Whole body vibrations on the low back using a suspension versus non-suspension seat post during off-road cycling
by Laura Michelle Stanley

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial and Management Engineering
Montana State University
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Abstract:

Mountain bikes were introduced nearly two decades ago and have since become the number-one type of bicycle sold in America. Nearly every major bicycle manufacturer now offers many types of suspensions systems. The rationale behind a suspension system is that it provides: (a) increased comfort levels, (b) decreased fatigue, and (c) fewer injuries. However, many of these claims are purely anecdotal and are not based on scientific evidence. Accordingly, more quantitative measures need to be taken to assess the effect of bicycle shock absorption systems on skeletal loading, muscle fatigue, and potential injury. The objective of this study was to compare the effects of a suspension and a non-suspension seat post on whole body vibration energy and muscle activity in the lumbar and abdominal muscles during off-road cycling in recreational cyclists. A randomized block ANOVA with repeated measures was used to document the effects of seat condition over one hour riding in off-road conditions. Acceleration of the seat and EMG activity of abdominal and low back muscles were recorded. The findings of this study indicate that there were no significant ($p > 0.05$) differences in muscle activity (peak amplitude, median frequency, and 95% of frequencies) between the seat post treatments. The suspension seat post did not significantly reduce total vibration energy ($p = 0.816$) or the total vibration energy ($p = 0.412$) during impact with the simulated obstacles, though the suspension seat post significantly ($p = 0.02$) reduced peak accelerations by up to 27%. Furthermore, an early indication of muscular fatigue was observed in the low back and abdominal muscle regions during the riding sessions based upon EMG frequency analysis. A 10% decrease in median frequency was observed during both riding sessions. This study suggests that the suspension seat post's ability to reduce peak accelerations will prolong the time at which the onset of muscular fatigue occurs. It is believed that muscle fatigue of the core muscles may contribute to low back pain. Any delay in the reduction in muscle power might result in less or no low back pain. Additionally, reducing peak accelerations will place less strain on the spinal structures with the anticipation of reducing any cervical, dorsal, or lumbar back pain or injury. As an off-road cyclist, the Rock Shox suspension seat post would be health beneficial because of its characteristics in reducing peak accelerations.

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MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Mountain bikes were introduced nearly two decades ago and have since become the number-one type of bicycle sold in America. Nearly every major bicycle manufacturer now offers many types of suspensions systems. The rationale behind a suspension system is that it provides: (a) increased comfort levels, (b) decreased fatigue, and (c) fewer injuries. However, many of these claims are purely anecdotal and are not based on scientific evidence. Accordingly, more quantitative measures need to be taken to assess the effect of bicycle shock absorption systems on skeletal loading, muscle fatigue, and potential injury. The objective of this study was to compare the effects of a suspension and a non-suspension seat post on whole body vibration energy and muscle activity in the lumbar and abdominal muscles during off-road cycling in recreational cyclists. A randomized block ANOVA with repeated measures was used to document the effects of seat condition over one hour riding in off-road conditions. Acceleration of the seat and EMG activity of abdominal and low back muscles were recorded. The findings of this study indicate that there were no significant ($p > 0.05$) differences in muscle activity (peak amplitude, median frequency, and 95% of frequencies) between the seat post treatments. The suspension seat post did not significantly reduce total vibration energy ($p = 0.816$) or the total vibration energy ($p = 0.412$) during impact with the simulated obstacles, though the suspension seat post significantly ($p = 0.02$) reduced peak accelerations by up to 27%. Furthermore, an early indication of muscular fatigue was observed in the low back and abdominal muscle regions during the riding sessions based upon EMG frequency analysis. A 10% decrease in median frequency was observed during both riding sessions. This study suggests that the suspension seat post's ability to reduce peak accelerations will prolong the time at which the onset of muscular fatigue occurs. It is believed that muscle fatigue of the core muscles may contribute to low back pain. Any delay in the reduction in muscle power might result in less or no low back pain. Additionally, reducing peak accelerations will place less strain on the spinal structures with the anticipation of reducing any cervical, dorsal, or lumbar back pain or injury. As an off-road cyclist, the *Rock Shox* suspension seat post would be health beneficial because of its characteristics in reducing peak accelerations.

CHAPTER 1

INTRODUCTION

Mountain bikes were introduced nearly two decades ago and have since become the number-one type of bicycle sold in America (Berry and Woodward, 1993). This popularity has been accompanied by industry wide research and development, which has in turn produced numerous technological innovations. For example, nearly every major bicycle manufacturer now offers many types of suspensions systems. The rationale behind a suspension system is that it provides: (a) improved control of the bicycle, (b) increased comfort levels, (c) decreased fatigue, (d) fewer injuries, and (e) increased enjoyment. However, many of these claims are purely anecdotal and are not based on scientific evidence. Accordingly, more quantitative measures need to be taken to assess the effect of bicycle shock absorption systems on skeletal loading, muscle fatigue, and potential injury.

The possibility that suspension systems can prevent injuries and/or reduce fatigue is of paramount importance. According to Berry and Woodward (1993), 30-70 % of cyclists suffer from cervical, dorsal, or lumbar back pain. Although the current scientific evidence is not conclusive, a recent review of epidemiological and laboratory studies by Wilder and Pope (1996) indicates that a relationship exists between whole body vibrations and low back pain. Vibrations at lower accelerations have been suggested to cause fatigue failures in the discs of the spine, while large vertical accelerations cause

spine fractures during repetitive compression (Sandover 1981, 1983). If vibration is reduced with a suspension system it may be possible to decrease the risk of low back pain and injury during cycling.

The lumbar and abdominal muscles are used to stabilize the pelvis on the bicycle seat while in a bent over position and are a crucial component to efficient power transfer between the upper and lower body during cycling. Hence, if the lumbar and abdominal muscles begin to fatigue during off-road cycling, a reduction in muscle power should result. This reduction in muscle power induces discomfort and pain, and, in the long term, is believed to contribute to low back pain, hence making the quantification of fatigue extremely relevant.

Objective Statement

The objective of this study is to compare the effects of a suspension seat post and a non-suspension seat post on whole body vibration energy and muscle activity in the lumbar and abdominal muscles during off-road cycling in recreational cyclists.

Hypotheses

The following null hypotheses will be tested:

- 1) There is no significant difference in whole body vibration energy of acceleration (root-mean-square) or peak acceleration during non-suspension seat post and suspension seat post use:

$$H_0: u_1 = u_2$$

$$H_a: u_1 \neq u_2$$

Where u_i , i = seat post condition (1 = non-suspension seat post, 2 = suspension seat post).

- 2) There is no significant difference in whole body vibration energy of acceleration (root-mean-square) or peak acceleration during either non-suspension seat post or suspension seat post use over time:

$$H_o: u_1 = u_2 = u_3 = u_4$$

$$H_a: u_1 \neq u_2 \neq u_3 \neq u_4$$

Where u_i , i = cycling time (1 = 15 minutes of cycling duration, 2 = 30 minutes cycling duration, 3 = 45 minutes of cycling duration, 4 = 60 minutes of cycling duration).

- 3) There are no significant differences in EMG activity (peak amplitude, median frequency, 95% of frequencies) of the core muscles, lumbar and abdominal muscles, during non-suspension seat post and suspension seat post use:

$$H_o: u_1 = u_2$$

$$H_a: u_1 \neq u_2$$

Where u_i , i = seat post condition (1 = non-suspension seat post, 2 = suspension seat post).

- 4.) There are no significant differences in EMG activity (peak amplitude, median frequency, 95% of frequencies) of the core muscles, lumbar and abdominal muscles, during non-suspension seat post and suspension seat post use over time:

$$H_0: u_1 = u_2 = u_3 = u_4$$

$$H_a: u_1 \neq u_2 \neq u_3 \neq u_4$$

Where u_i , i =cycling time (1=15 minutes of cycling duration, 2=30 minutes cycling duration, 3=45 minutes of cycling duration, 4=60 minutes of cycling duration).

Delimitations and Limitations

There are two primary delimitations to this study. First, the study was delimited to female recreational cyclists. Recreational cyclists are those who ride occasionally, approximately one to five hours per week, and are not competitive cyclists. Second, all testing was conducted under simulated conditions. These conditions were designed to simulate off-road cycling, but exact off-road conditions were near impossible to mimic. The major limitations of this study are due to the equipment used to measure muscle activity. Since the electromyogram (EMG) electrodes were applied to the surface of the skin, movement of the equipment on the skin was an inherent error, although every precaution was taken to minimize this error. Also, this study was limited to only a small

group of female recreational cyclists. Other groups, such as male cyclists, professional cyclists, beginner cyclists, etc. were not included.

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this study was to compare whole body vibrations sustained to the lower back during suspension seat post and non-suspension seat post use during off-road cycling. No known studies have analyzed this particular situation in the off-road cycling setting, yet many studies have been conducted on the impact of vibrations on the lower back in an occupational setting. The following presents a background of characteristics of whole body vibration in the human body, studies on whole body vibration's effects on the lower back, measurements and quantifications of vibrations, muscle activity during exposure to vibrations, and the International Standard Organization (ISO) standards and guideline recommendations.

Characteristics of Whole Body Vibration in the Human Body

Whole-body vibration is known to affect human performance, health, and safety; so far, research is lacking a clear source of which outcome variables to measure when assessing whole-body vibration exposure. Current literature on the effect of prolonged exposure to whole-body vibration demonstrates the increased risk of developing back disorders. In the occupational setting, whole-body vibration usually occurs in combination with other risk factors, such as poor posture and prolonged sitting.

The following vibration factors influence the potential for injury to the human: frequency, amplitude, acceleration, duration and direction of vibration, contact of vibration to body, body posture and muscle tension. Of these, the main parameters are the frequency acceleration, velocity, and displacement of the vibration. When the human body is exposed to vibration some kinetic and potential energy is absorbed by the body's mechanized system, resulting in a dampening and loss of potential energy. When the transfer of kinetic energy to potential energy occurs, dampening by the body's tissues and organs and the muscle surrounding the tissues and organs compensates by causing voluntary and involuntary contractions, potentially leading to localized muscle fatigue (Chaffin and Anderson, 1991).

When the frequency of excitation coincides with the natural frequency of the system or person amplitudes add together and create large oscillations, called resonance. Resonance can create potentially harmful stresses to the body, by increasing the spinal load, which results in fatigue injury of the passive spinal structures (Hansson and Holm, 1991) and a nutritional deficiency in the intervertebral discs (Dickerson, 1991). When the body is positioned vertically, vertical vibrations in the 5-10 Hz range generally cause resonance in the thoracic-abdominal system. Panjabi (1986) found that vibrations in the 2-30 Hz range are where most body tissue resonance occurs and that the average resonant frequency of the lumbar vertebrae is 4.4 Hz. Furthermore, it has been determined that vibrations between 2.5 and 5 Hz generate strong resonance in the vertebra of the neck and lumbar region with amplification of up to 240%. Between 4 and 6 Hz resonances are set up in the trunk with amplification of up to 200% (Ergonomics Technologies,

http://www.ergotech.co.za/vib_wbv.htm, accessed April 2002). For other postures, different resonance frequencies are expected, but little is known.

The importance of resonance can be found in the situation of driving a vehicle, where spectral components of 4-8 Hz frequencies occur; these vibrations reach the operator's spine via the driver's seat, then the spine will most likely involuntarily respond by actually amplifying and exacerbating the effects of the whole body vibration exposure. Our body has the ability to compensate the exposure by selecting, accepting, and amplifying certain vibration frequencies over others. When the body proceeds to select, accept, or amplify certain vibration frequencies an exacerbation effect can occur, resulting in more harm to the body. Beyond resonance, whole-body vibration exposure can cause horizontal shifting, rotation, and torsional movements in the spinal segments resulting in wear and tear of the outer ring of the intervertebral discs. From years of exposure early degeneration of the discs can result.

Studies on Whole Body Vibration's Effects on the Lower Back

A study conducted at Projekt-WELLCOM in Germany found that the lower back is the most vulnerable part of the human body while riding a bicycle (Projekt-WELLCOM, <http://www.projekt-wellcom.de/>, accessed April 2002). Their data collection during the *Transalp Challenge Race*, included 620 kilometers of 20,300 meters of vertical gain in eight days where they measured the gravitational forces ($1\text{ g} = 9.8\text{ m/sec}^2$) while riding on a fully suspended bicycle (suspension on front and rear) and a hard-tail bicycle (front suspension and no rear suspension). The researchers found that the full

suspension bike reduced accelerations by 23.3 % compared to the hard-tail bicycle over the entire race. Furthermore, the subjects were experiencing shock impacts of 13.4 g's while riding a hard-tail bike. In addition to measuring acceleration, the researchers split the body into two parts: upper body and the back. The researchers found that the upper body, including the arms, shoulders and neck, demonstrates a very strong support system of tissue and muscles resulting in a better suspension absorption system than the back. In the back, they found the erector spinae was used only to keep the spine straight while demonstrating no support of the vertebra. Because of the lack in support by the erector spinae, vibrations traveled directly into the lower back.

When comparing the *Rock Shox* suspension seat post and a fully suspended bicycle (suspension on front and rear) to a hard tail, Project-WELLCOM researchers found that the suspension seat post reduced shocks by up to 24% and 33%, respectively. On the downhill portions, where the riders were mostly standing and the legs do most of the shock absorption, the researchers saw a 20% reduction of vibration in the full-suspension versus the hard-tail. Furthermore, based on health-standards for shock forces, the hard-tail design exceeded recommendations by up to 30%.

The literature concerning the effects of whole-body vibration on the human body in an occupational setting are more numerous than in the sports setting. Frymoyer et al. (1980) found that patients experiencing low back pain tend to be employed in occupations that involve whole-body vibration exposure. Wilder and Pope (1996) also found a clear relationship between exposure to vibration and low-back disorders. Drivers of trucks (Kelsey and Hardy, 1975; Gruber, 1976; Frymoyer et al., 1980), of tractors

(Dupuis and Christ, 1972; Bovenzi and Betta, 1994), of heavy-equipment (Spear and Keller, 1976), of buses (Gruber and Ziperman, 1974; Kelsey and Hardy, 1975; Bpvenzi and Zadini, 1992), and airplane pilots (Fitzgerald and Crotty, 1972) have all experienced an increased risk of low back pain due to various frequencies and peak accelerations during vibration exposure.

Studies done by Kitazak and Griffm (1998), found a decrease in resonance frequency when subjects switched from an erect position to a slouching position, suggesting that the greater risk of back problems may be from the bending deformation of the spine when it is subjected to vibrations less than the 10 Hz range. Furthermore, it is well known that large vertical accelerations cause spine fractures, while smaller accelerations have been suggested to cause fatigue failures in the discs of the spine; these vibrations interfere with the nutrition of the disc, ultimately resulting in premature degenerative changes (Sandover 1981, 1983).

Dupuis and Zerlett (1987) reported that two-thirds of operators of earth-moving vehicles complained about spinal discomfort. Further examining these operators they found that operators with at least ten years of vibration exposure showed the occurrence of morphological changes in the lumbar spine much earlier than in non-exposed persons. Troup (1988) reviewed epidemiological and clinical studies and found that those who spend more than half of their working lives driving a motor vehicle were three times more likely to suffer back trouble than the rest of the population. Seidel and Heide (1996) further established that there is an increase in musculoskeletal disorders of the back after intense long-term exposure to whole-body vibrations.

Additional studies have been conducted in the attempts to reduce vibration exposure. Griffin (1978) reported that factors such as the suspension characteristics of the vehicle, nature of the road/track surface, vehicle speeds and the vibration attenuation characteristics of the seat influence vibration levels experienced by vehicle operators. Wasserman (1995) concluded that proper use of newer technologies such as active vibration control in conjunction with an improved seat design could substantially reduce the vibration exposure experienced by vehicle operators. The results of these reports indicated the resonance of the human body depended on various factors: posture, the materials of the seat surface, vibration magnitude and frequency.

Measurement and Quantification of Vibrations

The most widely used standard in assessing whole-body vibration exposure is the ISO 2631 (1985) document prepared by the International Organization for Standardization. The need to standardize whole-body vibration measurement and evaluation techniques led to the development of the ISO 2631. The standard provides acceptable exposure limits based on four physical factors of primary importance in determining the human body's response to whole-body vibration: intensity, frequency, direction, and duration of vibration exposure. The document provides a tri-axial coordinate system to measure whole-body vibrations, using assumptions that human tolerance to vibration differs for vibrations of different frequencies, and that within a 24-hour time span human tolerance decreases. The standard sets three exposure limits according to three criteria: (1) reduced comfort boundary (preserving comfort), (2)

fatigue-decreased proficiency or FDP boundary (working efficiency); and (3) exposure limit (health and safety). The guidelines recommend quantifying frequency analysis using a third octave bandwidth with spectrum frequencies 1 to 80 HZ. The levels for the fatigue-decreased proficiency limits for various vibration exposures are given in diagrams of vertical acceleration versus frequency diagrams, as shown in Figure 1.

Both the reduced comfort and exposure health limits are based on the fatigue-decreased-proficiency limits; by dividing the fatigue-decreased-proficiency limits by 3.15, reduced comfort boundary can be determined; multiplying the proficiency limits by two, the exposure limit can be obtained. For example, if the whole body vibration energy of vertical acceleration (m/s^2) for a particular task was measured to be 4 m/s^2 at a frequency of 2 Hz, then based on the diagram shown in Figure 1, the limit for the fatigued-decreased-performance proficiency would be for no longer than one minute of whole body vibration exposure for that particular task. To obtain the exposure health limit, the proficiency limit of one-minute would be multiplied by two, resulting in an exposure limit of two minutes. Furthermore, by dividing the fatigue-decreased-proficiency limits by 3.15 ($1 \text{ minute} / 3.15 = 19 \text{ seconds}$) the reduced comfort limit equals 19 seconds of exposure.

Frequency or Center Frequency of Third-Octave Band, Hz

Figure 1. Limits for equal fatigue-decreased-performance proficiency. For vertical vibrations in third-of-an octave band (Hz) (From ISO 2631).

Of the four main parameters for quantifying vibration, acceleration is almost exclusively used to quantify magnitudes of vibration. The following equation, using the first derivative of the velocity function, gives the acceleration function:

$$a(t) = \omega^2 X \sin(\omega t + \pi)$$

where, X = Peak amplitude (in meters), ω = angular frequency = $2\pi f$ (in radians per second), and t = time in seconds

Frequently, the total amount of energy of the vibration is calculated as the Root-Mean-Square (RMS) of acceleration, where:

$$X_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T X^2(t) dt}$$

where: T =cycle time, X = instantaneous amplitude of vibration

Muscle Activity During Vibration Exposure

Surface electromyogram (EMG) is often used in assessing muscular fatigue in occupational field studies (Luttman, Jager, and Laurig, 1999). EMG is used to examine muscular reactions as a conventional non-invasive method because direct measurement of the back and abdominal muscle activity is impossible. Muscle fatigue is defined as “any reduction in the ability to exert force in response to voluntary effort” (Edwards, 1981; Bigland-Ritchie et. al. 1995). Since muscle fatigue reduces muscle power, induces discomfort and pain, and, in the long term, is believed to contribute to low back pain, it is important to quantify fatigue. Thus, if the muscles used to support the back, i.e. abdominals and erector spinae, during off-road cycling begin to demonstrate a fatigued state, then a possibility of acute or long-term low back pain might result.

During sustained or repetitive muscle contractions, as needed in off-road cycling, typical changes in EMG, including an increase in amplitude and/or shift in the frequency

spectrum towards lower frequencies, can be observed. Ergonomists agree that the onset of fatigue occurs at a minimum of 10% shift in the median frequency (Chaffin, 1999). In occupational electromyography, such EMG changes are commonly interpreted as indicators of muscular fatigue (Chaffin, 1973; Herberts, Kadefors, & Broman, 1980; Hagberg, 1981; Hansson et al., 1992; Kim Oberg et al., 1994). When a muscle is rested, the mean frequency of the myoelectric signal may be twice that found when the muscle is fatigued (Stulen & de Luca, 1979; Lindstrom, Kadefors, & Pertersen, 1977). The most often used measures to characterize EMG power spectral distributions are the median (Stulen & De Luca, 1981) and the mean power frequencies (Kwatny et al., 1970).

Studies performed by Seroussi et al. (1987); Pope et al. (1988); Zimmerman and Cook, (1997) found that specific trunk muscles demonstrate a cyclic EMG activity. They also found that significantly higher EMG activities existed during vibration as opposed to static moment loads on the torso. Furthermore, Magnuss et al. (1988) and Hansson et al. (1991) found an increase in erector spinae fatigue during whole-body vibrations. These studies were conducted in laboratory conditions where subjects were placed on a platform designed to study whole-body vibration effects while seated. Furthermore, a 10-percent decrease in the surface EMG spectrum median frequency obtained during sub-maximal isometric contractions of the erector spinae muscles has also been associated with the risk of developing low back pain (Mannion, 1997).

Siedel's (1988) studies demonstrated that during vertical sinusoidal vibration at very low frequencies (0.315-5 Hz), as in bicycling, there is a synchronized response in EMG of the erector spinae muscle at the lumbar level. Bonger et al. (1990) further

suggested that the cyclic response of the erector spinae in response to whole-body vibration might lead to muscle fatigue, causing low-back pain in such occupations as helicopter pilots. During off-road cycling, in order to maintain a steady state of contact with the bicycle seat, the cyclist must continuously contract core muscles at various amplitudes and frequencies as they cycle over varying terrain. This continuous contraction of the muscles might result in a cyclic response of the erector spinae. This continuous contraction in response to the whole-body vibration can lead to muscle fatigue, which might lead to low-back pain. No published studies to date have dealt with EMG responses to vibration while off-road cycling.

Another hypothesis for low-back pain is based on asymmetric postures that many occupations require, such as helicopter pilots; this may lead to different intensities in the EMG of the right and left erector spinae, as observed by van Dieen (1996) and Pope et al. (1986) in sitting with a rotated trunk. It is unclear at this point if cycling involves asymmetric postures, no studies to date have analyzed this particular situation.

Summary

Current research in the area of whole body vibration's effects on the lower back has been heavily researched within the occupational setting, but little has been devoted to off-road cycling. With the growing number of off-road cyclists today and with 30 - 70% of these cyclists suffering from cervical, dorsal, or lumbar back pain, it is important to develop a scientific analysis of manufacturer's claims on suspension systems "decreasing fatigue, hence fewer injuries". The purpose of this study is to develop more quantitative

measures to assess the effects of suspension seat post absorption systems on skeletal loading and muscle fatigue.

CHAPTER 3

METHODS

Description of Subjects

Five adult females volunteered for this study. All subjects reported having no history of lower-back pain, musculoskeletal or neuromuscular disorders, or spinal or abdominal surgery, and were in good physical condition. All subjects were recreational cyclists who rode their bicycles a minimum of 30 minutes per week and not more than three hours per week. Subjects were not competitive athletes in other sports and did not take part in strength training exercises any time during the year preceding testing. The Human Subject Committee at Montana State University approved the study and all subjects signed an informed consent form (Appendix A and Appendix B).

Procedures

Each subject completed two experimental sessions, for a total of three hours in duration. The weather conditions during all experimental sessions included dry conditions with temperatures between 4.4-12.8° C. The first session involved familiarization with the bicycle, suspension and non-suspension seat posts, accelerometer, EMG surface electrodes, and an introduction to the simulated off-road track. After the familiarization period, collection of the subjects' height, mass, and grip strength data were recorded. Grip strength was obtained using a *JAMAR* hand

dynamometer; the maximum value of two trials with one-minute rest periods between efforts was recorded.

Prior to actual data collection, each subject was given proper bike fit. Bike fit consisted of adjusting the saddle according to the conventional mountain bicycle setup where the subject's legs are nearly extended at the bottom of the pedal cycle (approximately 20-degree bend in the knee) (Burke, 1989). Each subject's knee measurements, using a goniometer, were recorded at the first trial and maintained for subsequent trials. Once preliminary data were collected and equipment was set-up, subjects were given a warm-up period of 10-minutes or longer depending on the comfort status of the subject. Following the warm-up period, each subject was asked to cycle on the simulated off-road track for one hour at a constant cadence of 55 rpm in a gear of 44 X 24, yielding a speed of 3.49 m/s. The simulated track consisted of a flat gravel path having a width of .914 m and a length of 800 m with .038 m X .01 m wooden boards loosely placed every 6.1 meters.

Predetermined by random assignment, each subject's first treatment was either a suspension or a non-suspension seat post (Appendix C). Data were collected every fifteen minutes for one hour through a portable data acquisition system. Following the data collection period, a cool-down period of 10 minutes was provided. The subjects were asked to return a minimum of 48 hours later for the second test session where they repeated the same protocol as in the first; this session subjects rode the other seat post treatment. Forty-eight hours was chosen to minimize possible fatigue effects of the muscles between test sessions. Both test sessions lasted approximately 1.5 hours each.

Under both experimental sessions, subjects were asked to avoid strenuous physical activity 24 hours prior to each session and to wear tight fitting shorts (i.e. bicycling shorts) or pants and a tight-fitting cycling jersey or long sleeve shirt and their own shoes so the equipment could be properly fitted to them.

Data Collection and Instrumentation

The data collection protocol was identical during both test sessions. The saddle acceleration measured in volts and erector spinae and abdominal EMG measured in microvolts data were collected. The electrodes and accelerometer were connected to a 68LP Connector Block (National Instruments, Austin TX), which was connected via a cable to a 12-bit 6024E Data Acquisition Card (National Instruments, Austin TX). The 6024E Data Acquisition Card was placed into a Gateway Solo 2500 Laptop (Gateway, North Sioux City SD) that was secured to a rear bicycle rack, for a total approximate weight of 17.26 kg.

EMG signals of the six muscles under investigation and the acceleration data were sampled at 1000 Hz. Data were collected at minutes 15, 30, 45 and 60 for 15 seconds, for a total of 60,000 samples per minute per channel. Data collection at minute 15 lasted 15 seconds and was denoted as "Time Period 1" in later analyses. The same denotation was used for successive data collection periods, i.e. data collection at minute 30 was denoted as "Time Period 2". The accelerometer required three channels on the 68LP Connector Block for acceleration data in the x, y, z – direction, two channels for left and right rectus abdominis and four channels for the left and right erector spinae muscles (longissimus and iliocostalis). All data acquisition was programmed through the data acquisition

system - *Labview 5.1* (National Instruments, Austin TX) and data were not electronically filtered (Appendix D). Furthermore, the six electrodes were powered through 9-volt batteries and the accelerometer was powered through the computer's battery source. Equipment set-up is shown in Figure 2.

Figure 2. Schematic of Equipment Set-up

Bicycle Setup

A 1.83 m (medium frame) stock equipped *Raleigh M80* (Raleigh, Kent WA) mountain bike (see Figure 3) having a mass 15 kg was used by all participants. The 1.83 m frame was chosen to accommodate the range of heights for a standard “medium” frame, accommodating heights from approximately 1.58 to 1.78 m. A 1.90 kg *Judy C* (Rock Shox, Colorado Springs CO) front suspension fork (see Figure 4), with 80 mm of travel was used during all testing sessions. Furthermore, *WTB Velociraptor* (WTB Mill Valley, CA) 0.66 m x 0.05 m tires inflated to 3.16 kg/cm² were used during all testing sessions. Proper bike fit was made possible by adjusting the fore-aft position of the saddle and the seat post height according to conventional methods. To ensure adequate speed was maintained, a *Performance* (Performance Inc., Chapel Hill NC) bicycling computer speedometer was installed on the handlebars. The bicycle was equipped with a rear rack for storing the laptop.

Figure 3. *Raleigh M80* Bicycle

Figure 4. *Rock Shox Judy C* Front Suspension

Suspension Seat Post

A 2.2 kg *Rock Shox* (Rock Shox, Colorado Springs CO) mountain bike rear suspension seat post (see Figure 5) was as the experimental comparator against the control (non-suspended seat post), depending on random treatment assignment. The *Rock Shox* seat post is designed to compress or “sag” when the subject sits on the bicycle. The “optimum setting” for the best all around performance, according to *Rock Shox*, is 0 to 20 mm of sag. To alter the sag and firmness of the initial post movement, adjustment of the preload adjuster plug on the bottom of the seat post is necessary. When the preload adjuster is turned clockwise, the seat post will sag less and will be firmer, and when turned counterclockwise, the seat post will sag more and be softer to the rider. Spring rate changes to the seat post involved cutting the provided elastomer or “bumper” to *Rock Shox* specifications. The suspension characteristics were adjusted according to *Rock Shox* guidelines based on weight of riders: for riders 100-160 lbs, as all subjects fell into

this range, spring rate was set with an elastomer length of 140 mm and 15 turns of the preload adjuster plug, having a total travel of 50 mm. Furthermore, the elastomer used in this study was in “new” condition. *Rock Shox* does not have currently have recommendations on when to replace the elastomer.

Figure 5. *Rock Shox* Suspension Seat Post

Off-Road Simulated Track

The simulated track consisted of a 0-2% grade gravel path having a width of 0.914 m and a length of 800 m with 0.038 m X 0.01 m wooden boards placed every 6.1 meters, as shown in Figure 6. There was a circle turn around at the end of each 800 m. The wooden simulated boards yielded a 0.038 m high obstacle every 6.1 meters. For

safety purposes, all riders were required to wear helmets. The riders were instructed to maintain a cadence of 55 rpm in 44 X 23 gear during both sessions, so no cardiovascular difficulties would result in the recreational cyclists.

Figure 6. Schematic of Off-Road Gravel Track

Vibration Data

The $\pm 5\text{ g}$ *tri*-axial accelerometer (ADXL05EM-3 Module Analog Devices, Norwood MA) was mounted under the saddle to measure acceleration. From this the root-mean-square acceleration levels among three mutually perpendicular axes, vertical (a_z), longitudinal (a_x), lateral (a_y) as per International Standard (ISO 2631/1, 1985), as shown in Figure 7 and Figure 8 were calculated.

Figure 7. Photograph of Accelerometer Mounted Under Saddle

Figure 8. Orientation of Axis on Accelerometer. +X, +Y, and +Z conforms to the right hand rule.

Computing the total amount of energy in the vibration signal included calculating the Root-Mean-Square (RMS):

$$X_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T X^2(t) dt}$$

where: T =cycle time, X = instantaneous amplitude of vibration

Prior to the RMS calculation the magnitude of the resultant acceleration data was computed as the equation below indicates:

$$\text{Magnitude} = \sqrt{x^2 + y^2 + z^2}$$

The diagram illustrates a 3D Cartesian coordinate system. A cube is drawn with its edges aligned with the axes. The vertical axis is labeled 'y-dir'. The horizontal axis pointing to the right is labeled 'x-dir'. The axis pointing diagonally down and to the left is labeled 'z-dir'.

where x = acceleration (m/sec^2) in x -direction, y = acceleration (m/sec^2) in y -direction, and z = acceleration (m/sec^2) in z -direction.

EMG Data

Tri-polar silver-silver chloride surface electrodes (Motion Control Inc., Salt Lake City UT), having a 1-cm contact surface, were placed on the skin according to the study of Dolan and Adams (1993). The electrodes were aligned with the direction of the muscle fibres and secured with adhesive tape with an additional neoprene back brace to hold electrodes tightly against the skin. The electrodes were placed bilaterally, as shown in Figure 9. Four electrodes were placed on the erector spinae muscles at about 2 cm from midline at the level of L3 (Longissimus) and T10 (Iliocostalis), which enabled detection of EMG signals from the thoracic and lumbar regions and are the main extensor

muscles of the trunk. Additionally, two electrodes were placed on the Rectus Abdominis 2 cm lateral to the midline at the level of the umbilicus (Dolan and Adams, 1993). The following connotation will be used when referring to the placement of electrodes over the muscle in question: Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

Figure 9. Placement of Electrodes

Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

Prior to placement of electrode units, the skin was wiped with alcohol. In order to maintain consistent electrode placement from session one to session two, a permanent ink marker was used to mark placement of all six electrodes.

Data Analysis

Vibration Data Analysis

There were three measures used for vibration analysis. The first two measures used the root-mean-square calculation and the third measure used the peak acceleration values: 1.) "Total vibration energy" included the RMS (of acceleration) calculation for the entire 15 seconds of data collection, which integrated the RMS values on the wooden simulated obstacles as well as the RMS values between the simulated obstacles; 2.) "Simulated obstacle" impact data included the RMS calculation from only the point of contact with the simulated obstacle; a "simulated obstacle" impact was considered the point of contact with the wooden board until last point of contact with the wooden board. The point of contact until the last point of contact was subjectively determined from the acceleration data; and 3.) "Peak acceleration" value was defined as the absolute highest acceleration during the entire 15 second window in either x, y, or z-direction and was subjectively determined from the acceleration data. Figure 10 is a sample output from a single subject during one time period for the three measures used in analyzing the vibration data.

Figure 10. Sample Output for a Single Subject at One Time Period of the Three Measures of Vibration Analysis

EMG Data Analysis

The samples of the EMG signals obtained during data acquisition constitute a time domain representation, which gives the amplitude of the signal at instants of time during sampling. In order to analyze the EMG data with respect to muscle fatigue, a frequency representation rather than amplitude was required; this representation of the signal in terms of frequency is known as the frequency domain representation of the signal. To transform samples of data from the time domain into its frequency domain a

Discrete Fourier Transform (DFT) algorithm was performed. In *Labview 5.1*, a “Power Spectrum Analysis” was applied to the EMG data through the use of a DFT and Fast Fourier transformation (FFT). The Power Spectrum Analysis enabled a fast and accurate computation of the harmonic power content of the EMG periodic signals. Figure 11 is an arbitrary example of the EMG signal resulting in a power spectrum, which is a histogram of the signal intensity plotted against frequency. The area under the curve is the total power and it represents the overall strength of the EMG signal at all frequencies. The median frequency splits the graph into two halves and the 95% frequency indicates the point at which 95% of all frequencies occur.

Figure 11. Exemplar Power Spectrum of an EMG Signal

Prior to the Power Spectrum Analysis, a “Hanning Window” was applied. The Hanning Window “is considered a general purpose window” (National Instruments User Manual for *Labview 5.1*, Austin TX) and is used to suppress leakage of the signal. Suppressing the leakage reduces any artificial frequencies that may occur, i.e. the Hanning Window removes the initial high frequency witnessed from the calculation of the Power Spectrum. After filtering, analysis of the frequency content of each muscle at each time period and on both seat post treatments was possible. The most often used measures to characterize EMG power spectral distributions are the Median Frequency according to Stulen and De Luca (1981) and the Mean Power Frequency as defined by Kwatny et al. (1970). For this study, median frequency and peak amplitude were used for the analysis, as well as the frequency at which 95% of all frequencies occurred. By acquiring the frequency at which 95% of all frequencies occurred, a more in-depth analysis of frequency content could be performed.

Statistical Analysis

To test for differences between suspension seat post use and non-suspension seat post use over cycling time, a two-factor repeated measures analysis of variance (ANOVA) was performed on the mechanical dependent variables, EMG and vibration data, with repeated measures over the time and seat post condition by blocking over subjects using EXCEL 2000 (Microsoft, Redmond WA) per Ferguson and Takan (1989). The two-way ANOVA was tested on two factors: suspension seat post/non-suspension seat post use and time. (Appendix E). Given a non-suspension and a suspension seat post

treatment and four time periods, each subject was tested under each of the treatments over the four time periods. Hence, there are eight treatment combinations for each subject, arranged in random order: non-suspension/time period 1, non-suspension/time period 2, non-suspension/time period 3, non-suspension/time period 4, suspension/time period 1, suspension/time period 2, suspension/time period 3, suspension/time period 4. The model here is a mixed model with seat post treatment and time being a fixed variable and subjects being a random factor. The constrained parameters model, is shown below:

$$Y_{ijk} = \mu + \tau_i + D_j + (\tau D)_{ij} + E_{ijk}$$

Where μ = mean

τ_i = effect of i th level of seat post condition

D_j = effect of j th level of time

τD_{ij} = interaction of seat post condition by time

E_{ij} = Residual error

For, $i = 1, 2$

$j = 1, 2, 3, 4$

An experiment wide alpha level of 0.05 was required in order to reject the null hypothesis for all results.

CHAPTER 4.

RESULTS

Subject Results

Subject's grip strength, body mass, stature, and ages are presented in Table 1: average age was 24 years of age ($SD = \pm 2.86$), height 1.66 m ($SD = \pm .055$), mass 64.32 kg ($SD = \pm 7.25$). Grip strength of the sample mean was compared to a population mean (Mathiowetz, et al., 1985) using a t-test, no significant ($p > 0.05$) differences were found between the sample ($m = 36$ kg) and the population ($M = 30$ kg) means.

Table 1. Grip strength, body mass, stature, and age.

Subject #	Grip Strength (kg force)	Mass (kg)	Height (m)	Age (yrs)
1	35	65.9	1.58	22
2	38	73.0	1.65	24
3	45	68.6	1.68	26
4	34	59.1	1.73	20
5	28	55.0	1.68	27
Mean	36	64.32	1.66	23.8
SD	6.2	7.25	0.06	2.86

Vibration Data Results

On average, the cyclists rode over four to five simulated obstacles within each 15-second sample period. An example of the vibration data for a subject is shown below in Figure 12. Spikes in data are where the subjects rode over the simulated obstacle.

Figure 12. Sample Output a Subject During 15-Seconds of Acceleration Data Collection

Total Vibration Energy of Acceleration Results

An insignificant ($p = 0.816$) 1% total reduction in vibration energy of acceleration (RMS) from non-suspension to suspension seat post use was determined. The 1% value was calculated using the following equation across all subjects:

$$\frac{\sum (\text{Non-Suspension}_{\text{RMS/TIME 1}} + \text{Non-Suspension}_{\text{RMS/TIME 2}} + \text{Non-Suspension}_{\text{RMS/TIME 3}} + \text{Non-Suspension}_{\text{RMS/TIME 4}})}{\sum (\text{Suspension}_{\text{RMS/TIME 1}} + \text{Suspension}_{\text{RMS/TIME 2}} + \text{Suspension}_{\text{RMS/TIME 3}} + \text{Suspension}_{\text{RMS/TIME 4}})} * 100 \%$$

Table 2 provides the average RMS of acceleration values for each seat post treatment for each time period. Figure 13 depicts the total vibration energy of acceleration (RMS) as an area with non-suspension seat post having slightly more area, hence a higher RMS value than the non-suspension seat post.

Table 2. Total Vibration Energy and RMS values per Time Period

Treatment	Time 1 (m/sec ²)	Time 2 (m/sec ²)	Time 3 (m/sec ²)	Time 4 (m/sec ²)
Non-Suspension	4.600 ± .059	4.610 ± .021	4.618 ± .017	4.598 ± .034
Suspension	4.598 ± .050	4.593 ± .024	4.598 ± .022	4.600 ± .021

Figure 13. RMS vs. Time Period of Non-Suspension vs. Suspension

The two-way repeated measures ANOVA found that no significant ($p = 0.816$) difference in total vibration energy of acceleration (RMS) was found between seat post treatments. Additionally, no significant ($p = 0.99$) difference in vibration energy of acceleration (RMS) was found between seat post treatments over the four time periods. No interaction was found between seat post and time ($p = 1.00$). Table 3 illustrates the statistical data for the total vibration energy of acceleration data.

Table 3. ANOVA Table for Total Vibration Energy

EFFECT	SS	df	MS	F	p
SUBJECT	0.019	4	0.0047		
seatpost	9E-05	1	9E-05	.062	0.816
time	0.0002	3	6E-05	.01	0.99
seatpost*time	89061.924	3	0.00014	3.874E-06	1.00
seatpost*SUBJECT	0.006	4	0.0015		
time*SUBJECT	0.006	12	0.0005		
seatpost*time*SUBJECT	423.571	12	35.298		
TOTAL	423.603	39	35.305		

Total Vibration Energy of Acceleration of Simulated Obstacles Results

For the simulated obstacle data, the RMS values were nearly identical for both the non-suspension and suspension seat post. An insignificant ($p = 0.412$) 0.2 % reduction was calculated from non-suspension to suspension seat post use.

The 0.2 % value was calculated using the following equation across all subjects:

$$\frac{\Sigma (\text{Non-Suspension}_{\text{RMS of Obstacle Data / TIME 1}} + \text{Non-Suspension}_{\text{RMS of Obstacle Data / TIME 2}} + \text{Non-Suspension}_{\text{RMS of Obstacle Data / TIME 3}} + \text{Suspension}_{\text{RMS of Obstacle Data / TIME 4}}) / \Sigma (\text{Suspension}_{\text{RMS of Obstacle Data / TIME 1}} + \text{Suspension}_{\text{RMS of Obstacle Data / TIME 2}} + \text{Suspension}_{\text{RMS of Obstacle Data / TIME 3}} + \text{Suspension}_{\text{RMS of Obstacle Data / TIME 4}}) * 100 \%}{}$$

Table 4 provides the average RMS for the simulated obstacle data for each seat post treatment for each time period. Figure 14 depicts the total vibration energy of acceleration of the simulated obstacle data as an area with non-suspension seat post having slightly more area, hence a higher RMS value than the non-suspension seat post.

Table 4. Data for RMS of Simulated Obstacle Results

Treatment	Time 1 (m/sec ²)	Time 2 (m/sec ²)	Time 3 (m/sec ²)	Time 4 (m/sec ²)
Non-Suspension	4.632 ± .025	4.624 ± .069	4.618 ± .026	4.629 ± .045
Suspension	4.627 ± .034	4.615 ± .060	4.617 ± .0321	4.611 ± .030

Figure 14. RMS for Simulated Obstacle Data vs. Time Period

The two-way repeated measures ANOVA found that no significant ($p = 0.412$) difference in simulated obstacle vibration energy of acceleration (RMS) between seat post treatments. Additionally, no significant ($p = 0.870$) difference in simulated obstacle vibration energy of acceleration (RMS) was found between seat post treatments over the four time periods. No interaction was found between seat post and time ($p = 1.00$).

Table 5 below illustrates the statistical data for RMS of the simulated obstacle data.

Table 5. ANOVA Table for RMS of the Simulated Obstacles

EFFECT	SS	df	MS	F	p
SUBJECT	0.049	4	0.012		
seatpost	0.0003	1	0.0003	0.837	0.412
time	0.0007	3	0.0002	0.232	0.870
seatpost*time	0.002	3	0.0005	1.485E-05	1.000
seatpost*SUBJECT	0.002	4	0.0004		
time*SUBJECT	0.012	12	0.001		
seatpost*time*SUBJECT	427.572	12	35.631		
TOTAL	427.638	39	35.645		

Peak Acceleration Results

The suspension seat post reduced peak accelerations, or “shock”, by a significant ($p = 0.02$) 6.88 % to 27.08 % ($p = 0.02$). Average reduction in peak acceleration across subjects was 15.4 %. These percentages were calculated by taking the peak acceleration values from each subject for each time period during both seat post treatments, as shown in the following equation:

$$\frac{\sum (\text{Non-Suspension}_{\text{Peak Acceleration/TIME 1}} + \text{Non-Suspension}_{\text{Peak Acceleration/TIME 2}} + \text{Non-Suspension}_{\text{Peak Acceleration/TIME 3}} + \text{Non-Suspension}_{\text{Peak Acceleration/TIME 4}}) / \sum (\text{Suspension}_{\text{Peak Acceleration/TIME 1}} + \text{Suspension}_{\text{Peak Acceleration/TIME 2}} + \text{Suspension}_{\text{Peak Acceleration/TIME 3}} + \text{Suspension}_{\text{Peak Acceleration/TIME 4}})}{1} * 100 \%$$

Figure 15 demonstrates a comparison between seat post treatments, with non-suspension seat post peak accelerations having higher peak accelerations than the suspension seat post.

Figure 15. Peak Acceleration of Non vs. Suspension Seat Post Condition

The two-way repeated measures ANOVA found that a significant ($p = 0.02$) difference in peak acceleration was found between seat post treatments, yet no significant ($p = 0.395$) difference in peak acceleration was found between seat post treatments over the four time periods. No interaction was found between seat post and time ($p = 1.00$).

Table 6 below illustrates the statistical data for peak acceleration.

Table 6. ANOVA Table for Peak Acceleration

EFFECT	SS	df	MS	F	p
SUBJECT	1.498	4	0.375		
seatpost	5.468	1	5.468	14.09	0.02
time	0.378	3	0.126	1.08	0.395
seatpost*time	0.789	3	0.0005	0.008	1.00
seatpost*SUBJECT	1.552	4	0.388		
time*SUBJECT	1.398	12	0.116		
SUBJECT*seatpost*time	393.557	12	35.631		
TOTAL	404.642	39	35.645		

EMG Data Results

An example of the EMG data for the LT10 muscle is shown in Figure 16.

Highest levels of muscle activity occurred when the subjects rode over the simulated obstacles. Impact with the simulated obstacles was not as clear in the EMG data as was in the vibration data. Due to the rigorous environment in which the equipment was placed in, the loss of some EMG data occurred (See Appendix E).

Figure 16. Sample Non-Suspension EMG Activity of LT10 Muscle

Peak Amplitude Results

The non-suspension seat post peak EMG frequency illustrated an unsteady array of data points. In Table 7 are the corresponding peak frequencies (and standard deviations) for each muscle per seat post condition over time. The RL3 and LL3 peak amplitudes show higher peak amplitudes for the non-suspension than the suspension seat post. Yet the RT10, RRA, and LRA peak amplitudes demonstrate higher peak amplitudes during suspension seat post use.

Table 7. Peak Amplitude per Muscle per Seat Post Condition over Time (Mean $\pm$ SD).

	Time 1 (Hz)	Time 2 (Hz)	Time 3 (Hz)	Time 4 (Hz)
RL3				
Non-Suspension	2.72 $\pm$ 2.77	3.71 $\pm$ 4.61	0.90 $\pm$.13	0.99 $\pm$ 1.31
Suspension	2.77 $\pm$ 4.41	1.06 $\pm$ 1.41	1.46 $\pm$ 1.43	0.75 $\pm$ 0.50
LL3				
Non-Suspension	3.07 $\pm$ 1.65	3.42 $\pm$ 2.81	3.23 $\pm$ 3.13	2.14 $\pm$ 2.86
Suspension	1.22 $\pm$ 0.95	3.15 $\pm$ 4.30	0.32 $\pm$ 0.41	3.25 $\pm$ 5.18
RT10				
Non-Suspension	3.71 $\pm$ 3.95	1.52 $\pm$ 1.32	2.03 $\pm$ 3.57	1.54 $\pm$ 4.07
Suspension	5.46 $\pm$ 6.46	4.76 $\pm$ 2.46	2.00 $\pm$ 1.39	3.23 $\pm$ 2.30
LT10				
Non-Suspension	3.33 $\pm$.68	2.55 $\pm$ 1.40	3.57 $\pm$ 0.25	4.07 $\pm$ 0.49
Suspension	5.46 $\pm$ 6.46	4.76 $\pm$ 2.46	2.00 $\pm$ 1.39	3.23 $\pm$ 2.30
RRA				
Non-Suspension	3.18 $\pm$ 4.69	1.39 $\pm$ 1.48	0.67 $\pm$ 0.39	0.45 $\pm$ 0.39
Suspension	6.98 $\pm$ 7.50	3.87 $\pm$ 3.99	1.06 $\pm$ 1.24	0.56 $\pm$ 0.43
LRA				
Non-Suspension	1.46 $\pm$ 1.34	1.02 $\pm$ 1.40	0.25 $\pm$ 0.33	0.49 $\pm$ 0.50
Suspension	6.75 $\pm$ 7.24	1.34 $\pm$ 1.63	3.55 $\pm$ 6.83	11.49 $\pm$ 4.41

No significant differences in peak amplitudes for the muscles were found between seat post treatments. Additionally, there were no significant differences in peak amplitudes between seat post treatments over time. Table 8 illustrates the statistical analysis for peak amplitude.

Table 8. ANOVA Table for Peak Amplitude

EFFECT for RL3 Muscle	SS	df	MS	F	p
SUBJECT	67.904	3	22.650		
seatpost	3.170	1	3.170	0.622	0.489
time	24.185	3	8.062	1.179	0.371
seatpost*time	13.696	3	4.565	0.318	0.812
seatpost*SUBJECT	15.273	3	5.091		
time*SUBJECT	61.488	9	6.832		
seatpost*time* SUBJECT	128.883	9	14.320		
TOTAL	314.598	31	64.675		
EFFECT for LL3 Muscle	SS	df	MS	F	p
SUBJECT	35.349	3	11.783		
seatpost	7.621	1	7.621	1.912	0.261
time	12.117	3	4.039	0.337	0.799
seatpost*time	21.552	3	7.184	0.3245	0.808
seatpost*SUBJECT	11.956	3	3.985		
time*SUBJECT	107.750	9	11.972		
seatpost*time*SUBJECT	199.244	9	22.138		
TOTAL	395.589	31	68.723		
EFFECT for RT10 Muscle	SS	df	MS	F	p
SUBJECT	28.801	4	7.200		
seatpost	31.400	1	31.400	2.407	0.195
time	29.174	3	9.725	1.517	0.260
seatpost*time	13.780	3	4.593	0.216	0.883
seatpost*SUBJECT	52.179	4	13.045		
time*SUBJECT	76.891	12	6.408		
seatpost*time*SUBJECT	255.140	12	21.262		
TOTAL	487.364	39	93.632		

Table 8. ANOVA Table for Peak Amplitude (continued)

EFFECT for LT10 Muscle	SS	df	MS	F	p
SUBJECT	219.297	4	54.824		
seatpost	22.861	1	22.861	3.774	0.124
time	79.793	3	26.598	1.752	0.210
seatpost*time	90.293	3	30.098	0.802	0.516
seatpost*SUBJECT	24.229	4	6.057		
time*SUBJECT	182.200	12	15.183		
seatpost*time*SUBJECT	450.287	12	37.52393		
TOTAL	1068.960	39	193.1454		
EFFECT for RRA Muscle	SS	df	MS	F	p
SUBJECT	174.630	3	58.21011		
seatpost	129.492	1	129.492	1.912	0.261
time	58.982	3	19.66082	0.772	0.538
seatpost*time	9.409	3	3.136443	0.113	0.950
seatpost*SUBJECT	203.158	3	67.71942		
time*SUBJECT	229.455	9	25.49505		
seatpost*time*SUBJECT	248.995	9	27.66612		
TOTAL	1054.123	31	331.38		
EFFECT for LRA Muscle	SS	df	MS	F	p
SUBJECT	1195.384	2	597.6921		
seatpost	870.769	1	870.7689	1.647	0.328
time	1103.191	3	367.7302	0.6033	0.636
seatpost*time	1179.692	3	393.2306	0.534	0.676
seatpost*SUBJECT	1057.064	2	528.5322		
time*SUBJECT	3657.082	6	609.5137		
seatpost*time*SUBJECT	4417.380	6	736.23		
TOTAL	13480.562	23	4103.698		

Median Frequency Results

The median EMG frequencies showed no consistent pattern over time, though there appeared to be consistently lower median frequencies during non-suspension compared to the suspension seat post use. In Table 9 are the corresponding median frequencies for each muscle per seat post condition over time.

Table 9. Median Frequency per Muscle per Seat Post Condition over Time (Mean $\pm$ SD).

RL3	Time 1 (Hz)	Time 2 (Hz)	Time 3 (Hz)	Time 4 (Hz)
Non-Suspension	5.25 $\pm$ 1.04	6.31 $\pm$ 5.40	4.24 $\pm$ 3.34	3.82 $\pm$ 3.57
Suspension	5.86 $\pm$ 5.38	6.52 $\pm$ 4.81	3.23 $\pm$ 2.58	3.81 $\pm$ 3.55
LL3				
Non-Suspension	4.61 $\pm$ 2.02	7.48 $\pm$ 7.03	7.57 $\pm$ 6.06	2.55 $\pm$ 2.20
Suspension	4.33 $\pm$ 3.86	12.88 $\pm$ 11.83	10.64 $\pm$ 10.62	16.32 $\pm$ 12.40
RT10				
Non-Suspension	7.84 $\pm$ 6.65	5.11 $\pm$ 2.61	4.74 $\pm$ 2.96	2.98 $\pm$ 1.48
Suspension	12.14 $\pm$ 9.43	9.85 $\pm$ 4.24	4.41 $\pm$ 1.47	4.42 $\pm$ 2.86
LT10				
Non-Suspension	4.60 $\pm$ 1.77	4.69 $\pm$ 1.06	6.32 $\pm$ 3.48	4.74 $\pm$ 5.02
Suspension	14.95 $\pm$ 14.73	7.78 $\pm$ 5.42	5.60 $\pm$ 1.29	2.70 $\pm$ 2.11
RRA				
Non-Suspension	5.86 $\pm$ 6.68	2.85 $\pm$ 2.02	2.03 $\pm$ 1.59	1.13 $\pm$ 1.06
Suspension	24.76 $\pm$ 26.62	6.57 $\pm$ 9.12	7.49 $\pm$ 4.70	10.54 $\pm$ 18.05
LRA				
Non-Suspension	4.16 $\pm$ 5.48	4.73 $\pm$ 3.39	2.63 $\pm$ 2.08	4.07 $\pm$ 4.98
Suspension	11.15 $\pm$ 9.75	6.02 $\pm$ 1.92	2.98 $\pm$ 5.87	14.58 $\pm$ 8.41

As previously mentioned, whenever there is a 10% decrease in the median frequency of the EMG signal then the onset of fatigue of that muscle is said to occur. All the muscles median frequencies slightly decreased during non-suspension seat post use, except the LRA and LT10, from time period one to time period four. A similar scenario

was observed in the suspension seat post median EMG frequency values where all muscles, except LL3 and LRA, had a slight decrease in median frequency, as shown in Figure 17.

Figure 17. Non-suspension Median Frequency vs. Time Period.

Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

Figure 18. Suspension Median Frequency vs. Time Period.

Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

The following graphs (Figures 19-24) provide a visual comparison of the median frequency per seat post condition for each muscle investigated. The statistical analysis found nonsignificant ($p > 0.05$) differences in median frequencies between suspension versus non-suspension seat post use. All muscles, except RL3, show a higher median frequency for the suspension seat post as shown in Figure 19. The RL3 was excluded due to the almost identical pattern of median frequencies between the two seat post treatments, as shown in Figure 19.

Figure 19. RL3 Median Frequency of Non vs. Suspension Over Time. Right Longissimus at level 3 of the lumbar region (RL3).

Figure 20. LL3 Median Frequency of Non vs. Suspension Over Time. Left Longissimus at level 3 of the lumbar region (LL3).

Figure 21. RT10 Median Frequency of Non vs. Suspension Over Time. Right Iliocostalis at level 10 of the thoracic region (RT10).

Figure 22. LT10 Median Frequency of Non vs. Suspension Over Time. Left Iliocostalis at the level 10 of the thoracic region (LT10).

Figure 23. RRA Median Frequency of Non vs. Suspension Over Time. Right Rectus Abdominis (RRA).

Figure 24. LRA Peak Amplitude of Non vs. Suspension Over Time. Left Rectus Abdominis (LRA).

No significant ($p > 0.05$) differences in the median frequency for the muscles were found between seat post treatments. Additionally, there was no significant ($p > 0.05$) difference in the median frequency between seat post treatments over time. No interaction was found between seat post and time ($p > 0.05$). Table 10 illustrates the statistical analysis for median frequency.

Table 10. ANOVA Table for Median Frequency

EFFECT for RL3 Muscle	SS	df	MS	F	p
SUBJECT	168.940	3	56.313		
seatpost	3.727	1	3.727	0.156	0.719
time	51.471	3	17.157	1.395	0.306
seatpost*time	25.830	3	8.610	0.158	0.922
seatpost*SUBJECT	71.578	3	23.859		
time*SUBJECT	110.692	9	12.299		
seatpost*time*SUBJECT	489.846	9	54.427		
TOTAL	922.084	31	176.393		
EFFECT for LL3 Muscle	SS	df	MS	F	p
SUBJECT	650.859	2	325.429		
seatpost	207.162	1	207.162	0.864	0.451
time	129.598	3	43.199	0.517	0.686
seatpost*time	182.568	3	60.856	0.287	0.833
seatpost*SUBJECT	479.460	2	239.730		
time*SUBJECT	501.541	6	83.590		
seatpost*time*SUBJECT	1271.814	6	211.969		
TOTAL	3423.002	23	1171.936		

Table 10. ANOVA Data for Median Frequency (continued)

EFFECT for RT10 Muscle	SS	df	MS	F	p
SUBJECT	314.416	4	78.604		
seatpost	75.763	1	75.763	6.882	0.056
time	147.671	3	49.224	2.108	0.153
seatpost*time	42.161	3	14.0536	0.170	0.920
seatpost*SUBJECT	44.036	4	11.009		
time*SUBJECT	280.155	12	23.346		
seatpost*time*SUBJECT	994.587	12	82.882		
TOTAL	1898.789	39	334.882		
EFFECT for LT10 Muscle	SS	df	MS	F	p
SUBJECT	476.523	4	119.131		
seatpost	130.899	1	130.899	6.792	0.060
time	163.964	3	54.655	2.898	0.079
seatpost*time	193.912	3	64.637	0.690	0.575
seatpost*SUBJECT	77.085	4	19.271		
time*SUBJECT	286.417	12	23.868		
seatpost*time*SUBJECT	1124.913	12	93.743		
TOTAL	2453.713	39	506.204		
EFFECT for RRA Muscle	SS	df	MS	F	p
SUBJECT	460.149	3	153.383		
seatpost	1026.786	1	1026.786	3.519	0.157
time	554.397	3	184.799	1.924	0.196
seatpost*time	300.921	3	100.307	0.422	0.742
seatpost*SUBJECT	875.259	3	291.753		
time*SUBJECT	864.404	9	96.045		
seatpost*time*SUBJECT	2139.098	9	237.678		
TOTAL	6221.014	31	2090.751		

Table 10. ANOVA Data for Median Frequency (continued)

EFFECT for LRA Muscle	SS	df	MS	F	p
SUBJECT	315.185	3	105.062		
seatpost	285.530	1	285.530	3.809	0.146
time	77.603	3	25.868	0.948	0.458
seatpost*time	34.949	3	11.650	0.107	0.954
seatpost*SUBJECT	224.835	3	74.945		
time*SUBJECT	245.622	9	27.291		
seatpost*time*SUBJECT	976.860	9	108.540		
TOTAL	2160.585	31	638.885		

As mentioned previously, when the onset of fatigue occurs, typical changes in EMG demonstrate an increase in amplitude and/or shift in the frequency spectrum towards lower frequencies. Furthermore, ergonomists agree that the onset of fatigue occurs at a minimum of 10% shift in the median frequency. Table 11 and 12 are summaries of mean median frequencies across all subjects for the muscles on both seat post treatments and the numeric value needed for a 10 % shift needed. During non-suspension seat post use, all muscles but the LT10 reached the 10% shift indicating the onset of fatigue (See Table 11). During suspension seat post use, all muscles but the LRA reached the 10% shift needed indication the onset of fatigue (See Table 12). Furthermore, because the LT10 and LRA did not reach onset of fatigue indicates that asymmetric use of muscles is present.

Table 11. Mean Median Frequency for Non-Suspension

Median Frequency for Non-Suspension						
Time Period	RL3	LL3	RT10	LT10	RRA	LRA
1	5.25	4.61	7.84	4.60	5.86	4.16
2	7.89	7.48	5.11	4.69	2.85	4.73
3	4.24	7.57	4.74	6.32	2.03	2.63
4	3.82	2.55	2.98	4.74	1.13	4.07
10% shift needed	4.72	4.15	7.06	4.14	5.28	3.74
Shift?	Y	Y	Y	N	Y	Y

Table 12. Mean Median Frequency for Suspension

Median Frequency for Suspension						
Time Period	RL3	LL3	RT10	LT10	RRA	LRA
1	5.86	4.33	12.14	14.95	24.76	11.15
2	6.52	12.88	9.85	7.78	6.57	6.02
3	3.23	10.64	4.41	5.60	7.49	5.96
4	5.08	16.32	4.42	2.70	10.54	14.58
10% shift needed	5.27	3.89	10.93	13.46	22.29	10.03
Shift?	Y	N	Y	Y	Y	N

95% Frequency Content Results

Figure 25 and 26 illustrates 95% of all EMG frequency content of all muscles over time for the non-suspension and suspension seat post respectively. For the non-suspension seat post, the EMG values for all muscles, except the RL3, show a decrease towards lower frequencies over time. The only muscle that showed a slight increase in higher frequency content was the RL3. Figure 26 depicts a different scenario for the suspension seat post, with a shift towards higher frequencies in the LRA, LL3, and RL3, while a shift to lower frequencies in the RT10, RRA, and LT10.

Figure 25. Non-Suspension 95% of all frequency content of EMG vs. Time Period. Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

Figure 26. Suspension 95% of all frequency content of EMG vs. Time Period.
 Right Longissimus at level 3 of the lumbar region (RL3), Left Longissimus at level 3 of the lumbar region (LL3), Right Iliocostalis at level 10 of the thoracic region (RT10), Left Iliocostalis at the level 10 of the thoracic region (LT10), Right Rectus Abdominis (RRA), and Left Rectus Abdominis (LRA).

In addition to the Figures, Table 13 displays the corresponding 95% frequency content (and standard deviations) for each muscle per seat post condition over time.

Table 13. 95% Frequency Content per Muscle over Time (Mean $\pm$ SD).

RL3	Time 1 (Hz)	Time 2 (Hz)	Time 3 (Hz)	Time 4 (Hz)
Non-Suspension	13.35 $\pm$ 9.13	61.01 $\pm$ 53.57	34.37 $\pm$ 4.54	15.63 $\pm$ 23.58
Suspension	65.35 $\pm$ 71.34	48.79 $\pm$ 28.57	12.97 $\pm$ 7.73	136.41 $\pm$ 185.14
LL3				
Non-Suspension	57.19 $\pm$ 84.84	33.31 $\pm$ 32.96	44.62 $\pm$ 55.92	12.48 $\pm$ 5.94
Suspension	61.61 $\pm$ 50.87	147.22 $\pm$ 172.44	245.04 $\pm$ 185.70	282.81 $\pm$ 171.23
RT10				
Non-Suspension	42.75 $\pm$ 69.20	35.38 $\pm$ 26.91	39.45 $\pm$ 31.42	51.43 $\pm$ 69.42
Suspension	110.47 $\pm$ 169.28	62.59 $\pm$ 44.68	33.33 $\pm$ 31.90	17.04 $\pm$ 10.11
LT10				
Non-Suspension	16.01 $\pm$ 2.07	30.32 $\pm$ 23.84	51.71 $\pm$ 70.04	9.67 $\pm$ 3.04
Suspension	128.29 $\pm$ 174.59	109.95 $\pm$ 52.80	125.67 $\pm$ 92.16	31.39 $\pm$ 12.77
RRA				
Non-Suspension	91.93 $\pm$ 138.56	16.76 $\pm$ 13.88	10.80 $\pm$ 10.85	11.96 $\pm$ 7.42
Suspension	126.51 $\pm$ 192.63	114.72 $\pm$ 128.23	188.52 $\pm$ 195.96	49.85 $\pm$ 52.37
LRA				
Non-Suspension	103.00 $\pm$ 66.01	124.25 $\pm$ 105.80	37.32 $\pm$ 51.32	51.56 $\pm$ 26.31
Suspension	113.39 $\pm$ 155.01	90.40 $\pm$ 122.64	291.82 $\pm$ 203.22	149.83 $\pm$ 65.82

No significant difference in the 95% frequency content for the muscles was found between seat post treatments. Additionally, there was no significant difference in the 95% frequency content between seat post treatments over time. No interaction was found between seat post and time ($p = 1.00$). Table 14 illustrates the statistical analysis for the 95% frequency content.

Table 14. ANOVA Table for 95% Frequency Content

EFFECT for RL3 Muscle	SS	df	MS	F	p
SUBJECT	31108.393	3	10369.460		
seatpost	8232.596	1	8232.600	1.603	0.295
time	14253.459	3	4751.150	0.797	0.526
seatpost*time	21655.873	3	7218.620	0.807	0.521
seatpost*SUBJECT	15409.367	3	5136.460		
time*SUBJECT	53653.377	9	5961.490		
seatpost*time*SUBJECT	80509.354	9	8945.480		
TOTAL	224822.417	31	50615.260		
EFFECT for LL3 Muscle	SS	df	MS	F	P
SUBJECT	147991.640	2	73995.800		
seatpost	196155.431	1	196155.400	4.568	0.166
time	40592.041	3	13530.700	1.085	0.424
seatpost*time	68841.804	3	22947.300	0.427	0.741
seatpost*SUBJECT	85889.440	2	42944.700		
time*SUBJECT	74803.816	6	12467.300		
seatpost*time*SUBJECT	322297.478	6	53716.200		
TOTAL	936571.650	23	415757.500		
EFFECT for RT10 Muscle	SS	df	MS	F	P
SUBJECT	44326.050	2	22163.020		
seatpost	548.044	1	548.040	0.678	0.497
time	5636.660	3	1878.890	0.257	0.854
seatpost*time	11467.001	3	3822.330	0.445	0.730
seatpost*SUBJECT	1615.409	2	807.700		
time*SUBJECT	43880.843	6	7313.470		
seatpost*time*SUBJECT	51512.116	6	8585.350		
TOTAL	158986.123	23	45118.820		

Table 14. ANOVA Table for 95% Frequency Content (continued)

EFFECT for LT10 Muscle	SS	df	MS	F	p
SUBJECT	22974.371	3	7658.124		
seatpost	22984.42	1	22984.42	8.650	0.061
time	23652.328	3	7884.109	2.056	0.177
seatpost*time	7035.495	3	2345.165	0.237	0.868
seatpost*SUBJECT	7971.473	3	2657.158		
time*SUBJECT	34519.991	9	3835.555		
seatpost*time*SUBJECT	89061.924	9	9895.769		
TOTAL	218830.932	31	67891.23		
EFFECT for RRA Muscle	SS	df	MS	F	p
SUBJECT	97899.900	3	32633.3		
seatpost	91745.747	1	91745.7	7.309	0.074
time	37533.545	3	12511.2	0.701	0.574
seatpost*time	38022.823	3	12674.3	0.622	0.618
seatpost*SUBJECT	37658.906	3	12553.0		
time*SUBJECT	160641.923	9	17849.1		
seatpost*time*SUBJECT	183346.937	9	20371.9		
TOTAL	646849.781	31	200338.5		
EFFECT for LRA Muscle	SS	df	MS	F	p
SUBJECT	20722.906	4	5180.727		
seatpost	54257.219	1	54257.22	7.319	0.054
time	19064.952	3	6354.984	0.342	0.796
seatpost*time	71499.974	3	23833.32	0.764	0.536
seatpost*SUBJECT	29651.419	4	7412.855		
time*SUBJECT	222722.172	12	18560.18		
seatpost*time*SUBJECT	374319.324	12	31193.28		
TOTAL	792237.967	39	146792.6		

CHAPTER 5

DISCUSSION

The findings of this study indicate that there were no significant ($p > 0.05$) differences in muscle activity (peak amplitude, median frequency, and 95% of frequencies) between the seat post treatments or in muscle activity over time. The suspension seat post did not significantly reduce total vibration energy ($p = 0.816$) or the total vibration energy ($p = 0.412$) during impact with the simulated obstacles, though the suspension seat post significantly ($p = 0.02$) reduced peak accelerations by up to 27%.

During whole-body vibration exposure the tissues of the body, including antagonistic muscles, absorb some of the vibration energy, possibly leading to muscle fatigue. As was seen in this study, when subjects were exposed to whole-body vibrations, a 10% decrease in the median frequency was obtained, indicating the "onset of muscular fatigue" in the low back and abdominal muscle regions. This onset of fatigue might coincide with the studies performed by Seroussi et al. (1987); Pope et al, (1988) and Zimmerman and Cook (1997) where they found that specific trunk muscles demonstrate a cyclic EMG activity when exposed to vibration. Additionally, that significantly higher EMG activities existed during vibration as opposed to static moment loads on the torso. Static moment loads in this study are comparable to the static loads between the simulated obstacles. The cyclic response of the erector spinae in response to the vibration experienced while off-road cycling might have led to muscle fatigue, but it was difficult to determine in the EMG data if there was a true cyclic response due to

partially noisy data. Bonger et al. (1990) further suggested that the cyclic response of the erector spinae in response to whole-body vibration might lead to muscle fatigue, which can potentially lead to low back pain. This might be the reason, according to Berry and Woodward (1993), that 30-70 % of cyclists suffer from cervical, dorsal, or lumbar back pain.

Furthermore, asymmetric use of the muscles was witnessed, where some muscles were more active than others. This might be due to a type of learning effect, where initially subjects required more muscle activity to maintain their balance on the bicycle, while over time they might have become more comfortable requiring less muscle activity.

Because of these findings, engineering applications in the form of "industrial ergonomics" may be applied. The goal of industrial ergonomics is to design the workspace, equipment, machine, tool, product, environment, and systems to the human's physiological, biomechanical, and psychological capabilities while also optimizing the work system. Whenever hazards, dangers, or risks are present, ergonomists apply three classifications for control strategies: (1) Engineering controls; (2) Administrative controls; and, (3) Control using personal protective equipment (PPE). Engineering controls are the preferred methods because they modify the environment to eliminate exposure to hazards, dangers, and risks (Fernandez & Marley, 1998).

When dealing with whole-body vibration, as in off-road cycling, engineering controls fall into three categories: isolation, dampening, and reduction in the amount vibration produced. Isolation consists of separating the vibration source from the person, such as isolating a bicycle frame from the person. Such actions are applied in the use of

heavy equipment; isolating the seat through suspending the driver's seat from the vibrating engine so vibration is not fully transmitted to the body of the operator. This type of control does not seem feasible with present technology when attempting to isolate vibration from the cyclists.

Another engineering change to eliminate vibration is the placement of an additional vibrating system or dynamic absorber that is timed to the frequency of the vibrating source so that when two systems work together no net vibrational effect exists. However, during off-road cycling, there is not a constant frequency of vibration, all vibration is totally random; present technology for use of a timed absorber for use on bicycles is not available. The only currently feasible engineering change to eliminating and/or reducing whole-body vibrations is a technique called "sandwiching", as in using the suspension seat post. Sandwiching is placing an elastic material, such as an elastomer used in the *Rock Shox* suspension seat post, between two metal plates to reduce or dampen the amount of vibration from plate to plate or from bicycle frame to cyclists. It was hoped that the suspension seat post would effectively utilize the elastomer as means of "sandwiching" vibration, yet because the suspension seat post was found to significantly ($p = 0.02$) "dampen" the peak acceleration and not the total vibration energy, a further design might be necessary. By decreasing the spring rate on the suspension seat post or customizing the spring rate more precisely to the cyclists weight might have produced more significant results.

Beyond engineering changes or controls that ergonomists use in reducing or eliminating whole-body vibrations, are administrative controls. In occupational tasks, the

most frequent implemented strategy is the rotation of job tasks and limiting exposure through rest breaks. In off-road cycling, the cyclists might consider taking complete rest breaks from cycling. A more feasible option might be to strength train the targeted muscles that are most likely to fatigue.

More accurate results might have been possible if the study was conducted in the laboratory setting or with telemetry. With the use of telemetry, EMG and vibration information can be sent by FM signal through the air to a receiver worn by the subject, making continuous monitoring of data possible. This would eliminate the use of cables, which can affect subject performance and data collection and can be cumbersome to the researcher. In addition, analysis of more rigorous terrain that better mimics true off-road cycling would be enhanced with telemetry. Telemetered systems have been used in both clinical and laboratory settings (Soderburg and Knutson, 2000). The use of telemetered systems or conducting this study in a laboratory might enable researchers to obtain more characteristic effects of suspension seat post versus non-suspension seat post through the analysis of time till fatigue, total vibration energy, and muscle activity of the core and lumbar muscles.

Furthermore, if current technology enabled continuous data acquisition for the entire hour period, rather than only 15-second snapshots a more representative analysis might have been possible. Because of the limitations in the hard-drive space of the laptop, saving one hour of data would have exceeded the space of the hard-drive.

In addition, EMG signals are currently under scrutiny in that a clear understanding of all the information contained in EMG signals continues to be somewhat

elusive (Miller, 2000). The fact that the collection of EMG is already dependent on precise electrode application and placement (Jenson, Vasseljen, Westgaard, 1993), perspiration and temperature of the skin (Winkel and Jorgensen, 1991), muscle fatigue (Hansson, Stromberg, Larsson, Ohlsson, Balogh, and Mortiz, 1992), contraction velocity and muscle length (McGill and Norman, 1986), cross talk from nearby muscles (Koh and Grabiner, 1993), activity in other synergists and antagonists (Mathiassen and Winkel, 1990), and subcutaneous fat thickness (McGill, 1991), to name a few, makes exact collection of EMG more difficult. Furthermore, skin artifact while riding in such a rigorous environment, electrode placement for second day (though every precaution was taken), few number of subjects, and higher percent body fat of women versus men compound the inaccuracy of the EMG data collection. Also, it is uncertain whether the subjects might have involuntarily have used their legs and/or arms during one of the treatments more than the other.

Furthermore, the finding in this study are similar to that found by the researchers at Projekt-WELLCOM. When comparing the *Rock Shox* suspension seat post to a hard tail, Project-WELLCOM researchers found that the suspension seat post reduced shocks by up to 24%, while in this study, reductions from non-suspension to suspension seat post use yielded a reduction in the 6.88% to 27.08% range. The discrepancies in peak vibration energy from non-suspension to suspension, or “shock”, between subjects might have been due to the amount of leg force used to stabilize the body on the saddle. Although subjects were asked to refrain from using their legs or any other assistance,

such as arms, while riding over the simulated obstacles some might have unconsciously used their legs or arms to absorb some of the shock.

A possible explanation of why the suspension seat post did not significantly ($p = 0.816$) reduce the total vibration energy is illustrated in Figure 27. Figure 27 demonstrates the oscillatory motion of simulated acceleration data for suspension versus non-suspension seat post, where the oscillatory motion of the suspension acceleration is spread over longer time duration and has a lower peak acceleration value than the non-suspended seat post. Due to these characteristics of motion, the RMS value i.e. the area or energy of vibration for both seat posts will be near equal, resulting in a non-significant ($p > 0.05$) difference between seat posts.

Figure 27. Explanation of Oscillatory Motion of Acceleration. The areas of the boxes, which represent the RMS of acceleration, are near identical in value.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

No significant ($p > 0.05$) differences were found in muscle activity (peak amplitude, median frequency, and 95% of frequencies) between the seat post treatments. Furthermore, the suspension seat post did not significantly ($p = 0.816$) reduce total vibration energy or the total vibration energy during impact with only the simulated obstacles ($p = 0.412$), though the suspension seat post significantly ($p = 0.02$) reduced peak accelerations by up to 27%.

As a consumer, the *Rock Shox* suspension seat post would be an advantageous purchase because of its characteristics in reducing peak accelerations while off-road cycling. Due to the limitations of the study, continuous and longer data acquisition measures were not possible. If these measures were taken, it is believed that the suspension seat post's ability to reduce peak accelerations will prolong the time at which onset of muscular fatigue occurs in the lower back and abdominal muscles. Additionally, the lumbar and abdominal muscles are used to stabilize the pelvis on the bicycle seat and are a crucial component in the power transfer between the upper and lower body during cycling. If these muscles fatigue at a slower rate using the suspension seat post, concomitantly muscle power will decrease at a slower rate. Because this reduction in muscle power induces discomfort and pain, and, in the long term, is believed to contribute to low back pain; any delay in the reduction in muscle power might result in

less or no low back pain. Furthermore, reducing peak accelerations will place less strain on the spinal structures with the anticipation of reducing any cervical, dorsal, or lumbar back pain or injury.

Further research might include a more in depth analysis through the use of telemetered systems. If telemetered systems are not available, ideally a study such as this should be conducted in the laboratory to control for variability through real time monitoring of vibration and EMG data.

Future research might include:

- 1.) Laboratory setting to better control variables or in field with telemetered systems to better mimic the task and real time monitoring.
- 2.) Having data collections every 5-minutes, if equipment is available, to obtain a more in-depth accurate analysis.
- 3.) More subjects to gain more statistical power.
- 4.) Same weight riders or more precise spring rate settings per weight.
- 5.) Using subjects with lower percent of body fat to obtain a better assessment of EMG activity.
- 6.) In addition to placement of electrodes on the low back and abdominal muscles, additional electrodes on arms and legs to determine which muscles are more active during the seat post treatments might provide a better assessment.
- 7.) A subjective questionnaire about subject's comfort levels per seat post treatment might have added value to this study.

- 8.) Measuring grip strength before and after each session might have added to the quantification of muscle fatigue between seat post treatments.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

7

SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN SUBJECT RESEARCH
MONTANA STATE UNIVERSITY
Principal Investigator: Laura Stanley 406/581-7019

Vibration Analysis During Simulated Off-Road Cycling

Purpose

You are being asked to participate in a study on the vibrations sustained to the lower back during simulated off-road cycling. This study is being conducted to determine muscle activity in the lower back and abdominal muscles as well as the amount of acceleration sustained to the lower back during an hour cycling episode. You will cycle at a slow speed of approximately 7-mph while maintaining a cadence of 55 rpm in a predetermined gear for one hour using a standard seat post and one hour using a suspension seat post.

Procedures

If you agree to participate, EMG (electromyography=muscle activity) electrodes will be attached to your lower back and abdominal muscles and an accelerometer (for obtaining vibration data) will be attached to the seat to collect necessary data. During each session you will be given a warm-up period and will then be asked to cycle at a constant cadence of 55 rpm in a predetermined gear (approximately 7-mph). You will cycle for one hour once using a standard mountain bike saddle secured to a standard seat post and then again using a standard mountain saddle secured to a suspension seat post. Data will be collected every fifteen minutes for ten seconds. Following the data collection period a cool-down period of 10 minutes will be given. Prior to data collection, you will receive proper bike fit, instructions on procedures and familiarization of equipment and be allowed to practice riding on the treadmill until you feel comfortable.

The first session will involve a questionnaire, familiarization and proper fit of equipment, collection of height, mass, and grip strength data, and an introduction to the simulated off-road track. Once preliminary data has been collected and you feel comfortable on the simulated off-road track a brief warm-up/familiarization will be given followed by the actual data collection period. During the data collection period you will be asked to cycle non-stop for one hour at a constant cadence of 55 rpm on a standard mountain bike saddle secured to a standard seat post. Once complete, a cool down period will be given. This first session will take approximately 1.5 hours. You will then return at least 48 hours later for the second session where you will repeat the same protocol as in the first, only this time you will ride on a standard mountain bike saddle secured to a suspension seat post. The second session will last approximately 1.5 hours. You will be asked to avoid strenuous physical activity 24 hours prior to each session and to wear tight fitting shorts (i.e. bicycling shorts) and a tight-fitting cycling jersey or t-shirt and your own shoes so the equipment can be properly fitted to you. If you agree to participate, a 3-hour commitment will be required.

Confidentiality

All data collected will remain confidential. The data will be kept in the Movement Science Laboratory and/or the Ergonomics Laboratory at Montana State University. Your data will be identified by code. Only the investigators will have access to this code. Your name will not be used in connection with any part of this study.

It is asked, however, with your consent, that this data remain available for viewing for educational purposes.

Risks

The risks for participating in this study are those assumed with any off-road cycling activity, i.e. losing balance, falling off bicycle, etc. which includes the possibility of musculoskeletal injury to the body. You may experience fatigue (muscular or cardiovascular) during this study and may have muscle soreness following this study.

Benefits

There is no direct benefit of this study to you, except possible extra credit for participating in research studies if you are enrolled in a Montana State University class that complies with this. The data from this study will be used to determine possible back injuries during off-road cycling in the hopes of reducing low back pain prevalence in off-road cyclists as well as possible industrial applications.

Injury and Compensation

No special medical arrangements have been made regarding your participation in this study. In the event your participation in this research results in injury, CPR and standard first aid will be provided by a certified CPR professional rescuer (Laura Stanley, principal investigator) and appropriate emergency personnel will be summoned. There is no compensation available for any injury; you are responsible for all medical costs. Further, information may be obtained by contacting Robert Marley at 406/994-2272 or the Principal Investigator, Laura Stanley at 406/581-7019.

The Human Subjects Committee, Montana State University, Bozeman, Montana, has reviewed this project. Additional questions concerning rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Montana State University, Mark Quinn, 406/994-5721.

Authorization

I have read the attached and understand the discomforts, inconvenience, and risks of this study. I agree to participate in this research project. I understand that I may later refuse to participate, and that I may withdraw from this study at any time without financial compensation. I have received a copy of this consent form for my own records and I understand that no one will know my individual results from this study.

Name (PRINT): _____

Signed (SIGN): _____

Witness: _____

Investigator: _____

Date: _____

APPENDIX B

HUMAN SUBJECTS COMMITTEE APPLICATION

Human Subjects Committee Application for Review
MONTANA STATE UNIVERSITY

THIS AREA IS FOR HUMAN SUBJECTS COMMITTEE USE ONLY. DO NOT
WRITE IN THIS AREA.

Approval Date:

Application Number:

PLEASE TYPE. SUBMIT 14 COPIES OF THIS APPLICATION (INCLUDING THE SIGNATURE COPY), ALONG WITH 14 COPIES OF THE SUBJECT CONSENT FORM AND ALL OTHER RELEVANT MATERIALS, TO HUMAN SUBJECTS COMMITTEE ADMINISTRATOR, STEPHEN GUGGENHEIM, 308 LEON JOHNSON HALL, MONTANA STATE UNIVERSITY, BOZEMAN, MT 59717. SUBMIT ONE COPY OF GRANT CONTRACT PROPOSAL. FOR INFORMATION AND ASSISTANCE, CALL 994-4411 OR CONTACT THE HUMAN SUBJECTS COMMITTEE CHAIR, MARK QUINN, 994-4707.

Date: 09/20/01

I. Investigators and Associates (list all investigators involved; application will be filed under name of first person listed)

Name	Title	Department	Address	Telephone
1. Laura Stanley	Graduate Student	I&ME	Roberts 417	581-7019
2. Robert Marley Roberts 214	Dean		College of Engineering	994-2272
3. Deborah King Romney 101E	Asst Prof		Health & Human Devl	994-7154
4. Dan Heil Romney 103A	Asst Prof		Health & Human Devl	994-6324

II. Title of Proposal: A comparison of whole body vibrations on the lower back with the use of a standard mountain bike saddle on a suspension seat post versus the use of a standard mountain bike saddle on a non-suspension seat post during off-road cycling

III. Beginning Date for Use of Human Subjects: 09/22/01

IV. Type of Grant (if applicable)

Research Grant:

Contract:

Training Grant:

Classroom Experiments/Projects:

Other (Specify):

V. Name of Funding Agency to which Proposal is Being Submitted (if applicable):

VI. Signatures

Submitted by Investigator

Typed Name: Laura Stanley

Signature:

Date: 09/20/01

Faculty sponsor (for student)

Typed Name: Robert Marley

Signature:

Date:

THIS AREA IS FOR HUMAN SUBJECTS COMMITTEE USE ONLY. DO NOT
WRITE IN THIS AREA.

Approved:

Disapproved:

HSC Chairman's Signature and Date:

Subject to the following conditions:

VII. Summary of Activity. Provide answers to each section and add space as needed. Do not refer to an accompanying grant or contract proposal.

A. RATIONALE AND PURPOSE OF RESEARCH (What question is being asked?)

The purpose of this research is to determine frequencies and amplitudes of vibrations

during simulated off-road cycling and if those vibrations can lead to fatigue resulting in low back pain in cyclists.

B. RESEARCH PROCEDURES INVOLVED. Provide a short description of sequence and methods of procedures that will be performed with human subjects. Include details of painful or uncomfortable procedures, frequency of procedures, time involved, names of psychological tests, questionnaires, restrictions on usual life patterns, and follow up procedures.

EMG (electromyography=muscle activity) electrodes will be attached to the subject's lower back and abdominal muscles and an accelerometer (for obtaining vibration data) will be attached to the seat of the bicycles to collect vibration data. All electrode placements will be non-invasive and might require shaving of the areas for application. Each subject will attend two sessions, for a total of approximately 2.5 hours.

The first session of will involve a questionnaire, familiarization and proper fit of equipment, collection of height, mass and grip strength data, and an introduction to the simulated off-road track. The simulated off-road track will consist of a 1-mile track on a flat gravel trail having wooden boards with dimensions of: two feet in length, two inches in height, and four inches wide positioned perpendicular to the trail spaced every 20 feet. Once preliminary data has been collected and the subject feels comfortable on the simulated off-road track a brief warm-up will be given followed by the actual data collection period. During the data collection period the subject will be asked to cycle a mountain bike non-stop for one hour at a cadence of 55 rpm in a predetermined gear (a rate of approximately 7-mph) on a standard mountain bike saddle secured to a standard seat post. Once complete, a 10-minute cool down period will be given. This first session will take approximately 1.5 hours. The subject will then return 48 hours later for the second session where the subject will repeat the same protocol as in the first; only this time the subject will ride on a standard mountain bike saddle secured to a suspension seat post. The second session will last approximately 1.5 hours for a total time commitment of 3 hours.

C. DECEPTION - If any deception (withholding of complete information) is required for the validity of this activity, explain why this is necessary and attach debriefing statement.

- **D. SUBJECTS**

- 1. Approximate number and ages
How Many Subjects: 6 – mean age of approx 26
Age Range of Subjects: 21-34
How Many Normal/Control: same

Age Range of Normal/Control: same

- 2. Criteria for selection: recreational cyclists-not competitive, people who ride for at least one hour per week.
- 3. Criteria for exclusion: no previous back injuries, currently experiencing no back pain and no back pain within the past year
- 4. Source of Subjects (including patients): school and community
- 5. Who will approach subjects and how? Explain steps taken to avoid coercion.
The principal investigator will ask subject's permission to test.
- 6. Will subjects receive payments, service without charge, or extra course credit? (Yes or No. If yes, what amount and how? Are there other ways to receive similar benefits?)
Subjects enrolled at Montana State University may receive extra course credit if professor agrees, no financial compensation will be given.
- 7. Location(s) where procedures will be carried out.
Human Movement Lab and on Nash Trail located in Bozeman, MT.

• E. RISKS AND BENEFITS (ADVERSE EFFECTS)

- 1. Describe nature and amount of risk and/or adverse effects (including side effects), substantial stress, discomfort, or invasion of privacy involved. Any type of musculoskeletal injury may result in typical off-road cycling, i.e. falling off the bicycle, losing balance, etc. Subjects might feel cardiovascular and/or muscle soreness after testing.
- 2. Will this study preclude standard procedures (e.g., medical or psychological care, school attendance, etc.)? If yes, explain. No
- 3. Describe the expected benefits for individual subjects and/or society. Subjects will be educated on proper bike fit and will contribute to the possibility of reducing low back pain and/or low back injury in the sport of off-road cycling as well as possible industrial applications.

- F. ADVERSE EFFECTS

- 1. How will possible adverse effects be handled?
By investigator(s): Principal Investigator is CPR Professional Rescuer Certified and has taken an EMT course within the past 4 months and is certified to perform first aid.
Referred by investigator(s) to appropriate care: Appropriate emergency personnel will be contacted if necessary.
Other (explain):
- 2. Are facilities/equipment adequate to handle possible adverse effects? (Yes or No. If no, explain.) First aid supplies will be available during all testing. Furthermore, the principal investigator has completed an EMT course within the past 4 months and is certified to perform CPR and/or first aid.
- 3. Describe arrangements for financial responsibility for any possible adverse effects.
MSU compensation (explain): none
Sponsoring agency insurance: none
Subject is responsible: yes
Other (explain):

- G. CONFIDENTIALITY OF RESEARCH DATA

- 1. Will data be coded? (Yes or No) Yes
- 2. Will master code be kept separate from data? (Yes or No) Yes
- 3. Will any other agency have access to identifiable data? (Yes or No. If yes, explain.) No
- 4. How will documents, data be stored and protected?
Locked file:
Computer with restricted password: stored and protected on computer with restricted password
Other (explain):

VIII. Checklist to be Completed by Investigator(s)

- A. Will any group, agency, or organization be involved? (Yes or No. If yes, please confirm that appropriate permissions have been obtained.)
No
- B. Will materials with potential radiation risk be used (e.g. x-rays, radioisotopes)? (Yes or No) No
 - 1. Status of annual review by MSU Radiation Sources Committee (RSC). (Pending or Approved. If approved, attach one copy of approval notice.)
 - 2. Title of application submitted to MSU RSC (if different).
- C. Will human blood be utilized in your proposal? (Yes or No. If yes, please answer the following:) No
 - 1. Will blood be drawn? (Yes or No. If yes, who will draw the blood and how is the individual qualified to draw blood? What procedure will be utilized?)
 - 2. Will the blood be tested for HIV? (Yes or No)
 - 3. What disposition will be made of unused blood?
 - 4. Has the Biosafety Committee been contacted? (Yes or No)
- D. Will non-investigational drugs or other substances be used for purposes of the research? (Yes or No.)
No
Name:
Dose:
Source:
How Administered:
Side effects:
- E. Will any investigational new drug or other investigational substance be used? (Yes or No. If yes, provide information requested below and one copy of: 1) available toxicity data; 2) reports of animal studies; 3) description of studies done

in humans; 4) concise review of the literature prepared by the investigator(s); and
5) the drug protocol.)

No

Name:

Dose:

Source:

How Administered:

IND Number:

Phase of Testing:

- F. Will an investigational device be used? (Yes or No. If yes, provide name, source description of purpose, how used, and status with the U.S. Food and Drug Administration FDA). Include a statement as to whether or not device poses a significant risk. Attach any relevant material.)

No

- G. Will medical or academic records be used? (Yes or No.)

No

- H. Will audio-visual or tape recordings or photographs be made? (Yes or No.)

No

- I. Will written consent form(s) be used? (Yes or No. If no, explain.)

Yes

APPENDIX C

RANDOM ASSIGNMENT OF SEAT POST TREATMENT

Subject	Assigned Random #*	
1	56.56749403	
2	2.042819965	
3	78.00436922	
4	1.533130197	
5	19.27302723	
6	70.49161392	
Subject	Random #	Condition 1
4	1.533130197	Suspension
2	2.042819965	Suspension
5	19.27302723	Suspension
1	56.56749403	Non-Suspension
6	70.49161392	Non-Suspension
3	78.00436922	Non-Suspension

Random # Generator and
Corresponding
Assignment
Using the "Rand () *100"
command in Excel

APPENDIX D

LABVIEW CODE

Labview 5.1. Block Diagram Program

ACCELERATION

Cursor 0 22539.5 -0.52

EMG

Cursor 0 0.00 17.00

RMS accel

0.00

RL3

LL3

RT10

LT10

RRA

LRA

Peak

0.00 0.00 0.00 0.00 0.00 0.00

95%

0.00 0.00 0.00 0.00 0.00 0.00

Median

0.00 0.00 0.00 0.00 0.00 0.00

APPENDIX E

LOST EMG DATA

MISSING DATA

Non-Suspension DATA*						
	RL3	LL3	RT10	LT10	RRA	LRA
Peak 1	2	2	2	2	2	2
Peak 2						
Peak 3	3	3	3	3	3	3
Peak 4	1	1	1	1	1	1
95% 1	2	2	2	2	2	2
95% 2						
95% 3	3	3	3	3	3	3
95% 4	1	1	1	1	1	1
Median 1	2	2	2	2	2	2
Median 2						
Median 3						
Median 4	1	1	1	1	1	1
Suspension DATA*						
	RL3	LL3	RT10	LT10	RRA	LRA
Peak 1						
Peak 2						
Peak 3						
Peak 4	4	4	4	4	4	3,4
95% 1						
95% 2						
95% 3						
95% 4	4	4	4	4	4	3,4
Median 1						
Median 2	5	5	5	5	5	5
Median 3						
Median 4						

*Number correlates to Subject number where missing data occurred.

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