Effects of Muscle Fatigue on Muscle Latency and Muscle Activation under Whole-Body Vibration

by

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ABSTRACT

EFFECTS OF MUSCLE FATIGUE ON MUSCLE LATENCY AND MUSCLE ACTIVATION UNDER WHOLE-BODY VIBRATION

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Whole-body vibration and muscle fatigue have both been shown to delay the trunk muscle reflex response and increase trunk muscle activation, leading to an increased risk of low back injuries. However, the effects of whole-body vibration on previously fatigued trunk muscles have never been tested, despite tests showing that prolonged exposure to whole-body vibration can lead to muscle fatigue. The purpose of this research was to investigate the effects of muscle fatigue on muscle latency, muscle activation and perceived discomfort when exposed to whole-body vibration. The results showed that a fatigued muscle state resulted in increased muscle latency, muscle activation and perceived discomfort, which all escalate the risk of low back injuries. Additionally, the ISO 2631-1 comfort ratings did not increase with fatigue, showing a disconnect between these comfort ratings and the perceived discomfort ratings in a fatigued muscle state.
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### Nomenclature

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<td>WBV</td>
<td>Whole-body vibration</td>
</tr>
<tr>
<td>SEAT</td>
<td>Seat Effective Amplitude Transmissibility</td>
</tr>
<tr>
<td>RMS</td>
<td>Root Mean Square</td>
</tr>
<tr>
<td>A(8)</td>
<td>Daily Equivalent Dose</td>
</tr>
<tr>
<td>MPF</td>
<td>Median Power Frequency</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>RVC</td>
<td>Reference Voluntary Contraction</td>
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<tr>
<td>MVC</td>
<td>Maximum Voluntary Contraction</td>
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<tr>
<td>PAR-Q</td>
<td>Physical Activity Readiness Questionnaire</td>
</tr>
<tr>
<td>TE</td>
<td>Thoracic Erector Spinae</td>
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<td>LE</td>
<td>Lumbar Erector Spinae</td>
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<td>IO</td>
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Chapter 1: Introduction

1.1 Background and Motivation

Workers in industries that utilize heavy mobile machinery are often exposed to high levels of whole-body vibration (WBV) [1]–[11]. These high levels of WBV can be harmful to the human body, leading to injuries of the intervertebral disks, vertebrae and many other low back injuries [12]. Consequently, many industries involving heavy mobile machine operation report a high prevalence for low back pain and other related injuries [1], [2], [4]–[6], [13]. The most common standard used to evaluate WBV is ISO 2631-1, which weights WBV frequencies based on their impact on the human body for health and comfort [14]. The health weightings are used to compare to the health guidance zone which provides weighted acceleration levels to stay below to reduce the risk of injury [14]. The comfort weightings provide levels of comfort based on the weighted acceleration level, with a reduced acceleration providing increased comfort [14]. However, these comfort levels are purely based on the acceleration input and testing has shown that the comfort of a seat is not solely based on the vibration transmission, but can be effected by external factors such as noise and temperature [15], [16] and can vary between individuals [12] as well as within individuals based on overall well being and mood [16]. In order to include these external factors into the assessment of comfort, perceived discomfort questionnaires are often used as a qualitative measurement of comfort [15]–[22]. Since increased discomfort in the human body can be linked to an increased risk of injury [20], [23], it is important to properly assess comfort levels.
WBV can also increase muscle activation in the trunk in order to maintain an upright posture, which increases the load on the spine [24]–[27]. This increased muscle activation over a prolonged period of time also leads to muscle fatigue [28], [29]. As a result of the increased muscle activation and the subsequent muscle fatigue, the stability of the spine can also be reduced [30], [31]. Muscle activation in the trunk muscles increases when the muscles are fatigued [32]–[34] and the spine is unstable [35] as the muscles must work harder in order to maintain the same posture. This further increase in muscle activation places an additional load on the spine and increases the risk for low back injuries [24]–[27].

When the human body is exposed to sudden perturbations, the muscles in the low back activate as a reflex to stiffen the spine and avoid injury [36], [37]. The time between the onset of the perturbation and the start of the reflexive muscle activation is called the muscle latency. If the muscle latency increases, the muscles may not stiffen the system in time, which increases the muscle activation to compensate for the delay and potentially causes injury [36]–[38]. A delay in the low back muscle activation reflex has been found as a result of WBV exposure [38]–[40] and muscle fatigue [41]. Additionally, an increase in the muscle activation of the reflex response has been found from muscle fatigue [41].

While the effects of WBV and muscle fatigue have been tested, and shown similar impacts on the low back, no studies have exposed participants to WBV after intentionally inducing back muscle fatigue. Additionally, no studies that have assessed the change in muscle latency resulting from WBV or muscle fatigue have used mechanical shocks similar to movements in off-road heavy mobile machinery as their perturbation method. Since operators of heavy mobile machinery often have prolonged exposure to WBV, which can lead
to muscle fatigue, it can be assumed that these workers are being exposed to WBV while their muscles are fatigued. Testing the impact of WBV on fatigued back muscles could provide further insight into what operators of heavy mobile machinery are experiencing after prolonged WBV exposure. Factors such as trunk muscle latency, trunk muscle activation and perceived discomfort levels may provide further insight into how the human body reacts to WBV after muscle fatigue.

1.2 Objectives

The purpose of this project was to assess the impact that back muscle fatigue and vertical whole-body vibration have on the human body. Specifically, the muscle latency and muscle activation levels of the trunk muscles and discomfort felt by the participants was of the most interest. This research was also intended to determine if future research using horizontal and multi-axial whole-body vibration would be relevant.

1.3 Thesis Structure

This thesis is written in journal format, with each chapter being a stand-alone section with its own reference list. The breakdown of the chapters is as follows:

**Chapter 1:** This chapter outlines the thesis material and provides a brief introduction on the background, motivation and objectives of this project.

**Chapter 2:** Chapter 2 provides an in-depth literature review on all relevant work and how it relates to the project.

**Chapter 3:** This chapter consists of a study on the impact of muscle fatigue on the human body when exposed to whole-body vibration.
Chapter 4: Chapter 5 summarizes the findings and conclusions drawn from the study and discusses how future work will be built off of this research.

1.4 References


D. E. De Carvalho and J. P. Callaghan, “Passive stiffness changes in the lumbar spine and effect of gender during prolonged simulated driving,” *Int. J. Ind. Ergon.*, vol. 41, no. 6,


Chapter 2: Literature Review

2.1 Whole-Body Vibration Definition

Whole-body vibration (WBV) occurs when the surface supporting a person is shaking or vibrating, which transmits into the human body [1], [2]. The most common occurrence of WBV is in a seated posture, where the vibration can be transmitted from the ground into the feet, from the seat-surface into the lower body and from the seat-back into the upper body [2].

There are 12 axes associated with seated WBV [3] (Figure 1), however the z-axis (vertical) vibration from the seat-surface will be the focus of this report as studies have shown that vertical vibration is often most predominant in heavy mobile machinery and off road vehicles [4], [5]. The principal factors that affect WBV are the frequency, magnitude, duration and direction of the vibration [2], [3]. Additionally, the seat used by the driver has been shown to alter the transmission of WBV to the human body and affect driver comfort [1], [6], [7]. Seats can be evaluated by their Seat Effective Amplitude Transmissibility (SEAT) value, which is the acceleration at the seat divided by the acceleration on the cab floor multiplied by 100% [2]. The SEAT value provides a WBV attenuation effectiveness metric, with a value under 100% meaning the chair is attenuating the vibration (i.e., a lower magnitude of WBV reaching the occupant than the WBV in the cab floor or the vehicle chassis) [2], [8].
2.2 Whole-Body Vibration Standards

In North America, the standard that is typically used when working with WBV is ISO 2631-1: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General Requirements [3]. In particular, the current work will focus on the following sections of this standard: the health guidance zone for WBV and the effects of vibration on comfort [3]. Vibration weightings are provided by ISO 2631-1 which weight each frequency of WBV based on their impact on the human body for both health and comfort [3]. The health guidance zone provides the safety limits for WBV on the human body based on the weighted acceleration and vibration exposure duration [3]. The effects of vibration on comfort...
provides a measure of perceived comfort for the seated occupant based on the magnitude of vibration acceleration that is transmitted through the seat and into the occupant [3]. Additionally, this ISO standard provides information on the measurement and evaluation of WBV, including acceleration frequency weighting and equations for calculating the root mean square (RMS) and daily equivalent dose (A(8)) [3]. The daily equivalent dose evaluates a short vibration exposure and extrapolates it to an eight-hour exposure so that it can be compared to the health guidance zone to ensure the exposure will not harm the person being exposed to the vibration.

2.3 Effects of Whole-Body Vibration on the Human Body

Whole-body vibration affects the human body in different ways depending on factors such as the frequency and magnitude of the vibration. The human body is most sensitive to WBV in the range of 1-20Hz [2]. Horizontal vibrations have the largest impact on the body below 2Hz, while vertical vibrations above 2Hz are the most impactful as they have been found to cause vibration amplification in the body [1], [2]. These frequency ranges correspond with the peaks in the horizontal and vertical frequency weightings found in ISO 2631-1 [3]. While different parts of the body have different resonance frequencies, it is believed that the first major resonances in the human body occur around 4-5Hz, making vibration within these frequencies more likely to cause harm [1], [2]. Additionally, a higher magnitude of vibration is more dangerous to the human body since this increases the acceleration of the body, which is more likely to cause injuries [2].
2.4 Whole-Body Vibration Injuries

When WBV at specific frequencies and magnitudes transmits into the human body, it can cause different parts of the body to vibrate separately from one another and potentially lead to injury [1]. Specifically, in the spine, WBV can move each vertebrae separately, stretching and compressing the intervertebral disks and potentially leading to tearing or slipping of the disks or damage to the vertebrae [1]. Exposure to WBV has also been shown to increase forces on the spine and muscle activation in the trunk, which places additional compressive forces on the spine and makes it more susceptible to injury [9]–[11]. Prolonged muscle activation, even at low-levels, has also been shown to lead to injuries [12]. For these reasons, WBV has been linked to many different low back injuries and disorders [1], [4], [13]–[15]. Additionally, WBV can have a negative effect on various systems in the human body, including the nervous [16], urinary [15] and digestive systems [1]. The increased trunk muscle activation caused by WBV can also lead to muscle fatigue due to the prolonged activation [17]–[19]. A decrease in the spine’s ability to maintain stability has been found when muscles are weakened or fatigued as this decreases the stiffness of the spinal system [20].

2.5 Spine Stability

The general behaviour of a stable static spine is its ability to return to its original position when a small perturbation is applied and react according to the size of the perturbation [20]. This means that if a force is applied to the spine, there should be a deviation from the neutral posture that is equivalent to the force applied before the spine returns to equilibrium [20]. The ability for a spine to maintain stability is called robustness, which is the perturbation size that can be applied to a spine before it becomes unstable [20], [21]. The
robustness of the spine is improved when there is a higher activation in the back muscles and antagonistic abdominal muscles as they create a stiffer system around the spine [20], [22], [23]. Whole-body vibration has a significant impact on spinal stability as it causes a person’s center of pressure to be consistently farther from the neutral posture by decreasing postural control and robustness [9], [24]. WBV also increases error in the ability to sense and reproduce lumbar postures by altering joint dynamics and causing neuromotor habituation and adaptation to the vibration [25]. This error caused by WBV reduces the ability to sense the posture of the trunk and leads to reduced postural control [25]. The speed of response to unexpected loads on the spine is also affected by WBV [25]–[27]. When a person is exposed to WBV their trunk adjusts and adapts to the vibration, making it less responsive to external forces, thereby reducing the speed of the response [25]–[27]. Whole-body vibration can also cause spine instability through its effects on the musculature of the back, specifically in the lumbar region [28]. In order to maintain a neutral posture, the trunk must increase muscle activation when exposed to WBV which leads to fatigue, specifically in the lumbar erector spinae muscles [28]. Muscle fatigue has been shown to impair spine proprioception and the ability for the back muscles to regulate force, which can lead to spinal instability and cause the antagonistic muscles to activate in order to maintain stability [20], [22], [29].

2.6 Low Back Muscle Fatigue

Muscle fatigue is defined as the decline of muscle performance after repeated, intensive use which later reverts to its normal level of performance [17]. Fatigue is commonly measured by evaluating the decline in median power frequency (MPF) over time in the frequency spectrum of electromyography (EMG) data. A significantly lower MPF value over time indicates...
the presence of fatigue in muscles. Fatigue can occur quickly from near maximal muscle exertion, or over a longer period of time as a result of prolonged, low-level muscle loading [17]. This low level loading can occur during WBV when the muscles of the low back are activated to provide stability, which allows the spine to maintain an upright posture [18], [30]. When the muscles of the low back are fatigued, their ability to produce force and the rate that they produce force declines [17], decreasing their ability to maintain spinal stability [20]. This causes an increase in antagonistic muscle cocontraction which increases the load on the spine [20], [22], [29]. Additionally, muscle fatigue can cause an increased latency in the trunk muscle reflex activation when a sudden load is applied to the body [25], [31]. This is due to fatigued muscles not being able to contract at the same rate as unfatigued muscles [17].

2.7 Muscle Latency

When a sudden load or perturbation is applied to a seated person, the body must activate postural muscles in the trunk in order to maintain spinal stability and avoid injury. This is done by a reflexive muscle activation, which typically happens within 120 msec after the perturbation, and a voluntary reaction, which typically happens between 120-180 msec after the perturbation [26]. The time between the perturbation and the reflexive muscle activation is called the muscle latency. The reflexive muscle activation is one of the main forms of protection when the spine is exposed to sudden perturbations as it provides the force necessary to resist the load caused by the perturbation [32], [33]. When this muscle activation is delayed, the spine system may not be stiffened at the correct time, potentially leading to a buckling of the spine and further low back injuries [32], [33]. This delayed reflex may also cause the muscles to have a greater activation in order to compensate for the delay, placing additional compressive
forces on the spine [26]. When exposed to WBV, a person’s body adapts to the constant movement and loading placed on the body from the vibration, making it less responsive to external forces and increasing the latency in the trunk muscles [25]–[27]. Additionally, when trunk muscles are fatigued they cannot activate at the same rate as unfatigued muscles, increasing the muscle latency [17].

2.8 Fatigue Studies

Several studies have looked at the connection between WBV and fatigue. Studies have shown that there is a connection between trunk muscle fatigue onset and prolonged exposure to WBV due to the increased muscle activation required to maintain spinal stability [18], [34]–[36]. The trunk muscle latency period has also been tested when muscles are fatigued, with the results showing that the amplitude of the reflex response to perturbations increases [31] or isn’t affected [37], [38] by fatigue. Additionally, testing has shown that fatigue in the low back causes antagonistic muscle cocontraction to increase in order to properly stabilize the spine since the back muscles cannot provide the necessary force [22], [29], [39]. However, none of these studies have directly studied how the human body reacts to WBV at different frequencies when the low back muscles are purposefully fatigued prior to WBV exposure.

2.9 Whole-Body Vibration Studies

Since there are indications that injury can occur if the human body has a perturbation applied to it when there is an impaired reflex response, researchers have looked into the effect of WBV on muscle latency [25]–[27], [35]. Testing in this area has either shown no effect [35] or proven that the back muscles will take longer to respond to a sudden perturbation when the
human body is exposed to WBV [25]–[27]. Additionally, none of these studies have tested the effects of WBV on muscle latency using a mechanical shock similar to what would be experienced in an off-road vehicle as the perturbation. The only testing that has used these types of mechanical shocks have been tests to assess the impacts of different directions, quantities and magnitudes of shocks [40], [41]. There have also been many studies performed to determine the level of WBV transmitted to workers and determine the presence of injuries related to WBV in various industries. These industries include farming [42]–[46] steel manufacturing [47], [48], forestry [49] and other heavy machinery operators [4], [13], [50]. It has been determined that operators of heavy machinery are exposed to high levels of WBV, often greater than the levels recommended by vibration standards. This exposure leads to an increased risk of low back pain and other associated injuries, which surveys have shown are prevalent in these industries [4], [42]–[45], [51].

2.10 Seat Comfort

Increased discomfort in the human body has been linked to future risk of musculoskeletal injury [52], [53]. Quantitatively, the comfort of a seat can be assessed by comparing the RMS of the frequency weighted acceleration to values provided by ISO 2631-1 [3]. This provides a level of comfort based on the acceleration level being transmitted into the occupant through the seat. This measurement of comfort based on acceleration implies that improved comfort is directly related to reduced acceleration, which is associated with lowered risk of injury from vibration [2]. This also corresponds with the health guidance zone provided by ISO 2631-1, which directly relates RMS weighted acceleration exposure to health risks for the person exposed to the WBV [3]. However, the comfort of a seat is not solely based on the
vibration transmission and can be effected by external factors such as noise and temperature [54], [55] and can vary between individuals [1] as well as within individuals based on overall well being and mood [55]. In order to accommodate these factors, another common method of assessing seat comfort is with a qualitative discomfort rating scale [53]–[60]. There are many different types of discomfort scales that have been used to assess seat comfort, however Dempsey et al. determined that the scale with the greatest reliability is a 9 point continuous scale [61]. Dickey et al. then created an updated scale based on this 9 point continuous scale that allowed for verbal cues for the level of discomfort [62].

2.11 Electromyography

Electromyography (EMG) is the collection of electrical signals produced by the activation of muscles to determine the amount of muscle activation. Surface EMG data are collected by placing the electrode on the surface of the skin, directly above the muscle belly of the muscle being collected [63]. Differential electrodes use an electrode pair and subtract one signal from the other in order to remove any noise that is common between the two electrodes [63]. EMGs use a reference electrode to remove any common electrical noise that is present in all electrodes [63]. The EMG data is then band-pass filtered to remove any low and high frequency noise that is not part of the EMG signal [63].

EMG is used to determine the amount of muscle activity that is required to perform certain tasks. This activation level can then be compared between conditions and participants to see how the muscle activation changes. In order to compare between participants, reference voluntary contractions (RVCs) are used to normalize the data. These RVCs can involve maximum voluntary contractions (MVCs) which show the highest muscle activation possible for a muscle,
or sub-maximal MVCs, which show a sub-maximal muscle activation for a certain task such as lifting a 10kg weight. The MVCs or sub-maximal MVCs are used as a reference for muscle activations by dividing the activation by the reference to determine the percentage of the reference that was achieved during the task.

MVCs are collected by muscle specific or task-based activations [63]. Muscle specific activations isolate a single muscle or muscle group at the optimal muscle length in order to produce the largest muscle activation. Task-based activations place the participant in the same anatomical orientation that they will be in during data collection to evaluate the maximal muscle activation in that posture [63].

2.12 Conclusion

The above literature has shown the risk of injury associated with WBV exposure and muscle fatigue. Both WBV and muscle fatigue are linked to spinal instability, increased muscle activation, and a delayed trunk muscle reflex response when perturbations are applied to the body. While this literature has shown the negative impacts of WBV and muscle fatigue on the reflex response of the trunk muscles, no testing has been performed to determine the impact that WBV and mechanical shocks have on the human body after the back muscles have been fatigued. Furthermore, while the effects of WBV and muscle fatigue on trunk muscle latency has been assessed individually when perturbations are applied to the body, none of these perturbations have been from mechanical shocks similar to what would be experienced in the operation of heavy mobile machinery.
2.14 References


Chapter 3: Effects of Muscle Fatigue on Muscle Latency and Muscle Activation under Whole-Body Vibration

3.1 Introduction

Operators of heavy mobile machinery are often exposed to high levels of WBV. These high levels of WBV have been studied in industries such as farming [1]–[5], steel manufacturing [6], [7] and forestry [8] where heavy equipment has been shown to transmit WBV to the operator. WBV exposure increases trunk muscle activation and forces on the spine [9]–[11], which can lead to muscle fatigue and decrease the spine’s ability to maintain stability [12], [13]. Additionally, prolonged low-level muscle activation is associated with repetitive strain injuries [14]. These risk factors increase the likelihood for injuries and disorders of the low back such as vertebral damage and intervertebral disc injuries [15]–[19]. This has been shown in heavy mobile machinery industries, where WBV related injuries to the low back, hip and other areas of the body are prevalent [1]–[5], [15], [20].

ISO 2631-1 is the standard used in North America to ensure the safety of people exposed to WBV. This standard utilizes frequency weightings to assess the impact that WBV has on the health and comfort of the human body [21]. The health weighted acceleration can be assessed with the health guidance zone, which provides weighted acceleration levels to stay below in order to reduce the risk of injury [21]. The comfort weighted acceleration can be compared to the comfort levels in ISO 2631-1 to assess the perceived comfort of the person exposed to the WBV, with a reduced acceleration providing increased comfort [21]. However, these comfort levels don’t include external factors such as noise and temperature [22], [23],
variations between individuals [16] as well as within individuals based on overall well being and mood [23], which have all been shown to affect comfort. Perceived discomfort questionnaires are often used as a method of including these external factors in a qualitative measurement of comfort [22]–[29]. Since the risk of injury has been shown to be amplified when discomfort in the human body is greater [27], [30], it is important to properly assess comfort levels.

When the human body is exposed to WBV for a prolonged period of time the muscles of the trunk activate in order to maintain spinal stability and prevent injury, eventually resulting in muscle fatigue [31]–[33]. Fatigued trunk muscles are not able to activate at the same rate as unfatigued muscles, therefore, when a sudden load is applied to the body, the trunk muscles can not properly stabilize the spine to prevent injury [34]–[38].

Previous testing has shown a connection between prolonged WBV exposure and the onset of trunk muscle fatigue [32], [39], [40]. Additionally, there have been tests showing that WBV can delay the trunk’s neuromuscular response to sudden spinal loading [35], [36], [40], [41] and reduce a person’s ability to maintain a proper lumbar posture [35]. The effects of trunk muscle fatigue on trunk muscle latency have also been tested with varied results. Some tests have shown an increased muscle latency that was not statistically significant [34] while others showed no effect on muscle latency [42], [43]. One common feature of WBV and fatigue is that they both increase the activation level of the trunk muscles [32], [40], [44], [45], which has been shown to increase muscle latency either significantly [46] or insignificantly [34].
While there has been an abundance of studies looking at WBV, trunk muscle fatigue and trunk muscle latency, no study has combined all three to evaluate how previously fatigued trunk muscles react under WBV. There has also not been testing that has assessed the impact of WBV or trunk muscle fatigue on trunk muscle latency using perturbations from mechanical shocks, which would be similar to what would be found in heavy mobile machinery. Since it has been shown that muscle fatigue can occur after prolonged exposure to WBV [32], [39], [40], assessing the impact that WBV has on fatigued trunk muscles will provide an understanding of how operators of heavy mobile machinery react to WBV after a prolonged exposure. Using mechanical shocks as the method of perturbation would also create a more realistic environment to test how operators of heavy mobile machines would react to sudden impacts transmitted to them from the machinery.

The purpose of this study was to assess the effect of WBV on the muscle latency period and activation levels of the trunk muscles, as well as the perceived discomfort of the participant, following the completion of a fatiguing protocol.

3.2 Methods

3.2.1 Subjects

18 male participants and 11 female participants were recruited from the University of Guelph population. Approval was received from the University of Guelph Research Ethics Board prior to the beginning of the testing. Participants had no history of low back pain or injuries, which was confirmed by passing the Spine Injury Risk Assessment Questionnaire, and were deemed fit to perform maximum voluntary contractions (MVCs) by passing the physical activity readiness questionnaire (PAR-Q). Participants were familiarized with the testing
procedure and then provided informed consent before testing began. Age, mass and height information were collected from the participants (Table 1).

**Table 1: Participant sex, age, height and weight**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n=18)</td>
<td>23.8 ± 2.8</td>
<td>176.3 ± 7.5</td>
<td>78.7 ± 15.3</td>
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<tr>
<td>Female (n=11)</td>
<td>22.7 ± 2.2</td>
<td>166.4 ± 6.6</td>
<td>65.2 ± 11.0</td>
</tr>
</tbody>
</table>

### 3.2.2 Electromyography Setup

A Delsys Trigno DST01 system (Delsys Inc., Boston MA) was used to collect the EMG data at a sampling rate of 2000 Hz. Eight EMG sensors (four SP-W01 Trigno sensors and four SP-W04 Trigno mini sensors) were placed on the torso of the participant to determine the level of activations while being exposed to WBV and sudden vertical shocks. The EMGs were placed bilaterally on the thoracic erector spinae (TE), lumbar erector spinae (LE), internal oblique (IO) and external oblique (EO) muscles. The placement of the lumbar erector spinae and external oblique EMGs followed the methods used by Cram [47] while the thoracic erector spinae and internal oblique EMGs followed the methods used by O’Sullivan [48] (Figure 2 & Figure 3). Skin was shaved if necessary, abraded with medical-grade sandpaper and cleaned with an alcohol swab prior to electrode placement. Following EMG placement, MVCs were performed in order to determine the maximum muscle activation level for each muscle. These data were later used to normalize the muscle activation data. MVCs were performed for the abdominal and back muscles based on the methods used by Moreside et al. [49]. For the abdominal muscles, participants were in a sit-up position and performed a sit-up, right twist and left twist at maximal effort while their movement was resisted by a research assistant [49]. The back muscle MVCs were performed on a roman chair in the Biering-
Sorensen position with the participant performing a back extension at maximal effort while a research assistant resisted their movement [49]. Each movement was performed three times to ensure the maximum activation level was attained by the participant, with breaks given between each to ensure no fatigue occurred.

3.2.3 Test Procedure

Participants sat on a conventional farm tractor seat which was attached to the hexapod robot (Figure 4). The tractor seat had the suspension system locked out in order to reduce the complexity of the system by removing the effect of the seat suspension on vibration transmission. Participants were seated in a neutral posture, keeping their back off the backrest and their hands loosely holding ropes in front of them to ensure their arms were not providing support. Twenty-five, 20 second vibration profiles and three, single wavelength mechanical shocks were applied to the participants for each sequence. The presentation of the vibration profiles and shocks were completely randomized for each sequence, with every sequence being unique and every participant receiving unique sequences. The length of the 20
second profiles were determined by Dickey et al. to provide an adequate vibration duration to obtain reliable discomfort scores [50]. The total vibration exposure for each participant was determined to be under the daily exposure limit for the ISO 2631-1 Health Guidance Caution Zone [21]. The vibration profiles had a displacement of 5mm and consisted of five different frequencies (1.25Hz, 2Hz, 2.5Hz, 4Hz and 4.5Hz), each repeated five times. These frequencies were found to be the most common frequencies present in field testing of heavy mobile machinery [51] that were within the hexapod robot’s allowable range of 0-4.5Hz. The single wavelength shocks were at the maximum allowable frequency of 4.5Hz, with a displacement of 14mm, lasting 0.23s having a crest factor of 7.0.

![Hexapod robot setup](image)

Figure 4: Hexapod robot setup

After each 20 second vibration profile or single wavelength shock, a 5 second rest was provided while the participant was asked to provide a verbal rating of the vibration discomfort
ranging from 0 (no vibrational discomfort) to 8 (maximum vibrational discomfort) which was based on the scale used in a seat discomfort questionnaire by Dickey et al. [50]. The 5 second break was determined by Dickey et al. to be an adequate duration for participants to report their discomfort while not interrupting the testing [50]. After each sequence of twenty-five vibration profiles and three single wavelength mechanical shocks, participants were asked to complete a more thorough seat discomfort questionnaire based on a previously validated 9 point continuous scale discomfort questionnaire from Dickey et al. [50].

Following the first sequence, participants had their low back muscles fatigued using the Modified Biering-Sorensen Test, which has been used previously to effectively fatigue the low back muscles [52]. Low back muscle fatigue was confirmed by ensuring the median power frequency of the low back muscles after the fatiguing protocol was significantly lower than the median power frequency before the fatiguing protocol. Once back muscle fatigue was confirmed, participants returned to the robot for a second sequence of vibration profiles.

3.2.4 Accelerometer Setup

Z-axis (vertical) acceleration data were collected using two Dalimar Modal array, ceramic shear ICP® accel PCB model 333B40 uniaxial accelerometers (Dalimar Instruments, Vaudreuil, QC). One of the accelerometers was carpet taped to the base of the robot (Figure 5) and one was embedded in a seat pad (Figure 6), which was secured to the seat and placed between the ischial tuberosities of the participant, according to ISO 2631-1 [21]. The accelerometer on the base of the robot was used to measure the input acceleration, while the accelerometer in the seat pad measured the acceleration being transmitted into the participant.
3.2.5 Data Analysis

Data analysis was performed using four custom MATLAB® programs (version 8.3, The MathWorks Inc., Natick, MA): EMG_Processing.m, ISO_Processing.m, Muscle_Latency.m, and Peak_EMG.m (Appendix B). Raw EMG data for each condition were band pass filtered between 30 and 400 Hz using a fourth order butterworth filter to remove noise, then full wave rectified and linearly enveloped using a fourth order low pass 7 Hz butterworth filter [47]. Filtered EMG data were then normalized by dividing by the maximum value found during the three MVC trials for each muscle. The EMG data were then separated into each vibration profile and the rms value was determined for each profile. Peak EMG data found by determining the maximum value in the 0.5 seconds following each mechanical shock.

Accelerometer data were band pass filtered between 0.4 and 40 Hz in MATLAB® according to ISO 2631-1. ISO 2631-1 health and comfort weightings were applied using the Vibratools™ software package (Axiom EduTech, Ljuserö, Sweden) and then the rms value for
each vibration profile was calculated and used to determine the SEAT value by dividing the seat pad acceleration by the robot acceleration.

Perceived discomfort values were normalized for each participant by subtracting the mean and dividing by the standard deviation according to Dickey et al. [28]. This was done for the perceived discomfort values collected for each vibration profile as well as for the discomfort questionnaire values.

Lastly, muscle latency was determined using an algorithm involving a 25ms sliding window to determine when a value was two standard deviations greater than the baseline EMG data [53]. Visual inspection of the data was also used to confirm when the first peak in EMG data was found following the shock from the robot [53].

3.2.6 Statistics

All statistical analyses were performed using Minitab (version 17.1.0, Minitab, State College, PA) with the exception of one test which could only be performed on SAS (SAS University Edition, SAS Institute, Cary, NC). All analyses performed on Minitab used a multifactorial general linear model. The model equations are found in Table 2. Any data which did not meet conditions of normality had a Johnson transformation applied to produce normalized data that could be used in a multifactorial general linear model. The GLIMMIX procedure, which can only be performed on SAS, was used for the seat pad acceleration data in order to attain the normalized distribution of residuals that is required for a parametric test. The model equation for this procedure can also be found in Table 2. Bonferroni post-hoc procedures were performed when appropriate (p≤0.05).
Table 2: Model equations for statistical analyses

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle Latency</td>
<td>Participant number(sex) + sex + muscle number + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>Peak Muscle Activation</td>
<td>Participant number(sex) + sex + muscle number + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>RMS Muscle Activation</td>
<td>Participant number(sex) + sex + muscle side + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>SEAT Value</td>
<td>Participant number(sex) + sex + frequency + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>Perceived Discomfort (Individual Profiles)</td>
<td>Participant number(sex) + sex + frequency + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>Perceived Discomfort (Questionnaire)</td>
<td>Participant number(sex) + sex + fatigue condition + two way interactions + three way interactions</td>
</tr>
<tr>
<td>Seat Pad Acceleration</td>
<td>Participant number(sex) + sex + frequency + fatigue condition + two way interactions + three way interactions</td>
</tr>
</tbody>
</table>

3.3 Results

The results are separated into the following three sections: acceleration, comfort and electromyography. These results look at similarities and differences between fatigue condition, muscle, frequency and sex that were found within the study.

3.3.1 Acceleration

There was no significant difference in acceleration measured at the seat pad transducer between fatigue conditions. Since ISO predicted comfort scores are directly related to the acceleration measured at the seat pad transducer, this means that there was also no significant difference between fatigue conditions for the ISO predicted comfort scores. Significant differences in the acceleration measured at the seat pad transducer were found between all frequencies, with the exception of 4 Hz and 4.5 Hz (Figure 7). As seen in Figure 7, the acceleration is the highest at 4 Hz, followed closely by 4.5 Hz. The remaining frequencies
have significantly lower accelerations, which decrease as frequency decreases. The 4 Hz frequency having the highest acceleration corresponds with it having the highest SEAT value.

![Seat Pad Acceleration and Seat Effective Amplitude Transmissibility (SEAT) Value for Each Frequency](image)

*Figure 7: Seat pad acceleration and SEAT value (mean ± standard deviation) displayed for each vibration frequency (n=29). 4Hz and 4.5Hz are significantly higher than the other three frequencies, which are all significantly different from one another. All SEAT values are significantly different from one another. Significance is shown separately for acceleration and SEAT.*

3.3.2 Comfort

The perceived discomfort scores for each frequency are presented in Figure 8. A significant difference was found for comfort between fatigue conditions as well as between frequencies, with the fatigued condition and higher frequencies having greater perceived discomfort ratings. It can also be noted that the 4 Hz and 4.5 Hz frequencies have positive normalized scores while the lower frequencies have negative normalized scores. A similar trend can be seen in Figure 9 with all three questions from the perceived discomfort questionnaire. In all three of the questions the fatigued condition yielded significantly higher, positive scores while the unfatigued condition had negative scores.
3.3.3 Electromyography

A significant difference was found in the muscle latency of the back muscles with the post-fatigue condition being significantly longer (0.0738 ± 0.0107s) than pre-fatigue (0.0647 ± 0.0068s). This difference in muscle latency associated with fatigue is also shown in Figure 10,
where the average onset of the muscle activation across all participants is compared to the acceleration of the base and seat pad transducer. This figure demonstrates that the pre-fatigue muscle activation occurs just prior to a rapid decrease in acceleration while the post-fatigue muscle activation occurs slightly after this decrease in acceleration. This rapid decrease in acceleration represents the point when the seat is changing from an increase in velocity to a decrease in velocity, as outlined by Figure 11. The approximate base displacement is also shown (Figure 12) as a reference.

Figure 10: Average muscle onset of the erector spinae muscles following mechanical shock before and after back muscle fatigue (n=29). A significant difference was found between fatigue conditions for the muscle latency. Representative base and seat acceleration for one participant are also plotted.
The mean peak muscle activation following the shock for all of the muscles was found to be significantly higher in the fatigued condition (8.05 ± 7.73%) in comparison to the unfatigued condition (6.91 ± 7.03%). Additionally, muscle activation differences between muscles and sex combined for both fatigue conditions were found and can be seen in Figure 13.
Figure 13: Peak muscle activation after shock (mean ± standard deviation) comparing males (n=18) and females (n=11) for 1: left lumbar erector spinae (LLE) and right lumbar erector spinae (RLE), 2: left thoracic erector spinae (LTE) and right thoracic erector spinae (RTE), 3: left external oblique (LEO) and right external oblique (REO), and 4: left internal oblique (LIO) and right internal oblique (RIO).

Muscle activation data for the four muscles can be found below in Figure 14 through 16. The common factor between all muscle groups is that the activation increased when the frequency increased with the exception of a slight decrease from 4 Hz to 4.5 Hz in LE. When comparing between fatigue conditions the TE muscle activation increased significantly with fatigue, the LE muscle activation increased but not significantly with fatigue and the EO and IO muscle activation were fairly similar between fatigue conditions. The data also shows that while not statistically significant, when comparing males and females, the females used TE more and LE less than males and used both abdominal muscles significantly more than males.
Figure 14: RMS muscle activation (mean ± standard deviation) for the 1: lumbar erector spinae (LE), 2: thoracic erector spinae (TE), 3: external obliques (EO) and 4: internal obliques (IO) for each vibration frequency (n=29).

Figure 15: RMS muscle activation (mean ± standard deviation) for the lumbar erector spinae (LE), thoracic erector spinae (TE), external obliques (EO) and internal obliques (IO) before and after back muscle fatigue (n=29). Statistical comparisons are not made between muscles, significance is shown separately for each muscle.
Additionally, for the lumbar erector spinae there was a significant two-way interaction between frequency and muscle side, as well as significant three-way interactions between sex, frequency and muscle side as well as sex, muscle side and fatigue condition. The thoracic erector spinae, external obliques and internal obliques had a significant muscle side*fatigue condition interaction. The external obliques had a significant interaction between sex*muscle side. While these interactions were statistically significant, the interaction with muscle side did not provide any practical relevance as all differences between muscle side were slight and the side with the higher activation varied between muscles with no discernable pattern.

Additionally, there were not enough left-handed participants to determine if the difference was caused by handedness. All interaction plots can be found Appendix A.
3.4 Discussion

When looking at the acceleration data it is apparent that the 4 Hz and 4.5 Hz frequencies produce higher accelerations than the lower frequencies, increasing their likelihood of causing injury to the person exposed to the vibration over an extended period of time [15]–[19]. The SEAT value also shows that 1.25 Hz, 2 Hz and 4.5 Hz are all close to 100% transmissibility, while 2.5 Hz and 4 Hz significantly increase the acceleration at the seat pan. This indicates that the natural frequency of the seat is somewhere between these two frequencies, and most likely closer to 4 Hz since it has the highest SEAT value. This is because the transmissibility of a seat when looking between vibration frequencies is highest at the natural frequency of the seat and decreases as the frequency gets further from the natural frequency [54].

The perceived discomfort ratings for each 20 second vibration profile, as well as the questionnaire, showed that participants felt more discomfort after their back muscles were fatigued. This corresponds with a previous study that noted an increase in discomfort caused by muscle fatigue [55]. This increase in perceived discomfort shows that when people are fatigued, which happens from extended exposure to WBV [32], [39], [40], that they start to feel increased discomfort from the same vibration exposure. The increase in perceived discomfort from the same acceleration level is potentially due to external factors such as participant well being, mood and temperature which have been shown to affect discomfort [22], [23] and would be affected by the fatiguing process. The fatigued muscles may have felt the impact of the vibration more and been in some pain from the fatiguing process, which could have altered the well being or mood of the participants. Additionally, the participants
could have been hotter from performing the fatiguing protocol which could have also altered perceived discomfort.

These results contradict the ISO 2631-1 comfort values, which did not change between fatigue conditions since the seat pad acceleration values, and therefore the predicted comfort values, did not change. The assumption in ISO 2631-1 is that comfort values are the same throughout the entire WBV exposure and are solely dependent on the seat pad acceleration. What these results have shown is that ISO 2631-1 is not effective at predicting comfort after prolonged exposure to WBV as it overestimates comfort when participants are in a fatigued condition. Since discomfort can be used as an indicator for future risk of injury [27], [30], the increase in discomfort in the fatigued condition signifies that fatigued back muscles increase the risk of injury in the back when exposed to WBV.

Not only did the questionnaire results show that participants felt more discomfort from the seat and seat pan in the fatigued condition, but also that they felt it required more effort to maintain an upright posture when they were fatigued. This corresponds with the EMG data, which showed increases in the back muscle activity when participants were fatigued. The increased effort to maintain an upright posture meant that the back muscles had to be activated more after they were fatigued in order to keep the same posture. This increased effort to maintain an upright posture also signifies that the participants had more difficulty maintaining spinal stability when their back muscles were fatigued.

Another interesting result from the perceived discomfort ratings was that participants felt that the 4.5 Hz vibration was more uncomfortable than 4 Hz, despite 4 Hz having a higher seat pad acceleration. This could be due to their feet being in direct contact with the robot
platform and feeling a different level of acceleration than the rest of the body, or it could also be due to the robot making a louder noise at 4.5 Hz. Both of these factors can affect discomfort [22], [23].

The significant difference found between fatigue conditions for muscle latency shows how back muscle fatigue, which can occur after prolonged exposure to WBV [31], [32], [56], can leave the spine at an increased risk for injury. This is because the reflex muscle activation is one of the main forms of protection from shock injury due to it stiffening the system at the correct time [37], [38]. If this system is delayed even the slightest amount, it can cause a buckling of the spine that can lead to low back injuries [37], [38]. If the reflexes have a large enough delay, then instead of stabilizing the system, the muscle activation can destabilize it, causing further injury [57]. Additionally, the increased peak activation following the mechanical shocks in the fatigued condition also place the spine at greater risk for injury because this increases the compressive force on the spine [41]. The increased latency and muscle activation following the mechanical shocks show how muscle fatigue has created a less stable spinal system, which the body has attempted to counteract by increasing the muscle activation. However, if larger mechanical shocks were applied, this less stable system may not be able to stiffen in time and the spine may buckle and cause low back injuries [37], [38].

The electromyography results from all four muscles showed a relationship between acceleration and muscle activity, with a higher acceleration being associated with higher muscle activation in all muscles. Another trend that can be noted from the muscle activation is the increase in the two back muscles in the post-muscle fatigue condition, with TE increasing significantly over pre-fatigue levels. This increase was not noted in the abdominal muscles,
which had very similar activations before and after muscle fatigue. This difference is most likely because the back muscles were fatigued, which has been shown to increase muscle activation in order to maintain the same muscle force [44], [45].

The muscle activation levels for all muscles were typically between 1-5% MVC. While these levels are fairly low, when considering that operators of heavy machinery may be sustaining these muscle activation levels throughout an 8-hour work day and given that activation levels tend to increase with muscle fatigue, these low levels may still be dangerous. It has been hypothesized that prolonged muscle activation as low as 2-5% MVC can lead to injury [14], therefore, this level of WBV exposure has the potential to injure workers if they are exposed to it throughout the work day.

The difference in muscle activation between sexes is of interest since there hasn’t been a large amount of research in this area. The significantly higher abdominal muscle activation in females, which has been found in one previous study [58], could indicate that back muscles in females are not as strong as males, thus requiring increased abdominal activation to maintain spinal stability [13], [44], [59]. While not significantly different, the trend towards increased use of the TE relative to the decreased use of the LE in females compared to males, suggests that females use their back muscles in a different way than males to provide stability. This could be because males and females have been found to adopt different trunk postures when seated [60], [61]. Females have been found to rotate their pelvis more and keep their back straighter, while males tend to rotate their pelvis less and flex their backs more [61]. This more flexed posture in the males may cause flexion relaxation to occur, which is more likely to occur in more flexed lumbar postures [61], [62]. Flexion relaxation occurs when the muscles
begin to activate less and the passive tissues take more of the load [62]. While flexion relaxation is triggered by a flexed lumbar posture, it has been found to affect the thoracic erector spinae instead of the lumbar erector spinae [62]. This means that if flexion relaxation were happening, that the thoracic erector spinae would be activating less, which corresponds with the results shown in the males compared to the females. Therefore, it is possible that the difference found in the erector spinae muscles is due to males adopting a more flexed lumbar posture and causing flexion relaxation to occur. This is further reinforced by the increased muscle activation in the thoracic erector spinae and abdominal muscles in females, since maintaining a straighter posture requires increased muscle activation [61].

3.5 Conclusion

In general, results indicate that a person is at an increased risk for low-back injury when their back muscles are fatigued and they are exposed to WBV. This is due to the increase in trunk muscle latency, peak muscle activation following mechanical shock, rms muscle activation in the back muscles, and perceived discomfort following the fatiguing protocol, which all increase the risk of various low-back injuries. While some of these risks have been shown previously for WBV or muscle fatigue separately, the increase in all of these parameters in the fatigued condition has shown that the risks are amplified when both WBV and muscle fatigue are present.

Additionally, the increase in perceived discomfort and effort to maintain an upright posture in the fatigued condition indicate that the participants felt more vibrational discomfort when their muscles were fatigued and had more difficulty maintaining spinal stability. When comparing this increased discomfort in the fatigued condition to the ISO 2631-
1 comfort ratings, which did not change with fatigue, it is apparent that ISO 2631-1 overestimates comfort when muscles are fatigued. These results require further investigation to determine the significance and magnitude of this overestimation.

The difference found in muscle activation patterns between males and females also indicates that males may have adopted a more flexed spinal posture, leading to flexion relaxation and a decrease in thoracic erector spinae muscle activity. This change in muscle activation patterns between sexes may indicate a difference in posture based on these previous studies, however future testing that includes a spinal posture analysis would provide further confirmation of this conclusion.

While these results provided a clear indication that injury risk factors and perceived discomfort were increased following fatigue, additional testing is required for horizontal and multi-axial sinusoidal vibration as well as field-based vibration profiles in order to confirm if the results from this study can be generalized.

4.6 Reference


Chapter 4: Discussion, Conclusions and Recommendations

4.1 Introduction

This chapter provides a discussion on the previous chapters and draws conclusions from the entire thesis. Additionally, previously unavailable contributions to the literature are described and recommendations for future work are provided.

4.2 Discussion

Since it has been shown that prolonged exposure to WBV can lead to muscle fatigue [1]–[4], a fatigued muscle state can be used to simulate how the muscles of a person exposed to WBV for an extended period of time would react. This project was the first research to show the effects that a fatigued muscle state has on the human body exposed to WBV. These effects include an increase in back muscle latency and peak muscle activation following a mechanical shock, an increase in overall back muscle activation, and an increase in perceived discomfort despite no changes in comfort levels predicted by ISO 2631-1.

The increase in back muscle latency following fatigue means that the spine is more susceptible to shock injury when the back muscles are fatigued since the muscles cannot activate at the same rate to stiffen the spine system [5], [6]. This was further shown by the peak activation following the muscle reflex increasing, which occurs when the muscles compensate for the delay in the muscle reflex [7]. These results were found by using mechanical shocks that simulate the sudden movement of off-road mobile heavy machinery. These types of shocks have not been used to test changes in muscle latency and activation from WBV or muscle fatigue before.
Back muscle activation increased significantly in the TE and insignificantly in the LE following muscle fatigue, meaning that these muscles were placing a greater load on the spine in the fatigued condition, thus increasing the risk of injury [8]–[10]. Additionally, the differences found in activation patterns between males and females is of interest. The increased abdominal muscle activation indicates that females may have had a decreased spinal stability compared to males, requiring increased abdominal muscle activation to provide additional stability [11]–[13]. It is also possible that males and females adopted different postures, as males have been found to sit with a more flexed lumbar posture, which can cause flexion relaxation, thus leading to decreased thoracic lumbar muscle activation [14], [15]. This difference in posture may have also resulted in an increase in muscle activation in females, which was observed in three of the four muscles, as a more upright posture has been shown to increase muscle activation [14].

No differences were found between fatigue conditions for any acceleration level, which is expected since the acceleration levels are based on robot movement, not the condition of the participant. However, the lack of change in the acceleration levels means that the ISO 2631-1 comfort levels also remain unchanged, which is contrary to the perceived discomfort ratings. In all perceived discomfort testing (i.e., individual vibration profile ratings and questionnaire ratings), the fatigued condition resulted in higher perceived discomfort. This means that the perceived discomfort was not only impacted by the vibration, but also by external factors related to muscle fatigue. This result indicates that ISO 2631-1 comfort ratings do not account for the effects of muscle fatigue, and therefore, overestimate comfort for prolonged WBV exposure.
4.3 Conclusions

The results of this project provide insight into the negative impacts of fatigue on the human body when exposed to whole-body vibration. When fatigued back muscles experience sudden perturbations, they take longer to react and activate with increased magnitude to compensate for the delayed reaction in order to provide the necessary stiffness to the spine. The back muscles also have increased activation throughout the entire vibration exposure to compensate for being fatigued, which places a greater load on the spine. These results indicate that there is an increased risk for injury when the back muscles are fatigued during WBV exposure. Additionally, there was an increased discomfort perceived in the fatigued condition and it was more difficult to maintain an upright posture. This was contrary to the ISO 2631-1 comfort rating, which did not change with fatigue.

4.4 Contributions

This thesis work provided the following previously unavailable contributions to the literature:

- Effect of vertical whole-body vibration on fatigued back muscles was quantified.
- A possible overestimation of comfort levels predicted by ISO 2631-1 after prolonged exposure to whole-body vibration was identified.
- The impact of whole-body vibration and muscle fatigue on muscle latency was assessed using mechanical shocks similar to what would be experienced in off-road heavy mobile machinery.
- Differences in muscle activation patterns under WBV loading were observed between males and females following a fatiguing protocol.
4.5 Future Work

This research was intended as an initial analysis of the impacts of muscle fatigue during WBV on muscle latency and activation. Due to the success of this research in outlining the impacts that vertical whole-body vibration has on the fatigued human body, several areas of future research have been identified, which include:

• Determining the impact of muscle fatigue during horizontal, multi-axial and 6 degree-of-freedom whole-body vibration on muscle latency and activation.

• Field testing for heavy machinery with fatigued participants

• Assessment of ISO 2631-1 comfort rating accuracy after prolonged WBV exposure

• Determination of how postural changes affect muscle activation patterns in males and females when exposed to WBV

4.6 References


Appendix A – Interaction Plots

Lumbar Erector Spinae

**Figure 17:** Interaction plot for lumbar erector spinae RMS muscle activation with factors of muscle side and vibration frequency (n=29).

**Figure 18:** Interaction plot for lumbar erector spinae RMS muscle activation with factors of sex and vibration frequency (n=29).
Figure 19: Interaction plot for lumbar erector spinae RMS muscle activation with factors of sex and muscle side (n=29).

Figure 20: Interaction plot for lumbar erector spinae RMS muscle activation with factors of sex and fatigue condition (n=29).
Figure 21: Interaction plot for lumbar erector spinae RMS muscle activation with factors of muscle side and fatigue condition (n=29).

Thoracic Erector Spinae

Figure 22: Interaction plot for thoracic erector spinae RMS muscle activation with factors of muscle side and fatigue condition (n=29).
External Obliques

**Figure 23**: Interaction plot for external oblique RMS muscle activation with factors of sex and muscle side (n=29).

**Figure 24**: Interaction plot for external oblique RMS muscle activation with factors of muscle side and fatigue condition (n=29).
Internal Obliques

Figure 25: Interaction plot for internal oblique RMS muscle activation with factors of muscle side and fatigue condition (n=29).
CONSENT TO PARTICIPATE IN RESEARCH

“The Evaluation of a Vibration Dampening Device and Seating Configurations based on Vibration Transmission and Spine Posture”

I, ____________________________, am interested in participating in the study on Evaluation of a Vibration Dampening Device and Seating Configurations based on Vibration Transmission and Spine Posture (REB#: 17-08-006) conducted by Principal Investigator Dr. Michele Oliver (University of Guelph) and Masters Student Alex Nolan (University of Guelph).

PURPOSE OF THE STUDY

The purpose of this project is to evaluate the vibration dampening effects of different seats including a novel whole-body vibration dampening device. While evaluating these seats the spinal posture and abdominal and low back muscle activation will be assessed to understand the impact of vibration on the spine. The vibration profiles used to evaluate the seats will be similar to those found in heavy machinery and vehicle operation where occupants are often exposed to high levels of whole-body vibration.

PROCEDURES

If I agree to participate:

I will be asked questions about my health to determine if I am appropriate for this study. If I am not appropriate for this study I will not be able to be involved in this study.

If I pass the physical activity readiness questionnaire, I will be asked to sit on a seat on top of a hexapod robot. I will remain seated while the hexapod robot applies a vibration profile similar to what would be experienced while operating heavy machinery or vehicles. I will do this for multiple tests while wearing a form-fitting shirt.

Surface electromyography will be used to monitor the electrical activity of certain muscles during the study. Specialized electrodes will be placed on my skin using adhesive tape.

If the previous physical activity readiness questionnaire has determined me to be in good enough health, and without cardiovascular risk, I will be asked to perform isometric maximum voluntary contractions of each muscle individually for five seconds each, twice, with a three to five minute rest between each test. These measurements are used to compare my muscle activity during the study to a known value (normalization of the EMG signal).
I will be issued a special form-fitting t-shirt that has a special pouch made to hold a fiber-optic sensor. This fiber-optic sensor will sit against my spine to measure the posture of my spine.

I will perform a muscle fatiguing protocol which will involve the use of my low back and abdominal muscles until they are tired.

I will have a practice run on the hexapod robot with basic vibrations applied to ensure I am comfortable with the movements. I have been told that I can stop the motion in the hexapod robot at any time by pressing a switch. I have also been shown the railings on the robot and instructed to use these to stabilize myself if I feel that I may fall off of the seat. I have also been told that I may stop the motion of the robot at any time if I feel that I may fall off of the seat. My participation is strictly voluntary and I am free to withdraw from the study at any time or refuse to participate without any penalty.

POTENTIAL RISKS AND DISCOMFORTS

The electrodes will be placed directly on the skin using double sided tape, and some will be placed on areas including the front and back of the torso (placement can be seen in the diagram below). Therefore the electrodes will be placed under the t-shirt provided. If I am uncomfortable with the electrodes or their placement, I am free to terminate and leave the study.

When I change into another short-sleeved t-shirt there will be a change room provided so that I can change in privacy. If I feel uncomfortable I am free to withdraw from the study at any time.

The fatiguing protocol requires extensive use of the low back and abdominal muscles and there is a risk of developing soreness in these muscles. This can be considered fairly normal over the 24-48 hours after these actions are performed. However, if this discomfort persists, or the discomfort is considered substantial or unusual, I should contact a medical profession as well as Dr. Oliver (contact information below). Should I not feel comfortable performing the exercises required to tire these muscles I am free to withdraw from the study at any time.

When experiencing heavy vibration, especially after a fatigue protocol, there is a risk of low back injuries such as intervertebral disc injuries. Should I feel any tightness, pain or discomfort in my back beyond 48 hours of performing these tasks I should contact a medical professional as well as Dr. Oliver (contact information below). I have also been advised to avoid situations involving exposure to whole-body vibration such as the operation of heavy machinery or farm equipment within 24 hours of this completing this trial. Should I not feel comfortable with these risks I am free to withdraw from the study at any time. I have also been advised not to undertake any stressful activities, specifically activities that require the trunk muscles, immediately before or after participation.

When experiencing vibration on a hexapod robot, some people begin to feel uncomfortable. Should I begin to feel uncomfortable, I will tell the researcher and the robot will be stopped immediately. If these feelings are extremely mild, I will be given a chance to continue if I would like, but otherwise the experiment will be stopped and the researcher will take care of me until I feel better (cold water, rest). Research personnel will be able to see me at all times so that they can also keep an eye on me while I am on the robot to make sure I am not beginning to
experience any discomfort. If they see that I am showing signs of discomfort, they may stop the robot. The researchers can stop the procedure at any time for me and do not need to wait to notice my discomfort if they believe there is a reason to halt the procedure. Whether I stop the robot or it is stopped for me, I will be taken care of until I feel better. There is no penalty to stopping early.

Pictures

Figure 26: hexapod robot

Figure 27: vibration dampening seat

Figure 28: Location of the EMG electrodes

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.
I have received assurance from the researchers that all data collected will be de-identified and my identity will remain strictly confidential. **My participation is strictly voluntary** and I am free to withdraw from the study at any moment or refuse to participate without any penalty. If I choose to withdraw, I can have my data also withdrawn by notifying the research team. I have received assurance from the researchers that all data collected will remain strictly confidential. Data may be retained so that the current investigation may later be revisited and so that future investigations may be facilitated. Only group statistics will be reported, individual data will not be reported and my name will not be reported to anyone. All collected data will be coded with a participant number and the master list will be stored in a locked filing cabinet (in Dr. Oliver’s office) or a password secured laptop (only members of the research team will have access to the data). After a period of 10 years paper documents collected will be shredded.

**COMPENSATION FOR PARTICIPATION**
I understand that I will receive no immediate benefit from my participation.

**FUNDING FOR RESEARCH**
The funding for this research has been provided by NSERC.

There are two copies of this consent form; one which the researcher keeps and one that I keep.
If I have any questions or concerns about the study or about being a subject, I may call or email
Michele Oliver – 519-824-4120 ext. 52117, moliver@uoguelph.ca

If you have questions regarding your rights as a research participant, contact:
Director: Research Ethics
University of Guelph
437 University Centre
Guelph, ON N1G 2W1

Telephone: (519) 824-4120, ext. 56606
E-mail: sauld@uoguelph.ca

I agree to participate in this study. I have read the information provided for the study, and my questions have been answered to my satisfaction.

Participant’s Name (Please Print): _________________________
Participant’s Signature: ___________________________ Date: ___________________________

Researcher’s Name (Please Print): _________________________
Researcher’s Signature: ___________________________ Date: ___________________________

PID (assigned by the research team) _____________________ THANK YOU FOR YOUR PARTICIPATION.
Physical Activity Readiness Questionnaire

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

This form is used to ensure that a person is fit to perform maximum voluntary contractions.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

• You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
• Find out which community programs are safe and helpful for you.

If you answered NO to all questions

DELAY BECOMING MUCH MORE ACTIVE:
• You are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better.
• You are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional: Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.
Spine Injury Risk Assessment Questionnaire

Please answer the following questions honestly regarding your potential risk for spine injury. This information will be used to determine if you are at a potentially increased risk of spine injury from the activities that you will be performing.

1. Does your back tighten when you sit for 10-20 minutes, for example, in a car or at a desk? [Yes] [No]

2. When you first wake up in morning, do you experience low back stiffness that goes away after 15-20 minutes? [Yes] [No]

3. Do you experience tightness, tingling, or numbness in your buttock region or the back of your leg when you sit for prolonged periods? [Yes] [No]

4. Have you ever experienced pain in the abdominal or low back region that has caused you to miss school, work or any regular activity? [Yes] [No]

5. Have you ever sought medical treatment (physician, chiropractor, physiotherapist) relating to your abdominal or low back region? [Yes] [No]

6. Have you been exposed to whole-body vibration (such as operating heavy machinery or farm equipment) for a prolonged period of time within 24 hours of this trial? [Yes] [No]

If you answered yes to any of these questions please discuss this with the researcher.

ID Number: ____________________ Date: ____________________

Witness: ____________________
Seat Discomfort Questionnaire

For the following questions please make a mark along the scale to indicate at what point along the scale you would like to choose. Please note this can be either on a number or anywhere between the numbers.

ID Number: ______________

Test Number (1-4): ______

1. How would you rate the discomfort of the seat overall?

Zero Discomfort

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

Maximum Discomfort

2. How would you rate the discomfort of the seat pan (what you sit on)?

Zero Discomfort

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

Maximum Discomfort

3. How would you rate the effort it required for you to maintain your seated posture?

Zero Discomfort

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

Maximum Discomfort
Appendix C – Matlab® Code

EMG Processing

 globals

 % Author: Alex Nolan
 % Date Created: June 23, 2018
 % Code will:
 % - read in EMG data, process it and normalizes to MVC
 % - separate data by vibration profile and calculate rms
 % - write data to a file
 %

 clc
 clear all
 close all

%%%enter participant information before starting code
ppt = 34;
sex = 1; % 1 more male, 2 for female
age = 20;
weight = 72;
height = 1.73;
hand = 1; % 1 for right, 2 for left

%input sequence 1 data
emgraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 5, 2, [5, 2, 1320004, 9]);

% create time variable
etime1 = 0:(1/2000):((length(emgraw1)-1)/2000);

% Bandpass filter raw EMG
[b,a]=butter(4,[30/1000 400/1000], 'bandpass');
emgband1 = filtfilt(b,a,emgraw1);

% take absolute value of emg data
emgabs1 = abs(emgband1);

% create 7Hz linear envelope
[b,a]=butter(4,7/1000, 'low');
emgl = filtfilt(b,a,emgabs1);

% use MVC function to get MVCs
[MVCLEO,MVCLIO,MVCLLE,MVCLTE,MVCREO,MVCRIO,MVCRLE,MVCRTE]=MVCs(ppt);

% divide emg by MVCs to get %MVC activation
emgmvc1(:,1) = emgl(:,1)./MVCLLE*100;
emgmvc1(:,2) = emgl(:,2)./MVCRLE*100;
emgmvc1(:,6) = emg1(:,3)./MVCRIO*100;
emgmvc1(:,5) = emg1(:,4)./MVCLIO*100;
emgmvc1(:,3) = emg1(:,5)./MVCLTE*100;
emgmvc1(:,4) = emg1(:,6)./MVCRTE*100;
emgmvc1(:,8) = emg1(:,7)./MVCREO*100;
emgmvc1(:,7) = emg1(:,8)./MVCLEO*100;

%calculate average activation for each muscle
rmsemg1 = rms(emgmvc1);

%perform the same processing for the second sequence
emgraw2 = csvread(strcat(num2str(ppt), 'sequence2_1.csv'), 5, 2, [5, 2, 1320004, 9]);

%create time variables
etime2 = 0:(1/2000):((length(emgraw2)-1)/2000);

%Bandpass filter raw EMG
[b,a] = butter(4, [30/1000 400/1000], 'bandpass');
emgband2 = filtfilt(b,a,emgraw2);

%take absolute value of emg data
emgabs2 = abs(emgband2);

%create 7Hz linear envelope
[b,a] = butter(4, 7/1000, 'low');
emg2 = filtfilt(b,a,emgabs2);

%divide emg by MVCs to get %MVC activation
emgmvc2(:,1) = emg2(:,1)./MVCLLE*100;
emgmvc2(:,2) = emg2(:,2)./MVCRLE*100;
emgmvc2(:,6) = emg2(:,3)./MVCRIO*100;
emgmvc2(:,5) = emg2(:,4)./MVCLIO*100;
emgmvc2(:,3) = emg2(:,5)./MVCLTE*100;
emgmvc2(:,4) = emg2(:,6)./MVCRTE*100;
emgmvc2(:,8) = emg2(:,7)./MVCREO*100;
emgmvc2(:,7) = emg2(:,8)./MVCLEO*100;

%calculate average activation for each muscle
rmsemg2 = rms(emgmvc2);

%read in profiles from csv file
profile1 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 0, [0, 0, 27, 2]);
profile2 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 3, [0, 3, 27, 5]);

%sort vibration profiles
j = 1;
for i = 1:28
    if profile1(i,1) < 10
        vibprofile1(j,1:3) = profile1(i,1:3);
        j = j+1;
    end
end
end

j = 1;
for i = 1:28
    if profile2(i,1) < 10
        vibprofile2(j,1:3) = profile2(i,1:3);
        j = j+1;
    end
end

% change accel frames into emg frames
vibprofile1(:,2) = vibprofile1(:,2).*2;
vibprofile1(:,3) = vibprofile1(:,3).*2;

% change accel frames into emg frames
vibprofile2(:,2) = vibprofile2(:,2).*2;
vibprofile2(:,3) = vibprofile2(:,3).*2;

% separate emg data into vibration profiles
for i = 1:25
    profactiv11(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),1);
    profactiv12(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),2);
    profactiv13(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),3);
    profactiv14(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),4);
    profactiv15(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),5);
    profactiv16(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),6);
    profactiv17(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),7);
    profactiv18(:,i) = emgmvc1(vibprofile1(i,2):vibprofile1(i,3),8);

    profactiv21(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),1);
    profactiv22(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),2);
    profactiv23(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),3);
    profactiv24(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),4);
    profactiv25(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),5);
    profactiv26(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),6);
    profactiv27(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),7);
    profactiv28(:,i) = emgmvc2(vibprofile2(i,2):vibprofile2(i,3),8);
end

% sort by frequency for sequence 1
freq_num(1:5,1) = find(vibprofile1(:,1) == 1.25);
freq_num(1:5,2) = find(vibprofile1(:,1) == 2);
freq_num(1:5,3) = find(vibprofile1(:,1) == 2.5);
freq_num(1:5,4) = find(vibprofile1(:,1) == 4);
freq_num(1:5,5) = find(vibprofile1(:,1) == 4.5);

% calculate rms for each profile for sequence 1
for i = 1:5
    avg11(i,1) = mean(rms(profactiv11(:,freq_num(:,i))));
end
avg12(i,1) = mean(rms(profactiv12(:,freq_num(:,i))))
avg13(i,1) = mean(rms(profactiv13(:,freq_num(:,i))))
avg14(i,1) = mean(rms(profactiv14(:,freq_num(:,i))))
avg15(i,1) = mean(rms(profactiv15(:,freq_num(:,i))))
avg16(i,1) = mean(rms(profactiv16(:,freq_num(:,i))))
avg17(i,1) = mean(rms(profactiv17(:,freq_num(:,i))))
avg18(i,1) = mean(rms(profactiv18(:,freq_num(:,i))))
end

%sort by frequency for sequence 2
freq_num(1:5,1) = find(vibprofile2(:,1) == 1.25);
freq_num(1:5,2) = find(vibprofile2(:,1) == 2);
freq_num(1:5,3) = find(vibprofile2(:,1) == 2.5);
freq_num(1:5,4) = find(vibprofile2(:,1) == 4);
freq_num(1:5,5) = find(vibprofile2(:,1) == 4.5);

%calculate rms for each profile for sequence 2
for i = 1:5
    avg21(i,1) = mean(rms(profactiv21(:,freq_num(:,i))))
    avg22(i,1) = mean(rms(profactiv22(:,freq_num(:,i))))
    avg23(i,1) = mean(rms(profactiv23(:,freq_num(:,i))))
    avg24(i,1) = mean(rms(profactiv24(:,freq_num(:,i))))
    avg25(i,1) = mean(rms(profactiv25(:,freq_num(:,i))))
    avg26(i,1) = mean(rms(profactiv26(:,freq_num(:,i))))
    avg27(i,1) = mean(rms(profactiv27(:,freq_num(:,i))))
    avg28(i,1) = mean(rms(profactiv28(:,freq_num(:,i))))
end

%plot figures
figure()
subplot(2,4,1)
x = [1:5];
labels = {'1.25' '2' '2.5' '4' '4.5'};
bar(x,avg11)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg21, 0.5, 'r')
set(gca, 'xticklabel', labels)
legend('unfatigued', 'fatigued')
title('Left Lumbar Erector')

subplot(2,4,2)
bar(x,avg12)
hold on
%bar(avg22,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg22, 0.5, 'r')
set(gca, 'xticklabel', labels)
%legend('unfatigued', 'fatigued')
title('Right Lumbar Erector')

subplot(2,4,3)
bar(x,avg13)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg23, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Left Thoracic Erector')

subplot(2,4,4)
bar(x,avg14)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg24, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Right Thoracic Erector')

subplot(2,4,5)
bar(x,avg15)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg25, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Left Internal Oblique')

subplot(2,4,6)
bar(x,avg16)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg26, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Right Internal Oblique')

subplot(2,4,7)
bar(x,avg17)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg27, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Left External Oblique')

subplot(2,4,8)
bar(x,avg18)
hold on
%bar(avg21,'facecolor', 'r', 'BarWidth', 0.5)
bar(x,avg28, 0.5, 'r')
set(gca,'xticklabel',labels)
%legend('unfatigued', 'fatigued')
title('Right External Oblique')
suptitle('rms values for each muscle at each frequency pre and post fatigue')
figure()
x = [1:8];
labels = {'LLE' 'RLE' 'LTE' 'RTE' 'LIO' 'RIO' 'LEO' 'REO'};
bar(x, rmsemg1)
hold on
bar(x, rmsemg2, 0.5, 'r')
set(gca,'xticklabel',labels)
legend('unfatigued', 'fatigued')
title('rms data for each muscle pre and post fatigue')

%plot enveloped emg from sequence 1
figure()
subplot(2,2,1)
plot(etime1,emgmvc1(:,1))
hold on
plot(etime1,emgmvc1(:,2), 'r')
title('Lumbar Erectors')
legend('Left','Right')

subplot(2,2,2)
plot(etime1,emgmvc1(:,3))
hold on
plot(etime1,emgmvc1(:,4), 'r')
title('Thoracic Erectors')
legend('Left','Right')

subplot(2,2,3)
plot(etime1,emgmvc1(:,5))
hold on
plot(etime1,emgmvc1(:,6), 'r')
title('Internal Obliques')
legend('Left','Right')

subplot(2,2,4)
plot(etime1,emgmvc1(:,7))
hold on
plot(etime1,emgmvc1(:,8), 'r')
title('External Obliques')
legend('Left','Right')
suptitle('MVC activation over time for each muscle pre-fatigue')

%plot enveloped emg for same muscle
figure()
subplot(2,2,1)
plot(etime2,emgmvc2(:,1))
hold on
plot(etime2,emgmvc2(:,2), 'r')
title('Lumbar Erectors')
legend('Left','Right')

subplot(2,2,2)
plot(etime2,emgmvc2(:,3))
hold on
plot(etime2, emgmvc2(:,4), 'r')
title('Thoracic Erectors')
legend('Left','Right')

subplot(2,2,3)
plot(etime2, emgmvc2(:,5))
hold on
plot(etime2, emgmvc2(:,6), 'r')
title('Internal Obliques')
legend('Left','Right')

subplot(2,2,4)
plot(etime2, emgmvc2(:,7))
hold on
plot(etime2, emgmvc2(:,8), 'r')
title('External Obliques')
legend('Left','Right')
suptitle('%MVC activation over time for each muscle post-fatigue')

%comparing abs to back muscles
emgback1 = [rmsemg1(1) rmsemg1(2) rmsemg1(3) rmsemg1(4)];
emgab1 = [rmsemg1(5) rmsemg1(6) rmsemg1(7) rmsemg1(7)];
emgback2 = [rmsemg2(1) rmsemg2(2) rmsemg2(3) rmsemg2(4)];
emgab2 = [rmsemg2(5) rmsemg2(6) rmsemg2(7) rmsemg2(7)];

emgback1 = mean(emgback1);
emgab1 = mean(emgab1);
emgback2 = mean(emgback2);
emgab2 = mean(emgab2);

y = [emgback1 emgback2 emgab1 emgab2];

figure()
x = [1:4];
labels = {'back pre-fatigue' 'back post-fatigue' 'abs pre-fatigue' 'abs post-fatigue'};
bar(x, y)
set(gca,'xticklabel',labels)
title('rms values comparing back to ab muscles')

%write data to file
pptnum = repmat(ppt, [400,1]);
sex = repmat(sex, [400,1]);
age = repmat(age, [400,1]);
weight = repmat(weight, [400,1]);
height = repmat(height, [400,1]);
hand = repmat(hand, [400,1]);
z = [1:8]';
emgmvc(1:16,1) = repmat(ppt, [16,1]);
emgmvc(1:16,2) = repmat(z,[2,1]);
emgmvc(1:16,3) = [1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2]';
emgmvc(1:16,4) = [rmsemg1 rmsemg2]'
for i = 1:25
    profnum(i*8-7:i*8,1) = repmat(i,[8,1])';
    profnum(i*8-7+25*8:i*8+25*8,1) = repmat(i,[8,1])';
end
for i = 1:25
    freq(i*8-7:i*8,1) = repmat(vibprofile1(i,1),[8,1])';
    freq(i*8-7+25*8:i*8+25*8,1) = repmat(vibprofile2(i,1),[8,1])';
end
z = [1:8]';
muscle = repmat(z,[50,1]);
fatiguecond(1:200,1) = repmat(1, [200,1]);
fatiguecond(201:400,1) = repmat(2, [200,1]);
for i = 1:25
    profdata(:,i*8-7) = rms(profactiv11(:,i));
    profdata(:,i*8-6) = rms(profactiv12(:,i));
    profdata(:,i*8-5) = rms(profactiv13(:,i));
    profdata(:,i*8-4) = rms(profactiv14(:,i));
    profdata(:,i*8-3) = rms(profactiv15(:,i));
    profdata(:,i*8-2) = rms(profactiv16(:,i));
    profdata(:,i*8-1) = rms(profactiv17(:,i));
    profdata(:,i*8) = rms(profactiv18(:,i));
    profdata(:,200+i*8-7) = rms(profactiv21(:,i));
    profdata(:,200+i*8-6) = rms(profactiv22(:,i));
    profdata(:,200+i*8-5) = rms(profactiv23(:,i));
    profdata(:,200+i*8-4) = rms(profactiv24(:,i));
    profdata(:,200+i*8-3) = rms(profactiv25(:,i));
    profdata(:,200+i*8-2) = rms(profactiv26(:,i));
    profdata(:,200+i*8-1) = rms(profactiv27(:,i));
    profdata(:,200+i*8) = rms(profactiv28(:,i));
end
profdata = profdata';
emgprofiles =
    [pptnum,sex,age,weight,height,hand,freq,muscle,fatiguecond,profdata];
csvwrite(strcat(num2str(ppt),'EMG_Data_Profiles.csv'), emgprofiles);
ISO Processing

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Author: Alex Nolan
% Date Created: June 27, 2018
% %
% Code will:
% - read in accelerometer data and apply ISO weightings
% - separate data by vibration profile and perform calculations
% - write data to a file
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc
clear all
close all

%run vibrapath
run('vibrapath.m')

%%%enter participant information before starting code
ppt = 34;
sex = 1; % 1 more male, 2 for female
age = 20;
weight = 72;
height = 1.73;
hand = 1; % 1 for right, 2 for left

%load acceleration data for pre-fatigued trial
accelraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 1, 1320011, 2, [1320011, 2, 1980010, 3]);
accelraw1 = accelraw1./1000;
[b,a]=butter(2, [0.4/500 40/500], 'bandpass');
accelraw1 = filtfilt(b,a,accelraw1);

%create time variable
atime = 0:(1/1000):((length(accelraw1)-1)/1000);

%set sampling rate
fs = 1000;

%%%pad the data to prevent issues with ISO filtering%%% 

% calculate the amount of padding need to make the data file the new length
IIIpadding=115*fs;

% create an inverted mirror image of the end of the data that is the
% necessary padding length and pad the data
arraysize=size(accelraw1);
IIIlenght=arraysize(:,1);

post_datapadding=padarray(accelraw1,IIIpadding+2,'symmetric','post');
pre_datapadding=padarray(accelraw1,IIIpadding+2,'symmetric','pre');

inverted_post_datapadding=(post_datapadding(IIIlength+1:IIIlength+IIIpadding+2,:))|--1;
inverted_pre_datapadding=(pre_datapadding(1:IIIpadding+2,:))|--1;

clear post_datapadding
clear pre_datapadding

acc_padded1=[inverted_pre_datapadding(2:IIIpadding+1,:);accelraw1;inverted_post_datapadding(2:IIIpadding+1,:)];

clear inverted_post_datapadding
clear inverted_pre_datapadding

%%%%apply ISO weighting%%%%
weighted_acc_padded1 = isofilwk(acc_padded1(:,1),fs);
weighted_acc_padded2 = isofilwk(acc_padded1(:,2),fs);

%%%%remove padding%%%%
weighted_acc_unpadded1 = weighted_acc_padded1(IIIpadding+1:IIIpadding+IIIlength);
weighted_acc_unpadded2 = weighted_acc_padded2(IIIpadding+1:IIIpadding+IIIlength);

%%%find the peak weighted acceleration
peak_weighted1_1 = max(abs(weighted_acc_unpadded1));
peak_weighted2_2 = max(abs(weighted_acc_unpadded2));

%%%find rms of weighted accelerations%%%%
rms_weighted1_1 = (mean(weighted_acc_unpadded1.*weighted_acc_unpadded1))^0.5;
rms_weighted1_2 = (mean(weighted_acc_unpadded2.*weighted_acc_unpadded2))^0.5;

%%%find crest factor of weighted accelerations%%%%
CF_weighted1_1 = peak_weighted1_1./rms_weighted1_1;
CF_weighted1_2 = peak_weighted1_2./rms_weighted1_2;

%%%find the VDV value of weighted accelerations%%%%
VDV_weighted1_1 = (mean(weighted_acc_unpadded1.^4))^0.25;
VDV_weighted1_2 = (mean(weighted_acc_unpadded2.^4))^0.25;

%%%find the A(8) of weighted accelerations%%%%
A81_1 = rms_weighted1_1*(length(accelraw1)/1000/3600/8);
A81_2 = rms_weighted1_2*(length(accelraw1)/1000/3600/8);

%%%find the A(8) of weighted accelerations for 1 hour%%%%
A8_1hr1_1 = rms_weighted1_1*(1/8);
A8_1hr1_2 = rms_weighted1_2*(1/8);

clc

%%%find the SEAT value%%%%
SEAT1 = rms_weighted1_2/rms_weighted1_1

%load acceleration data for post-fatigued trial
accelraw2 = csvread(strcat(num2str(ppt), 'sequence2_1.csv'), 1320011, 2, [1320011, 2, 1980010, 3]);
accelraw2 = accelraw2 / 1000;
accelraw2 = filtfilt(b, a, accelraw2);

%%% pad the data to prevent issues with ISO filtering %%%

% calculate the amount of padding need to make the data file the new length
IIIpadding = 115 * fs;

% create an inverted mirror image of the end of the data that is the
% necessary padding length and pad the data

arraysize = size(accelraw2);
IIIlength = arraysize(:, 1);

post_datapadding = padarray(accelraw2, IIIpadding + 2, 'symmetric', 'post');
pre_datapadding = padarray(accelraw2, IIIpadding + 2, 'symmetric', 'pre');

inverted_post_datapadding = (post_datapadding(IIIlength + 1:IIIlength + IIIpadding + 2,:)) * -1;
inverted_pre_datapadding = (pre_datapadding(1:IIIpadding + 2,:)) * -1;

clear post_datapadding
clear pre_datapadding

acc_padded2 = [inverted_pre_datapadding(2:IIIpadding + 1,:); accelraw2; inverted_post_datapadding(2:IIIpadding + 1,:)];

clear inverted_post_datapadding
clear inverted_pre_datapadding

%%% apply ISO weighting %%%

weighted_acc_padded1 = isofilwk(acc_padded2(:, 1), fs);
weighted_acc_padded2 = isofilwk(acc_padded2(:, 2), fs);

%%% remove padding %%%

weighted_acc_unpadded1 = weighted_acc_padded1(IIIpadding + 1:IIIpadding + IIIlength);
weighted_acc_unpadded2 = weighted_acc_padded2(IIIpadding + 1:IIIpadding + IIIlength);

%%% find the peak weighted acceleration
peak_weighted2_1 = max(abs(weighted_acc_unpadded1));
peak_weighted2_2 = max(abs(weighted_acc_unpadded2));

%%% find rms of weighted accelerations %%%

rms_weighted2_1 = (mean(weighted_acc_unpadded1.*weighted_acc_unpadded1))^0.5;
rms_weighted2_2 = (mean(weighted_acc_unpadded2.*weighted_acc_unpadded2))^0.5;

%%% find crest factor of weighted accelerations %%%

CF_weighted2_1 = peak_weighted2_1 / rms_weighted2_1;
CF_weighted2_2 = peak_weighted2_2./rms_weighted2_2;

%%%find the VDV value of weighted accelerations%%%  
VDV_weighted2_1 = (mean(weighted_acc_unpadded1.^4))^0.25;  
VDV_weighted2_2 = (mean(weighted_acc_unpadded2.^4))^0.25;

%%%find the A(8) of weighted accelerations%%%  
A8_2_1 = rms_weighted2_1*(length(accelraw2)/1000/3600/8);  
A8_2_2 = rms_weighted2_2*(length(accelraw2)/1000/3600/8);

%%%find the A(8) of weighted accelerations for 1 hour%%%  
A8_1hr2_1 = rms_weighted2_1*(1/8);  
A8_1hr2_2 = rms_weighted2_2*(1/8);

%%%find the SEAT value%%%  
SEAT2 = rms_weighted2_2/rms_weighted2_1

%%%separate into vibration profiles%%%  
%read in profiles from csv file  
profile1 = csvread(strcat(num2str(ppt),'profiles.csv'),0,0,[0,0,27,2]);  
profile2 = csvread(strcat(num2str(ppt),'profiles.csv'),0,3,[0,3,27,5]);  
j = 1;  
for i = 1:28  
    if profile1(i,1) < 10  
        vibprofile1(j,1:3) = profile1(i,1:3);  
        j = j+1;  
    end  
end  

j = 1;  
for i = 1:28  
    if profile2(i,1) < 10  
        vibprofile2(j,1:3) = profile2(i,1:3);  
        j = j+1;  
    end  
end  

IIIlength=20000;

for i = 1:25  
    accprofiles1_1(:,i) = accelraw1(vibprofile1(i,2):vibprofile1(i,3),1);  
    accprofiles1_2(:,i) = accelraw1(vibprofile1(i,2):vibprofile1(i,3),2);  
    accprofiles2_1(:,i) = accelraw2(vibprofile2(i,2):vibprofile2(i,3),1);  
    accprofiles2_2(:,i) = accelraw2(vibprofile2(i,2):vibprofile2(i,3),2);  

end

for i = 1:25
    accprofile1 = [accprofiles1_1(:,i) accprofiles1_2(:,i)];
    post_datapadding=padarray(accprofile1,IIIpadding+2,'symmetric','post');
    pre_datapadding=padarray(accprofile1,IIIpadding+2,'symmetric','pre');
    inverted_post_datapadding=(post_datapadding(IIIlength+1:IIIlength+IIIpadding+2,:))*-1;
    inverted_pre_datapadding=(pre_datapadding(1:IIIpadding+2,:))*-1;
    clear post_datapadding
    clear pre_datapadding
    acc_padded=[inverted_pre_datapadding(2:IIIpadding+1,:);accprofile1;inverted_post_datapadding(2:IIIpadding+1,:)];
    clear inverted_post_datapadding
    clear inverted_pre_datapadding
    %%%apply ISO weighting%%%%
    weighted_acc_padded1 = isofilwk(acc_padded(:,1),fs);
    weighted_acc_padded2 = isofilwk(acc_padded(:,2),fs);
    %%%remove padding%%%%
    weighted_acc_unpadded1 = weighted_acc_padded1(IIIpadding+1:IIIpadding+IIIlength);
    weighted_acc_unpadded2 = weighted_acc_padded2(IIIpadding+1:IIIpadding+IIIlength);
    %%%find the peak weighted acceleration
    peak_weighted_base(i,1) = max(abs(weighted_acc_unpadded1));
    peak_weighted_seat(i,1) = max(abs(weighted_acc_unpadded2));
    %%%find rms of weighted accelerations%%%%
    rms_weighted_base(i,1) = (mean(weighted_acc_unpadded1.*weighted_acc_unpadded1))^0.5;
    rms_weighted_seat(i,1) = (mean(weighted_acc_unpadded2.*weighted_acc_unpadded2))^0.5;
    %%%find the A(8) of weighted accelerations%%%%
    A8_base(i,1) = rms_weighted_base(i,1)*(length(accprofile1)/1000/3600/8);
    A8_seat(i,1) = rms_weighted_seat(i,1)*(length(accprofile1)/1000/3600/8);
    %%%find the SEAT value%%%%
    SEAT_profile(i,1) = rms_weighted_seat(i,1)/rms_weighted_base(i,1);
    if A8_seat <0.45
ISO_health(i,1) = 1;
else
ISO_health(i,1) = 0;
end

if rms_weighted_seat(i,1) < 0.315
ISO_comfort(i,1) = 0;
elseif rms_weighted_seat(i,1) < 0.5
ISO_comfort(i,1) = 1;
elseif rms_weighted_seat(i,1) < 0.63
ISO_comfort(i,1) = 2;
elseif rms_weighted_seat(i,1) < 0.8
ISO_comfort(i,1) = 3;
elseif rms_weighted_seat(i,1) < 1
ISO_comfort(i,1) = 4;
elseif rms_weighted_seat(i,1) < 1.25
ISO_comfort(i,1) = 5;
elseif rms_weighted_seat(i,1) < 1.6
ISO_comfort(i,1) = 6;
elseif rms_weighted_seat(i,1) < 2
ISO_comfort(i,1) = 7;
elseif rms_weighted_seat(i,1) < 2.5
ISO_comfort(i,1) = 8;
elseif rms_weighted_seat(i,1) > 2.5
ISO_comfort(i,1) = 9;
end

accprofile2 = [accprofiles2_1(:,i) accprofiles2_2(:,i)];

post_datapadding=padarray(accprofile2,IIIpadding+2,'symmetric','post');
pre_datapadding=padarray(accprofile2,IIlIpadding+2,'symmetric','pre');

inverted_post_datapadding=(post_datapadding(IIIlength+1:IIIlength+IIIlIpadding+2,:))'*(-1);
inverted_pre_datapadding=(pre_datapadding(1:IIIlIpadding+2,:))'*(-1);

clear post_datapadding
clear pre_datapadding

acc_padded=[inverted_pre_datapadding(2:IIIlIpadding+1,:);accprofile2;inverted_post_datapadding(2:IIIlIpadding+1,:)];

clear inverted_post_datapadding
clear inverted_pre_datapadding

%%%apply ISO weighting%%%
weighted_acc_padded1 = isofilwk(acc_padded(:,1),fs);
weighted_acc_padded2 = isofilwk(acc_padded(:,2),fs);

%%%remove padding%%%
weighted_acc_unpadded1 = weighted_acc_padded1(IIIlIpadding+1:IIIlength);
weighted_acc_unpadded2 =
weighted_acc_padded2(IIIpadding+1:IIIpadding+IIIlength);

%%%find the peak weighted acceleration
peak_weighted_base(i,2) = max(abs(weighted_acc_unpadded1));
peak_weighted_seat(i,2) = max(abs(weighted_acc_unpadded2));

%%%find rms of weighted accelerations%%%
rms_weighted_base(i,2) =
(mean(weighted_acc_unpadded1.*weighted_acc_unpadded1))^0.5;
rms_weighted_seat(i,2) =
(mean(weighted_acc_unpadded2.*weighted_acc_unpadded2))^0.5;

%%%find the A(8) of weighted accelerations%%%
A8_base(i,2) = rms_weighted_base(i,2)*(length(accprofile2)/1000/3600/8);
A8_seat(i,2) = rms_weighted_seat(i,2)*(length(accprofile2)/1000/3600/8);

%%%find the SEAT value%%%  
SEAT_profile(i,2) = rms_weighted_seat(i,2)/rms_weighted_base(i,2);

if A8_seat <0.45
    ISO_health(i,2) = 1;
else
    ISO_health(i,2) = 0;
end

if rms_weighted_seat(i,2) <0.315
    ISO_comfort(i,2) = 0;
elseif rms_weighted_seat(i,2) <0.5
    ISO_comfort(i,2) = 1;
elseif rms_weighted_seat(i,2) <0.63
    ISO_comfort(i,2) = 2;
elseif rms_weighted_seat(i,2) <0.8
    ISO_comfort(i,2) = 3;
elseif rms_weighted_seat(i,2) <1
    ISO_comfort(i,2) = 4;
elseif rms_weighted_seat(i,2) <1.25
    ISO_comfort(i,2) = 5;
elseif rms_weighted_seat(i,2) <1.6
    ISO_comfort(i,2) = 6;
elseif rms_weighted_seat(i,2) <2
    ISO_comfort(i,2) = 7;
elseif rms_weighted_seat(i,2) <2.5
    ISO_comfort(i,2) = 8;
elseif rms_weighted_seat(i,2) >2.5
    ISO_comfort(i,2) = 9;
end
end

%manually add perceived discomfort scores
perceived1 = [3 0 4 0 5 1 0 3 2 0 5 4 5 2 2 2 2 6
1 5 1 2 0 2 6 1];
perceived2 = [4 2 2 3 5 5 6 0 2 3 4 6 5 1 3 6 0 1 5 6 1 3 6 4 0];

%normalize each discomfort measure by subtracting the mean and then dividing
%by the standard deviation (Dickey et al. 2007, Multi-axis pt 2)
perceived = [perceived1 perceived2];
avgperceived = mean(perceived);
stdperceived = std(perceived);
normperceived1 = (perceived1 - avgperceived)./stdperceived;
normperceived2 = (perceived2 - avgperceived)./stdperceived;

%set variables for data file
pptnum = repmat(ppt, [50,1]);
sex = repmat(sex, [50,1]);
age = repmat(age, [50,1]);
weight = repmat(weight, [50,1]);
height = repmat(height, [50,1]);
hand = repmat(hand, [50,1]);
freq = [vibprofile1(:,1);vibprofile2(:,1)];
fatiguecond(1:25,1) = repmat(1, [25,1]);
fatiguecond(26:50,1) = repmat(2, [25,1]);
data1 = [peak_weighted_seat(:,1) rms_weighted_base(:,1)
rms_weighted_seat(:,1) SEAT_profile(:,1) ISO_health(:,1) ISO_comfort(:,1)
normperceived1'];
data2 = [peak_weighted_seat(:,2) rms_weighted_base(:,2)
rms_weighted_seat(:,2) SEAT_profile(:,2) ISO_health(:,2) ISO_comfort(:,2)
normperceived2'];
data = [data1; data2];
accelprofiles = [pptnum,sex,age,weight,height,hand,freq,fatiguecond,data];
csvwrite(strcat(num2str(ppt),'.Accel_Data_Profiles.csv'), accelprofiles);

%sort by frequency
freq_num1(1:5,1) = find(accelprofiles(1:25,7) == 1.25);
freq_num1(1:5,2) = find(accelprofiles(1:25,7) == 2);
freq_num1(1:5,3) = find(accelprofiles(1:25,7) == 2.5);
freq_num1(1:5,4) = find(accelprofiles(1:25,7) == 4);
freq_num1(1:5,5) = find(accelprofiles(1:25,7) == 4.5);
freq_num2(1:5,1) = find(accelprofiles(26:50,7) == 1.25);
freq_num2(1:5,2) = find(accelprofiles(26:50,7) == 2);
freq_num2(1:5,3) = find(accelprofiles(26:50,7) == 2.5);
freq_num2(1:5,4) = find(accelprofiles(26:50,7) == 4);
freq_num2(1:5,5) = find(accelprofiles(26:50,7) == 4.5);

data1sorted = [data1(freq_num1(:,1),:); data1(freq_num1(:,2),:); data1(freq_num1(:,3),:);
data1(freq_num1(:,4),:); data1(freq_num1(:,5),:)];
data2sorted = [data2(freq_num2(:,1),:); data2(freq_num2(:,2),:);
data2(freq_num2(:,3),:); data2(freq_num2(:,4),:); data2(freq_num2(:,5),:)];
datasorted = [data1sorted; data2sorted];
peakplot1 = [mean(peak_weighted_seat(freq_num1(:,1),1)) mean(peak_weighted_seat(freq_num1(:,2),1)) mean(peak_weighted_seat(freq_num1(:,3),1)) mean(peak_weighted_seat(freq_num1(:,4),1)) mean(peak_weighted_seat(freq_num1(:,5),1))];
peakplot2 = [mean(peak_weighted_seat(freq_num2(:,1),2)) mean(peak_weighted_seat(freq_num2(:,2),2)) mean(peak_weighted_seat(freq_num2(:,3),2)) mean(peak_weighted_seat(freq_num2(:,4),2)) mean(peak_weighted_seat(freq_num2(:,5),2))];
figure()
bar(peakplot1)
hold on
bar(peakplot2, 0.5, 'r')
title('peak weighted acceleration')
legend('pre-fatigue', 'fatigued')

rmsplot1 = [mean(rms_weighted_seat(freq_num1(:,1),1)) mean(rms_weighted_seat(freq_num1(:,2),1)) mean(rms_weighted_seat(freq_num1(:,3),1)) mean(rms_weighted_seat(freq_num1(:,4),1)) mean(rms_weighted_seat(freq_num1(:,5),1))];
rmsplot2 = [mean(rms_weighted_seat(freq_num2(:,1),2)) mean(rms_weighted_seat(freq_num2(:,2),2)) mean(rms_weighted_seat(freq_num2(:,3),2)) mean(rms_weighted_seat(freq_num2(:,4),2)) mean(rms_weighted_seat(freq_num2(:,5),2))];
figure()
bar(rmsplot1)
hold on
bar(rmsplot2, 0.5, 'r')
title('rms weighted acceleration')
legend('pre-fatigue', 'fatigued')

SEATplot1 = [mean(SEAT_profile(freq_num1(:,1),1)) mean(SEAT_profile(freq_num1(:,2),1)) mean(SEAT_profile(freq_num1(:,3),1)) mean(SEAT_profile(freq_num1(:,4),1)) mean(SEAT_profile(freq_num1(:,5),1))];
SEATplot2 = [mean(SEAT_profile(freq_num2(:,1),2)) mean(SEAT_profile(freq_num2(:,2),2)) mean(SEAT_profile(freq_num2(:,3),2)) mean(SEAT_profile(freq_num2(:,4),2)) mean(SEAT_profile(freq_num2(:,5),2))];
figure()
bar(SEATplot1)
hold on
bar(SEATplot2, 0.5, 'r')
title('SEAT')
legend('pre-fatigue', 'fatigued')
healthplot1 = [mean(ISO_health(freq_num1(:,1),1)) mean(ISO_health(freq_num1(:,2),1)) mean(ISO_health(freq_num1(:,3),1)) mean(ISO_health(freq_num1(:,4),1)) mean(ISO_health(freq_num1(:,5),1))];
healthplot2 = [mean(ISO_health(freq_num2(:,1),2)) mean(ISO_health(freq_num2(:,2),2)) mean(ISO_health(freq_num2(:,3),2)) mean(ISO_health(freq_num2(:,4),2)) mean(ISO_health(freq_num2(:,5),2))];
figure()
bar(healthplot1)
hold on
bar(healthplot2, 0.5, 'r')
title('ISO health')
legend('pre-fatigue', 'fatigued')

comfortplot1 = [mean(ISO_comfort(freq_num1(:,1),1)) mean(ISO_comfort(freq_num1(:,2),1)) mean(ISO_comfort(freq_num1(:,3),1)) mean(ISO_comfort(freq_num1(:,4),1)) mean(ISO_comfort(freq_num1(:,5),1))];
comfortplot2 = [mean(ISO_comfort(freq_num2(:,1),2)) mean(ISO_comfort(freq_num2(:,2),2)) mean(ISO_comfort(freq_num2(:,3),2)) mean(ISO_comfort(freq_num2(:,4),2)) mean(ISO_comfort(freq_num2(:,5),2))];
figure()
bar(comfortplot1)
hold on
bar(comfortplot2, 0.5, 'r')
title('ISO comfort')
legend('pre-fatigue', 'fatigued')

perceivedplot1 = [mean(normperceived1(freq_num1(:,1))) mean(normperceived1(freq_num1(:,2))) mean(normperceived1(freq_num1(:,3))) mean(normperceived1(freq_num1(:,4))) mean(normperceived1(freq_num1(:,5)))];
perceivedplot2 = [mean(normperceived2(freq_num2(:,1))) mean(normperceived2(freq_num2(:,2))) mean(normperceived2(freq_num2(:,3))) mean(normperceived2(freq_num2(:,4))) mean(normperceived2(freq_num2(:,5)))];
figure()
bar(perceivedplot1)
hold on
bar(perceivedplot2, 0.5, 'r')
title('normalized perceived discomfort')
legend('pre-fatigue', 'fatigued')
clc
clear all
close all

%%enter participant number before starting code
ppt = 34;
sex = 1; % 1 more male, 2 for female
age = 20;
weight = 72;
height = 1.73;
hand = 1; % 1 for right, 2 for left

%input sequence 1 data
emgraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 5, 2, [5, 2, 1320004, 9]);
accelraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 1320011, 2, [1320011, 2, 1980010, 3]);

%change emg to only be the back muscles
emgraw1 = [emgraw1(:,1) emgraw1(:,2) emgraw1(:,5) emgraw1(:,6)];

%create time variables
etime1 = 0:(1/2000):((length(emgraw1) - 1)/2000);
atime1 = 0:(1/1000):((length(accelraw1) - 1)/1000);

%read in profiles from csv file
profile1 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 0, [0, 0, 27, 2]);
profile2 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 3, [0, 3, 27, 5]);

%bandpass filter raw accel
[b,a] = butter(4, [0.5/500 40/500], 'bandpass');
accel1 = filtfilt(b, a, accelraw1);

shockindex = find(profile1 == 99);
for i = 1:3
    startframe1 = profile1(shockindex(i),2)-500;
    frame = startframe1;

    w2 = accel1(frame:frame+10,1);
    w1 = accel1(frame-201:frame-1,1);

    while mean(w2)<10*std(w1)+mean(w1)
        frame = frame+1;
        w2 = accel1(frame:frame+10,1);
        w1 = accel1(frame-201:frame-1,1);
    end
    latencyframe1(i,1) = frame*2;
end

%bandpass filter raw EMG data for visual determination
[b,a]=butter(4,[10/1000 999/1000],’bandpass’);
emgvis1 = filtfilt(b,a,emgraw1);

%Bandpass filter raw EMG
[b,a]=butter(4,[10/1000 500/1000],’bandpass’);
emgba1nd1 = filtfilt(b,a,emgraw1);

%full wave rectify data
emgabs1 = abs(emgba1nd1);

%lowpass filter the bandpass filtered data
[b,a]=butter(4,50/1000);
emg1 = filtfilt(b,a,emgabs1);

for j = 1:4
    for i = 1:3
        startframe1 = latencyframe1(i,1)+100;
        frame = startframe1;

        w2 = emg1(frame:frame+50,j);
        w1 = emg1(frame-101:frame-1,j);

        while mean(w2)<2*std(w1)+mean(w1)
            frame = frame+1;
            w2 = emg1(frame:frame+50,j);
            w1 = emg1(frame-101:frame-1,j);
        end
        latencyframe1(i,j+1) = frame;
    end

    latency1(:,j) = (latencyframe1(:,j+1) - latencyframe1(:,1))./2000;
end

figure()
plot(emgvis1(:,j))
hold on
scatter(latencyframe1(:,1),[0 0 0], 'g')
scatter(latencyframe1(:,j+1),[0 0 0], 'r')
hold off
figure()
plot(emg1(:,j))
hold on
scatter(latencyframe1(:,1),[0 0 0], 'g')
scatter(latencyframe1(:,j+1),[0 0 0], 'r')
hold off
keyboard
close all
end

% %enter visual observations
% latencyframe1(:,2) = [; ; ];
% latencyframe1(:,3) = [; ; ];
% latencyframe1(:,4) = [; ; ];
% latencyframe1(:,5) = [; ; ];

%recalculate latency
for i = 1:3
    for j = 1:4
        latency1(i,j) = (latencyframe1(i,j+1) - latencyframe1(i,1))./2000;
    end
end

%input sequence 1 data
emgraw2 = csvread(strcat(num2str(ppt), 'sequence2_1.csv'), 5, 2, [5, 2, 1320004, 9]);
accelraw2 = csvread(strcat(num2str(ppt), 'sequence2_1.csv'), 1320011, 2, [1320011, 2, 1980010, 3]);

%change emg to only be the back muscles
emgraw2 = [emgraw2(:,1) emgraw2(:,2) emgraw2(:,5) emgraw2(:,6)];

%create time variables
etime2 = 0:(1/2000):((length(emgraw2)-1)/2000);
atime2 = 0:(1/1000):((length(accelraw2)-1)/1000);

%bandpass filter raw accel
[b,a]=butter(4, [0.5/500 40/500], 'bandpass');
accel2 = filtfilt(b,a,accelraw2);

shockindex = find(profile2==99);
for i = 1:3
    startframe2 = profile2(shockindex(i),2)-500;
    frame = startframe2;
    w2 = accel2(frame:frame+10,1);
    w1 = accel2(frame-201:frame-1,1);
    while mean(w2)<10*std(w1)+mean(w1)
        frame = frame+1;
        w2 = accel2(frame:frame+10,1);
        w1 = accel2(frame-201:frame-1,1);
    end
    latencyframe2(i,1) = frame*2;
end

%bandpass filter raw EMG data for visual determination
[b,a]=butter(4,[10/1000 999/1000],'bandpass');
emgvis2 = filtfilt(b,a,emgraw2);

%Bandpass filter raw EMG
[b,a]=butter(4,[10/1000 500/1000],'bandpass');
emgband2 = filtfilt(b,a,emgraw2);

%full wave rectify data
emgabs2 = abs(emgband2);

%lowpass filter the bandpass filtered data
[b,a]=butter(4,50/1000);
emg2 = filtfilt(b,a,emgabs2);

for j = 1:4
    for i = 1:3
        startframe2 = latencyframe2(i,1)+100;
        frame = startframe2;
        w2 = emg2(frame:frame+50,j);
        w1 = emg2(frame-101:frame-1,j);
        while mean(w2)<2*std(w1)+mean(w1)
            frame = frame+1;
            w2 = emg2(frame:frame+50,j);
            w1 = emg2(frame-101:frame-1,j);
        end
        latencyframe2(i,j+1) = frame;
    end
    latency2(:,j) = (latencyframe2(:,j+1) - latencyframe2(:,1))./2000;
figure()
plot(emgvis2(:,j))
```matlab
hold on
scatter(latencyframe2(:,1),[0 0 0], 'g')
scatter(latencyframe2(:,j+1),[0 0 0], 'r')
hold off
figure()
plot(emg1(:,j))
hold on
scatter(latencyframe2(:,1),[0 0 0], 'g')
scatter(latencyframe2(:,j+1),[0 0 0], 'r')
hold off
keyboard
close all
end

% enter visual observations
% latencyframe2(:,2) = [; ; ];
% latencyframe2(:,3) = [; ; ];
% latencyframe2(:,4) = [; ; ];
% latencyframe2(:,5) = [; ; ];
% recalculate latency
for i = 1:3
    for j = 1:4
        latency2(i,j) = (latencyframe2(i,j+1) - latencyframe2(i,1))./2000;
    end
end

% combine left and right latencies for each activation
for i = 1:3
    lumbar1 = [latency1(i,1) latency1(i,2)]';
    thoracic1 = [latency1(i,3) latency1(i,4)]';
    latency1comb(i,1) = mean(lumbar1);
    latency1comb(i,2) = mean(thoracic1);

    lumbar2 = [latency2(i,1) latency2(i,2)]';
    thoracic2 = [latency2(i,3) latency2(i,4)]';
    latency2comb(i,1) = mean(lumbar2);
    latency2comb(i,2) = mean(thoracic2);
end

figure()
bar(mean(latency1comb))
hold on
bar(mean(latency2comb), 0.5, 'r')
title('back muscle latencies averaged for lumbar and thoracic')
legend('pre-fatigue', 'fatigued')```
%write data to file

pptnum = repmat(ppt, [12,1]);
sex = repmat(sex, [12,1]);
age = repmat(age, [12,1]);
weight = repmat(weight, [12,1]);
height = repmat(height, [12,1]);
hand = repmat(hand, [12,1]);
muscle = [1 1 1 2 2 2 1 1 1 2 2 2]';
fatiguecond(1:6,1) = [1 1 1 1 1];
fatiguecond(7:12,1) = [2 2 2 2 2];
data = [latency1comb(:,1); latency1comb(:,2); latency2comb(:,1); latency2comb(:,2)];

latencyfile = [pptnum, sex,age,weight,height,hand, muscle, fatiguecond, data];

csvwrite(strcat(num2str(ppt),'Latency_Data.csv'), latencyfile);
% Peak EMG

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% % Author: Alex Nolan
% % Date Created: October 21, 2018
% % Code will:
% % - read in accelerometer and emg data and apply filters
% % - determine location of each shock from acceleration data
% % - find peak muscle activation following shock
% % - write data to a file
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc
clear all
close all

%% enter participant number before starting code
ppt = 28;
sex = 1; % 1 more male, 2 for female
age = 20;
weight = 72;
height = 1.73;
hand = 1; % 1 for right, 2 for left

% input sequence 1 data
emgraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 5, 2, [5, 2, 1320004, 9]);
accelraw1 = csvread(strcat(num2str(ppt), 'sequence1_1.csv'), 1320011, 2, [1320011, 2, 1980010, 3]);

% create time variables
etime1 = 0:(1/2000):((length(emgraw1)-1)/2000);
atime1 = 0:(1/1000):((length(accelraw1)-1)/1000);

% read in profiles from csv file
profile1 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 0, [0, 0, 27, 2]);
profile2 = csvread(strcat(num2str(ppt), 'profiles.csv'), 0, 3, [0, 3, 27, 5]);

% bandpass filter raw accel
[b,a] = butter(4, [0.5/500 40/500], 'bandpass');
accel1 = filtfilt(b,a,accelraw1);

% bandpass filter raw EMG
[b,a] = butter(4, [30/1000 400/1000], 'bandpass');
emgband1 = filtfilt(b,a,emgraw1);

% take absolute value of emg data
emgabs1 = abs(emgband1);

% create 7Hz linear envelope
\[ b, a = \text{butter}(4, \frac{7}{1000}, '\text{low}'); \]
\[ \text{emg1} = \text{filtfilt}(b, a, \text{emgabs1}); \]
\%
\%use MVC function to get MVCs
\[ [\text{MVCLEO, MVCLIO, MVCLLE, MVCLTE, MVCREO, MVCRIO, MVCRLE, MVCRTE}] = \text{MVCs}(\text{ppt}); \]
\%
\%divide emg by MVCs to get %MVC activation (make sure muscles are in correct order)
\[ \text{emgmvc1}(:,1) = \text{emg1}(:,1) ./ \text{MVCLLE} \times 100; \]
\[ \text{emgmvc1}(:,2) = \text{emg1}(:,2) ./ \text{MVCRLE} \times 100; \]
\[ \text{emgmvc1}(:,3) = \text{emg1}(:,3) ./ \text{MVCRIO} \times 100; \]
\[ \text{emgmvc1}(:,4) = \text{emg1}(:,4) ./ \text{MVCLIO} \times 100; \]
\[ \text{emgmvc1}(:,5) = \text{emg1}(:,5) ./ \text{MVCLTE} \times 100; \]
\[ \text{emgmvc1}(:,6) = \text{emg1}(:,6) ./ \text{MVCREO} \times 100; \]
\[ \text{emgmvc1}(:,7) = \text{emg1}(:,7) ./ \text{MVCRTE} \times 100; \]
\[ \text{emgmvc1}(:,8) = \text{emg1}(:,8) ./ \text{MVCRLE} \times 100; \]
\%
\%find shock frames
\[ \text{shockindex1} = \text{find}(\text{profile1} == 99); \]
\[ \text{shockframe1}(1,1) = \text{profile1}(\text{shockindex1}(1),2); \]
\[ \text{shockframe1}(2,1) = \text{profile1}(\text{shockindex1}(2),2); \]
\[ \text{shockframe1}(3,1) = \text{profile1}(\text{shockindex1}(3),2); \]
\[ \text{shockframe1} = \text{shockframe1} \times 2; \]
\[ \text{shockframe1}(1,2) = \text{shockframe1}(1,1) + 0.5 \times 2000; \]
\[ \text{shockframe1}(2,2) = \text{shockframe1}(2,1) + 0.5 \times 2000; \]
\[ \text{shockframe1}(3,2) = \text{shockframe1}(3,1) + 0.5 \times 2000; \]

\%
\%input sequence 2 data
\[ \text{emgraw2} = \text{csvread}(\text{strcat}(\text{num2str}(\text{ppt}), 'sequence2_1.csv'), 5, 2, [5, 2, 1320004, 9]); \]
\[ \text{accelraw2} = \text{csvread}(\text{strcat}(\text{num2str}(\text{ppt}), 'sequence2_1.csv'), 1320011, 2, [1320011, 2, 1980010, 3]); \]
\%
\%create time variables
\[ \text{etime2} = 0:(1/2000):((\text{length(\text{emgraw2})}-1)/2000); \]
\[ \text{atime2} = 0:(1/1000):((\text{length(\text{accelraw2})}-1)/1000); \]
\%
\%bandpass filter raw accel
\[ [b, a] = \text{butter}(4, [0.5/500 40/500], '\text{bandpass}'); \]
\[ \text{accel2} = \text{filtfilt}(b, a, \text{accelraw2}); \]
%Bandpass filter raw EMG
[b,a]=butter(4,[30/1000 400/1000],'bandpass');
emgband2 = filtfilt(b,a,emgraw2);

%take absolute value of emg data
emgabs2 = abs(emgband2);

%create 7Hz linear envelope
[b,a]=butter(4,7/1000,'low');
emg2 = filtfilt(b,a,emgabs2);

%divide emg by MVCs to get %MVC activation (make sure muscles are in correct order)
emgmvc2(:,1) = emg2(:,1)./MVCLLE*100;
emgmvc2(:,2) = emg2(:,2)./MVCRLE*100;
emgmvc2(:,6) = emg2(:,3)./MVCLIO*100;
emgmvc2(:,5) = emg2(:,4)./MVCLIO*100;
emgmvc2(:,3) = emg2(:,5)./MVCLTE*100;
emgmvc2(:,4) = emg2(:,6)./MVCLTE*100;
emgmvc2(:,8) = emg2(:,7)./MVCREO*100;
emgmvc2(:,7) = emg2(:,8)./MVCREO*100;

%find shock frames
shockindex2 = find(profile2==99);
shockframe2(1,1) = profile2(shockindex2(1),2);
shockframe2(2,1) = profile2(shockindex2(2),2);
shockframe2(3,1) = profile2(shockindex2(3),2);
shockframe2 = shockframe2.*2;
shockframe2(1,2) = shockframe2(1,1)+0.5*2000;
shockframe2(2,2) = shockframe2(2,1)+0.5*2000;
shockframe2(3,2) = shockframe2(3,1)+0.5*2000;

for i = 1:8
    for j = 1:3
        shock = emgmvc2(shockframe2(j,1):shockframe2(j,2),i);

        emg2max(j,i) = max(shock);
    end
end

figure()
bar(mean(emg1max))
hold on
bar(mean(emg2max), 0.5, 'r')
title('muscle activation maximums post-shock')
legend('pre-fatigue', 'fatigued')
% write data to file
pptnum = repmat(ppt, [48,1]);
sex = repmat(sex, [48,1]);
age = repmat(age, [48,1]);
weight = repmat(weight, [48,1]);
height = repmat(height, [48,1]);
hand = repmat(hand, [48,1]);
muscle = [1 1 1 2 2 2 3 3 3 4 4 4 4 5 5 5 6 6 6 7 7 7 8 8 8 8 1 1 1 2 2 2 3 3 3 4
4 4 5 5 5 6 6 6 7 7 7 8 8 8];
fatiguecond(1:24,1) = [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
fatiguecond(25:48,1) = [2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2];
data = [emg1max(:,1); emg1max(:,2); emg1max(:,3); emg1max(:,4); emg1max(:,5);
emg1max(:,6); emg1max(:,7); emg1max(:,8); emg2max(:,1); emg2max(:,2);
emg2max(:,3); emg2max(:,4); emg2max(:,5); emg2max(:,6); emg2max(:,7);
emg2max(:,8)];

latencyfile = [pptnum, sex, age, weight, height, hand, muscle, fatiguecond, data];

csvwrite(strcat(num2str(ppt), 'Shock_Data.csv'), latencyfile);