discussion:

Muscle Activity: Flex-Comp Infinity software was used to examine the activity of muscles while the subject was driving the tractor-trailer provided by National Seating, Vonore, Tennessee. The electromyographic study is very useful for truck manufacturers to efficiently design the seats, suspensions, etc., considering the comfort of the drivers. Lower back discomfort, potential spinal degeneration, etc., are frequently reported by many drivers which may relate to muscle fatigue and dehydration of the spinal disk. The raw data was recorded and analyzed by developing a Matlab code. The raw data collected using the Flex-Comp Infinity system was read and mean frequency, RMS frequency, median frequency, etc., were calculated. Cellular phones, portable phones, wireless networking devices and other devices which intentionally radiate RF energy caused interference with the signals [55]. It was observed that there were a few sudden shifts in the signals acquired which was due to the interference of RF energy. The RMS values figures obtained are displayed as 6.1a, 6.2a, 6.3a for each test. Each subplot in the graph represents one channel. Channel 1 represents the RMS data of the erector spinae (right hand side) muscle activity, channel 2 represents the erector spinae (left hand side) muscle, channel 3 represents the gluteus medius muscle and channel 4 represents the rectus abdominis. It is observed that the activity of the erector spinae muscle is higher, and the gluteus muscle activity is observed to be the lowest. Hence, it is observed that the pelvis motion is not a major factor for lower back pain and a good seat design reduces the affect of vibration on the pelvis. The degree of activation of each muscle is examined and correlated with ultrasonic results which explain the comfort of the driver and also correlates with the acceleration data. The correlation results are discussed below.

Muscle Fatigue: The fatigue of the muscle can be explained by observing the mean frequency figures. Table 6 shows the comparison or muscle fatigue rates of different core muscle related to spinal motion.

Table 6: Comparison of rate of fatigue in different muscles

	Test 1	Test 2	Test 3
Ch 1	Fatigue observed after 1hr 20mins, activation increased after 10mins to normal	Complete fatigue observed after every 1hr and got back less than 5mins	Fatigue observed after 1hr lasted for 10mins
Ch 2	Fatigued after 1hr 20 minutes, immediately increased activation to normal	Completely Fatigued after 1hr 10mins, lasted for nearly 10mins	Fatigue observed after 1hr and lasted for 10mins
Ch 3	Fatigued after 1hr 10mins and got back after about 10mins	Fatigue observed after 1hr and lasted for 10mins	Fatigue seen after an 1hr 40min and got back after 10mins
Ch 4	Fatigue observed after 1hr and activation is normal less than 10mins	Fatigued after 1hrs 40mins and lasted for 10-15mins	Fatigue seen after every 1hr 40mins and lasted for 5mins.

Correlation with the ultrasonic and EMG results: The EMG results are observed to be interrelated to ultrasonic results and acceleration data. The degree of muscle activation is observed by plotting the RMS value vs time. The activation of muscle is observed if the ISO 2631 filtered acceleration is greater than .300 and is attenuated with increased motion. Table 7 shows the ISO reactions and rating scale for different acceleration. The table shows that subject is uncomfortable for the acceleration values higher than 0.315. The same results are evidenced from the present study. It is reportedly seen that the activation of muscle is observed sometime later than the acceleration input, which may be due to the high input to the brain, due to which the muscles are tightened up converting into springs. The relaxed muscle acts as dampers whereas the tightened muscle act as springs, and it takes some time for tightened muscles to move. It is also observed that when the right muscles were activated due to high acceleration input, the driver unknowingly changed the body posture to the right due to discomfort. It is also observed that the activity of muscle is maximum when the acceleration input is maximum and vice versa. The muscle always responded to the increased motion and often responded to the acceleration inputs. Hence, the EMG activity correlated with ultrasonic results 75% of the time and is 60% correlated with acceleration input data. The accuracy of the correlation can be increased if more testing bouts are conducted for a longer time.

Table 7: ISO likely reactions and rating Scale

WBV, m/s^2	Likely Reaction, ISO	Perception
<0.315	Not uncomfortable	Very good
0.315-0.63	Slightly Uncomfortable	Good
0.5-1	Fairly uncomfortable	Fair
0.8-1.6	Uncomfortable	Poor
1.25-2.5	Very Uncomfortable	Very Poor
>2	Extremely Uncomfortable	Extremely Poor

Source: [4]

7. CONCLUSIONS AND FUTURE WORK

Three actual testing trials were performed to analyze the activity of muscle when exposed to WBV. The following are the conclusions that can be drawn from the present research

- The Flex-Comp Infinity can be used ideally for recording real-time large data sets of muscle activity for long periods of time while driving the truck.
- The device seems to be very comfortable and easy to mount on the driver with no side effects or discomfort to the driver's routine.
- The electromyographic technique is highly recommended to manufacturers for carrying out research before manufacturing the driver and passenger's seats in order to reduce various health issues.
- The EMG data showed approximately 70% correlation with ultrasonic results and 60% correlation with acceleration data.
- The muscle fatigue was observed after 1 hr 40 min-2 hr, and lasted for 10 min. Hence, the driver can be recommended to stop the vehicle after every 2 hr of driving.
- It is observed from the Table 3,4,5 that the muscle was activated more when there was postural change combined with the increase in acceleration and vice versa.
- The driver should improve his postures when the road is rough or the suspension of the seat is bad, which may give rise to high accelerations, in order to avoid long-term health problems.
- The present study's results are very useful for truck manufacturers in order to design suspension systems, seats, etc.

- The acceleration input is high when the road is rough and low when the road is smooth, so muscle activity is high on rough roads and low on smooth roads.
- An increased tension in the muscle was observed where the muscle tried to support the spinal position results in decreased spinal motion.
- It is observed from the correlation sheet that the response of the muscle to vibration was delayed a few minutes, which may be because the effects of the acceleration input on the spinal comfort may take a few minutes for the brain to respond to it.
- The muscle behaved like springs and tightened up during the rapid inputs, so that movement was observed to be less than that of relaxed muscles.
- Muscle activation was observed during the postural changes. However, high amount of activation was observed when the vibration acceleration was combined with it.
- Proper actions should be taken in order to avoid muscle fatigue by taking breaks for 10 mins after 2 hr of driving, which is mandatory for all drivers in Europe.
- Further research in this area may be useful to further reduce some serious effects of WBV.
- Various factors can be changed such as type of seat, type of truck, environmental conditions, etc., in order to examine the changes of muscle activation.
- There was some interference observed while the driver was using a cell phone or radio, hence care should be taken in future to completely avoid the interference.
- Further research can be done on the various driver postures when the vibration accelerations are high in order to avoid high muscle activations.

- Many more long driving tests should be carried out to improve the accuracy of EMG and also to better correlate with ultrasound results.
- Further testing can be done with the two or more breaks in driving long distances in order to examine the muscle activation when the muscle is reactivated after relaxation.

Research can be carried out not only on the effect of WBV on muscles related to the lumbar spine and back disorders, but also on the muscles related to neck and shoulder disorders, as many drivers also report serious impact on their health.

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APPENDIX

APPENDIX

Matlab code

```
% EMG data processing

close all;
clear all;
home;
fs=2048;
time=1200;
D=struct('time',time);
A=zeros(fs,time,4);
for k=1:4
CC=cell2mat(struct2cell(load('new1',['Column',num2str(k)]))));
b=['Column',num2str(k)];
j=1;
for i=0:2048:fs*time-2048
    A(:,j,k)=CC(i+1:i+fs);
    j=j+1;
end
end
clear Column1 Column2 Column3 Column4 CC C
for i=1:1200
    xx1=A(:,i,1);
    xx2=A(:,i,2);
    xx3=A(:,i,3);
    xx4=A(:,i,4);
    % Taking the mean out from those signals
    x1=xx1-mean(xx1);
    x2=xx2-mean(xx2);
    x3=xx3-mean(xx3);
    x4=xx4-mean(xx4);
    % defining no. of points, sampling freq, time and freq series
    Npt=2048;
    fs=2048;
    fc1=750;
    fc2=5;
    dt=1/fs;
    df=1/(dt*Npt);
    time=[0:Npt-1]*dt;
    freq=[0:Npt-1]*df;
    % Design of lowpass filter

    wf1=2*fc1/fs;
```

```

[a b]=butter(4,wf1,'low');
y1=filter(a,b,x1);
y2=filter(a,b,x2);
y3=filter(a,b,x3);
y4=filter(a,b,x4);

% Design of hihpass filter
wf2=2*fc2/fs;
[w v]=butter(4,wf2,'high');
z1=filter(w,v,y1);
z2=filter(w,v,y2);
z3=filter(w,v,y3);
z4=filter(w,v,y4);
% Taking FFT
X1=abs(fft(x1));
X2=abs(fft(x2));
X3=abs(fft(x3));
X4=abs(fft(x4));
Y1=abs(fft(y1));
Y2=abs(fft(y2));
Y3=abs(fft(y3));
Y4=abs(fft(y4));
Z1=abs(fft(z1));
Z2=abs(fft(z2));
Z3=abs(fft(z3));
Z4=abs(fft(z4));
% % Calculate Mean Frequency
s_num1=0.0;
s_num2=0.0;
s_num3=0.0;
s_num4=0.0;
s_den1=0.0;
s_den2=0.0;
s_den3=0.0;
s_den4=0.0;
for ii=1:fs/2
    s_num1=s_num1+freq(ii)*(z1(ii))^2*df;
    s_den1=s_den1+(z1(ii))^2*df;
    s_num2=s_num2+freq(ii)*(z2(ii))^2*df;
    s_den2=s_den2+(z2(ii))^2*df;
    s_num3=s_num3+freq(ii)*(z3(ii))^2*df;
    s_den3=s_den3+(z3(ii))^2*df;
    s_num4=s_num4+freq(ii)*(z4(ii))^2*df;
    s_den4=s_den4+(z4(ii))^2*df;
end

```

```

mnf1(i)=(s_num1/s_den1);
mnf2(i)=(s_num2/s_den2);
mnf3(i)=(s_num3/s_den3);
mnf4(i)=(s_num4/s_den4);
% % Calculation of RMS Value
z1sq=z1.^2;
z2sq=z2.^2;
z3sq=z3.^2;
z4sq=z4.^2;
n=size(z1sq);
Rms1(i)=sqrt(sum(z1sq)/n(1));
Rms2(i)=sqrt(sum(z2sq)/n(1));
Rms3(i)=sqrt(sum(z3sq)/n(1));
Rms4(i)=sqrt(sum(z4sq)/n(1));
end
disp('program finished')

Mean=[mnf1' mnf2' mnf3' mnf4'];
M=mean(Mean)
RMS=[Rms1' Rms2' Rms3' Rms4'];
R=mean(RMS);
figure(7);
subplot(2,2,1);
t1=0:1200-1;
plot(t1,mnf1);
title('Mean Frequency Graph of Right Erector Spinae Muscle activity data');
Xlabel('Time(sec)');
Ylabel('Mean Frequency(Hz)');
grid;
hold on;
subplot(2,2,2);
plot(t1,mnf2);
title('Mean Frequency Graph of Left Erector Spinae Muscle activity data');
Xlabel('Time(sec)');
Ylabel('Mean Frequency(Hz)');
grid;
hold on;
subplot(2,2,3);
plot(t1,mnf3);
title('Mean Frequency Graph of Gluteus Medius Muscle activity data');
Xlabel('Time(sec)');
Ylabel('Mean Frequency(Hz)');
grid;
hold on;
subplot(2,2,4);

```

```

plot(t1,mnf4)
title('Mean Frequency Graph of Rectus Abdominus Muscle activity data');
Xlabel('Time(sec)');
Ylabel('Mean Frequency(Hz)');
grid
hold on;
figure(9);
subplot(2,2,1);
t1=0:1200-1;
plot(t1,Rms1);
title('RMS Graph of Right Erector Spinae Muscle activity data');
Xlabel('Time(sec)');
Ylabel('RMS Value(Hz)');
grid;
hold on;
subplot(2,2,2);
plot(t1,Rms2)
title('RMS Graph of Left Erector Muscle activity data');
Xlabel('Time(sec)');
Ylabel('RMS Value(Hz)');
grid
hold on;
subplot(2,2,3);
plot(t1,Rms3)
title('RMS Graph of Gluteus Medius Muscle activity data');
Xlabel('Time(sec)');
Ylabel('RMS Value(Hz)');
grid
hold on;
subplot(2,2,4);
plot(t1,Rms4)
title('RMS Graph of Rectus Abdominus Muscle activity data');
Xlabel('Time(sec)');
Ylabel('RMS Value(Hz)');
grid
hold on;

```

Questionnaire

Pre experiment results

1. Sex:
2. Age:
3. Weight:
4. Height:
5. BMI:
6. Back Pain History:

Equipment Information:

1. Truck made:
2. Load on the truck:
3. Seat type:

Post Experiment Results

1. Distance covered:
2. Route:
3. Road conditions:
4. Was device bothersome?
5. Was the equipment interfering with your normal routine?
6. Did the testing equipment limit your normal movement?

Notes:

VITA

Harini Mangavelli was born in Hyderabad, A.P, India on May 20th, 1982. She received her B.S. in Mechanical Engineering at Jawaharlal Nehru Technological University, Hyderabad, A.P, India graduating in May 2003. In the year 2003 Harini joined Kilroy India Pvt Ltd, Hyderabad, India as a Design Engineer. In January 2005 she moved to the United States to further her education, and in December, 2007 Harini Mangavelli received her Masters in Mechanical Engineering from the University of Tennessee, Knoxville.