INVESTIGATING OCCUPATIONAL FACTORS LINKED TO BACK PAIN: REPETITIVE LIFTING STRATEGIES AND A METHOD FOR EXAMINING EFFECTS OF VIBRATION

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Abstract

Low back pain results in a significant burden to industrial nations worldwide from the medical costs and the loss of work productivity. The objective of the current work was to investigate repetitive lifting with high torso flexions and vibration, all factors linked to low back pain.

In the first study, lumbar-pelvic coordination was examined in novice and experienced lifters. It was hypothesized that novice lifters would select a lumbar-pelvic coordination that reached the kyphotic limits of their lumbar range of motion (ROM) while experienced lifters would select a more neutral strategy. Twenty-seven subjects participated in a repetitive lifting experiment to examine the kinematics and energetics of different lifting strategies. Three lifting strategies were examined using individual lumbar ROM for normalization. The first was a self-selected strategy followed by two strategies trained with a biofeedback. The trained strategies included a strategy approaching the kyphotic limits of ROM and a neutral strategy maintaining near the middle of ROM. The results demonstrate novice lifters select a lumbar-pelvic coordination approaching the kyphotic limits of their range of motion while experienced lifters remain near the middle. The energetics of the lifting task were also examined, but found no significant differences between the trained lifting strategies.

In another study, seven subjects participated in a study attempting to design a proprioceptive measurement acceptable for the occupational setting. The design criteria the task need to meet included: 1) portable, 2) minimal set up, 3) easy for subjects to understand, 4) minimal data collection time, and 5) able to identify effects of vibration exposure. A seated sway target pursuit task was designed to examine four tasks of increasing complexity to identify

the most appropriate task for the occupational setting. The target pursuit tasks included stable sway, linear tracking in ML and AP directions, and tracking a circle. Limited detected effects of vibration in these tasks suggest that further development is required.

In both efforts, dynamic control of lumbar motion was examined using repetitive trunk motion tasks. In the lifting study, experienced lifters chose a more neutral lumbar-pelvic coordination strategy, suggesting training such a strategy could reduce injury incidence.

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There are a number of people to thank for helping me throughout this process. Without their assistance this project would not have been possible. I would like to express gratitude to my advisor Dr. Sara Wilson for her constant support and guidance throughout my graduate career, especially in helping to define this overall work. She has helped me develop my skills in the research laboratory, provided opportunities as a reviewer, guided me through writing grants, and supported me during the transition from student to educator. I would also like to thank my committee members Dr. Terry Faddis, Dr. Lorin Maletsky, Dr. Neena Sharma, and Dr. Billinger for their support without which the project could not have been completed.

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CHAPTER ONE: INTRODUCTION

Background and Motivation

It has been reported that up to 80% of the general population will experience low back pain or low back injury during their lifetimes (Kelsey et al., 1984; Pai and Sundaram, 2004). Low back pain (LBP) is the leading cause of disability in individuals under 45 years old and accounts for approximately 40% of all compensation claims in the United States (Lis et al., 2007). Low back disorders are a leading cause of worker disability affecting up to 47% of workers and costing society from $25 to $100 billion annually (Andersson, 1981; Cats-Baril and Frymoyer, 1991). As such, research has focused on reducing the occurrence of LBP in industry by investigating low back motion, which is a complex task requiring coordination of sensory and motor dynamics.

Many investigators have focused on the factors that lead to injury by attempting to identify occupational risk factors (Bernard, 1997). Occupational risk factors commonly thought to be associated with LBP include heavy physical work, a static work posture, repetitive bending, twisting, lifting, whole body vibration, and psychological issues (Alexopoulos et al., 2008; Linton, 2000; Manchikanti, 2000). The National Institute for Occupational Safety and Health have identified both repetitive lifting and whole body vibration as key risk factors for low back disorders (Bernard, 1997; Health, 1981). As such, this dissertation focuses on examining low back sensory and motor dynamics in relation to the risk factors of repetitive lifting and whole body vibration.

The bulk of this dissertation is focused on repetitive lifting. The repetitive lifting project presented here examined different lumbar-pelvic coordination strategies in an attempt to identify safe lifting mechanics and improve rehabilitation approaches. This work examined the lumbar-pelvic coordination building on a preliminary study that observed that novice lifters performed a lifting task in a highly kyphotic posture approaching the limits of their lumbar range of motion during the extension phase of lifting (Maduri et al., 2008). In this previous research, it was hypothesized that the pattern of lengthening the trunk musculature followed by muscle shortening could be due to a stretch-shortening cycle within the back to improve mechanical efficiency of the lifting task. Although this may reduce the energy required to lift, this coordination could also result in increased moments on the spine or eccentric muscle damage and lifters may learn through experience to avoid such a strategy. This dissertation investigates this lumbar pelvic coordination pattern, examining novice and experienced lifters, examines training subjects to use different coordination patterns and examines the energy consumption relationship between different lifting strategies.

A second part of this project investigated whole body vibration. Exposure to whole body vibration (WBV) in the occupational setting is a common event; more than 7 million workers in the United Sates experience WBV on a daily basis(Wasserman et al., 1997). As WBV has been linked to an increased risk of low back pain, a number of studies have been conducted to understand the etiology of low back pain. This study attempted to design a method to measure the effects of vibration on the proprioceptive system using performance based tasks. The goal was to demonstrate the usefulness of this measure in the laboratory for future use in an occupational setting.

Specific Aims

The overall goal of this work was to investigate occupational factors that could identify training or strategies to reduce low back injury. Initially, the direction of this project was to design a method to examine the effects of vibration in an occupational setting after demonstrating the effectiveness of measuring the effects of vibration in the laboratory setting. However, new research funding opportunities and a lack of significant results in the vibration project changed the focus of this dissertation to investigating repetitive lifting. Both projects are included in this dissertation with the focus on the repetitive lifting project.

The goal of the repetitive lifting project was to investigate different coordination strategies in novice and experienced lifters. We hypothesized that the novice lifters would implement a strategy that may be more energetically favorable at the cost of increasing the risk of injury while experienced lifters will implement a strategy that avoids the increased risk of injury. The first study investigates the different lifting strategies between novice and experienced lifters. The second study investigates biofeedback to train specific lifting strategies. The third study investigates the metabolic energy consumption of the different lumbar-pelvic coordination strategies. The fourth study investigates the energy expenditure of the repetitive lift by investigating muscle activity of the torso musculature. The fifth study describes the original investigation into the design of a force-plate measurement method of the effects of occupational vibration.

Dissertation Content

This document contains eight chapters. Chapter 1 consists of an introduction to the project area of study. Chapter 2 consists of a detailed background survey of relevant published literature. Chapter 3 consists of a proposed journal article investigating postural differences between novice and experienced lifters during repetitive lifting. Chapter 4 consists of a proposed journal article investigating training lumbar-pelvic coordination in novice and experienced lifters. Chapter 5 consists of a proposed journal article investigating the metabolic energy consumption of different lifting strategies. Chapter 6 consists of a proposed journal article investigating the energy consumption through a work loop analysis. Chapter 7 consists of a proposed journal article investigating a method to examine effects of vibration in the occupational setting. Chapter 8 consists of a summary of this body of work.

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CHAPTER TWO: BACKGROUND

It has been reported that up to 80% of the general population will experience low back pain and low back injury during their lifetimes (Kelsey et al., 1984; Pai and Sundaram, 2004). Low back pain (LBP) represents the most common and costly musculoskeletal disorder experienced in the occupational setting. Low back disorders are a leading cause of worker disability affecting up to 47% of workers and costing society from $25 to $100 billion annually (Andersson, 1981; Cats-Baril and Frymoyer, 1991; Luo et al., 2004). LBP is the leading cause of disability in individuals under 45 years old and accounts for approximately 40% of all compensation claims in the United States (Lis et al., 2007). The United States Department of Labor Bureau of Labor Statistics reported that in 2013, musculoskeletal disorders were the leading occupational injury affecting 380,600 days, or a third of all days away from work due to a nonfatal occupational injury (Bureau of Labor Statistics, 2014). With the median days away from work due to musculoskeletal disorders reported as 11 days, compared to 8 days for all other types of cases (Bureau of Labor Statistics, 2014), it is understandable that the costs associated with LBP can quickly add up.

Many investigators have focused on the factors that lead to low back injury and worked to identify occupational risk factors (Bernard, 1997). Occupational risk factors commonly thought to be associated with LBP include heavy physical work, a static work postures, repetitive trunk flexion, twisting, lifting, whole body vibration, and psychosocial issues (Alexopoulos et al., 2008; Linton, 2000; Manchikanti, 2000). The National Institute for Occupational Safety and Health have identified both whole body vibration and repetitive lifting as key risk factors for low back disorders (Bernard, 1997; Health, 1981). Therefore, it is no surprise that the two of the top occupations with the greatest number of days lost due to musculoskeletal disorders are 1) laborers and freight, stock, and material movers – hand, and 2) heavy and tractor-trailer truck drivers (Bureau of Labor Statistics, 2014) , occupations that involve several of the risk factors identified to be linked with low back disorders. The material movers are often performing repetitive lifts in a variety of environments. Truck drivers often perform repetitive lifting when loading and unloading loads in addition to the often long durations of vibration exposure while in transit. As such, this dissertation will focus primarily on repetitive lifting, while also including a small examination of vibration exposure effects.

Elements of Spine Motion

Before discussing the link between occupational risk factors and low back injury and pain, it is important to understand some of the basic elements of spine motion that relate to such injury mechanisms. These include the mechanical loading on the spine (and in particular compression) and the dynamic stability of the spinal column. This dissertation will focus on the latter, maintaining dynamically stable motion. Additionally, this dissertation will examine energetic factors as they relate to dynamic lumbar motion.

Stability

White and Panjabi have described a segmental instability theory as the potential mechanism associated with low back pain (White, 1990). This theory, referred to as clinical spinal instability, theorizes that the spinal instability is the loss the ability to maintain the spine's pattern of displacement under physiological loads (White, 1990). More directly, spinal instability is a buckling dynamic of the long, slender, spinal column (Crisco & Panjabi, 1992). Clinical stability is maintained by the combination of the passive tissues of the spine or surrounding musculature as well as a neural component of the muscular response (Gardner-Morse and Stokes, 2001; Panjabi, 2003).

The lumbar spine is naturally unstable and a stabilization system is required to coordinate the motion of the multiple segments. Panjabi described the stabilization system in three subsystems including the spinal column, the muscle-tendon subsystem, and the neural control subsystem (Fritz et al., 1998; Gardner-Morse and Stokes, 2001). The first subsystem is the passive components of the spine and surrounding ligaments that may provide elastic forces to help return the spine to equilibrium position following a small perturbation (Panjabi, 2003). However, the possible force generated by these passive forces is insufficient to support even the weight of the head without buckling and therefore activated muscle is necessary for spinal stability (Bergmark, 1989).

A previous study observed the critical buckling load of the ligamentous spine column to be only 88N, well below the estimated 1500N minimum estimated for the in vivo spinal load (Crisco and Panjabi, 1992; Nachemson and Morris, 1964). Therefore, active muscle-tendon subsystem surrounding the spine must be acting as support cables to stiffen the spine and providing dynamic stability as well as increasing the maximum spinal loading (Panjabi, 2003). As a result, the stiffness of the muscle-tendon subsystem is an important contributor to spinal stability. As muscle stiffness is associated with muscle activation, there is evidence that decreasing muscle activation can increase risk of low back injury and pain (Hodges and Richardson, 1996).

The third subsystem is the neural control subsystem that controls the muscle activation. The neural control receives kinesthetic input from the other two subsystems. Using this input, the neural control subsystem coordinates the necessary muscle response to stabilize the spine

(Gardner-Morse et al., 1995). In this regard, the neural control subsystem not only identifies the appropriate muscles to activate, but the timing with which they need to coordinate as well.

To summarize, the three subsystems work together under normal conditions to maintain stability. First, the passive spinal components and the active musculature provide dynamic stiffness to stabilize the trunk. Both the passive subsystem and muscle-tendon subsystem provide dynamic proprioceptive information such as position, motion, and vertebral loading, to the neural control subsystem. Based on the proprioceptive information, the neural control subsystem coordinates the appropriate muscle response to maintain stability of the lumbar spine.

Proprioception

The human body contains a variety of complex sensors and motors to control limbs and joints, which allows interaction with the environment. An important sensory element is the muscle spindle organs throughout the musculature of the body. These sensors allow the body to internally identify orientation of limbs and joints. Information from the individual sensors is collected and processed to determine the limb's position and motion relative to the rest of the body; this type of perception is known as *proprioception*. The proprioceptive system provides the ability to perform routine tasks without looking at the arms or legs to see where in space they are. Consider an example of driving a car and needing to slow down for a red light. It is possible to move the foot from the accelerator to the brake pedal without visually looking at the leg.

When the proprioceptive system is operating properly, it is easy to learn new tasks and perform routine tasks with ease. However, there are environmental conditions that can affect the proprioceptive system. This has been shown in studies with performance-based tasks measuring the capabilities of the human proprioceptive system (Arashanapalli and Wilson, 2008; Kito et al., 2006; Verschueren et al., 1999). The altered signal interpretation creates errors in position sense and ability to replicate a motor control task such as a reposition task to examine how well a postural position can be matched from memory (Arashanapalli and Wilson, 2008; Li, 2006). Even 30 minutes after the condition has been removed, the effects of the altered position sense continue affecting the proprioceptive system, suggesting neuromotor habituation or adaptation to the altering stimuli (Li, 2006). When considering the spine, altered perception could lead to poor postural control that may result in motions that place excessive loads on the back ultimately leading to a low back injury.

Proprioception and Spinal Stability

In regards to the spine, the proprioceptive system interprets the status, using information of the position and movements of the joints, the sensation of loading, and the timing of the muscle contractions (Brumagne et al., 1999; Gandevia et al., 1992). The proprioceptive system is a fundamental component of the neural control subsystem, providing the information to coordinate the muscle activation response. Theoretically, any receptor providing position and movement sensation is called a proprioceptor, but some play a greater role than others do. Receptors like the Golgi tendon become active in extreme joint positions while muscle spindles provide information throughout the range of motion (Gedalia et al., 1999; Inglis et al., 1991). As muscle spindles contribute throughout the range of motion, many studies have examined the role of muscle spindles in proprioception of the extremities (Brumagne et al., 1999; Cordo et al., 1995). Altering the proprioceptive feedback of the muscle spindle alters the muscle activation coordination and may therefore increase risk of injury to the lumbar spine (Li et al., 2008).

Lumbar Neutral & Elastic Zones and Stability

Previously Panjabi described the motion of the spine by two regions, the neutral zone and the elastic zone. The neutral zone was defined as the region near neutral posture where the passive resistance of the spinal components was negligible. The elastic zone was defined as the region away from the neutral zone where the spinal components provide increased resistance as deformation continues. In the elastic region, the intervertebral discs, ligaments, and facet joints of the spine begin to inhibit further rotation. In addition as the limits of stretching of the trunk musculature are reached, the passive resistance increases. The coordination pattern observed by Maduri et al. could move the spine away from the neutral zone and be utilizing the elastic zone, resulting in increasing the passive resistance of the soft tissues (Maduri et al., 2008).

Solomonow et al. examined one of the soft tissues, the supraspinal ligament, a ligament along the spine contributing to spinal stability and control (Solomonow et al., 1999). They demonstrated that deformation of this ligament results in reflexive activation of nearby paraspinal muscles to prevent the vertebrae from moving away from their natural alignment. In that study, it was demonstrated that the stabilizing reflexes were reduced 85% within five minutes of repetitive stretching, significantly reducing their stabilizing reflexes and possibly reducing the ability to stabilize the spine. A repetitive lifting coordination that utilizes the elastic zone could not only increase the moment loading on the spine, but could also decrease the stabilization reflexes through this mechanism described by Solomonow et al. and therefore increase risk of injury.

Independent of lifting, highly flexed postures have been observed to lead to flexion-relaxation of the lumbar spine also potentially leading to possible impairment to the neuromotor response (Colloca and Hinrichs, 2005; Rogers and Granata, 2006). This flexion-relaxation has been observed as an increased trunk angle over time in a fully flexed posture due to increased tissue laxity and creep (Dickey et al., 2003; Olson et al., 2004).

Energetics: Stretch-Shortening and Work Loop

It is well known that muscles are the motors for force generation, but less known is how muscles provide other functionality as well. Muscles function as motors, brakes, and springs in locomotion (Dickinson et al., 2000). Examination of running has identified that the muscles, and associated tendons, of the calf store and release potential energy in a spring like mechanism (Bosco and Rusko, 1983).

Stretch-shortening is the active stretch (eccentric contraction) of a muscle followed by an immediate shortening (concentric contraction). This pattern allows for the storage and return of energy in elastic tissues within the system. As the energy is returned from the elastic tissues, already included in the system, there is a reduction in work that is required to be added to the system. This reduction in work improves mechanical efficiency in cyclic activities.

This stretch-shortening strategy has been used in describing the mechanics of running, specifically modeling the motion of the center of mass with springs (Farley and Ferris, 1998). With the muscles acting like springs, energy is stored and then returned as mechanical work free of any additional energy cost (Bosco et al., 1987). Stretch-shortening has been suggested as important to the mechanical efficiency of running and jumping in animals (Farley et al., 1991; Farley and Ferris, 1998; Farley et al., 1998; Farley and McMahon, 1992) (Figure 1). The stretch-shortening strategy has also been well documented in jumping exercises. Avela et al. reported that electromyographic (EMG) data demonstrated that muscle activated prior to landing when performing a drop-jump exercise and specifically that the muscle stiffening during the stretch-shortening exercise is largely controlled by previous experience (Avela et al., 1994). The previous experience allows appropriate stiffening to maximize power returned.

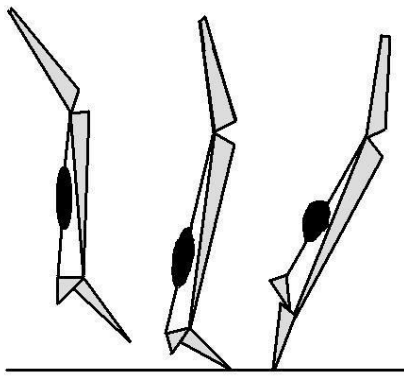

Figure 1. The stretch-shortening cycle is a sequence of three phases. The initial phase is preactivation where the muscle readies for the cycle. The next phase is the stretch phase, followed by the final phase of shortening. Here is an example of the gastrocnemius muscle going through the preactivation (left), stretch (middle), and shortening (right) phases during running.

The efficiency of the muscle can be examined by plotting the force generated by muscle relative to the length of the muscle during cyclic movement, also known as a work loop. The direction of the development of the work loop can describe the activity. If the loop develops in a counterclockwise direction, the muscle is performing work on the environment such as accelerating. Conversely, if the work loop develops in the clockwise direction the muscle is absorbing energy such as decelerating. In a highly efficient activity, the work loop would have a small area with a near net zero amount of work done (Figure 2).

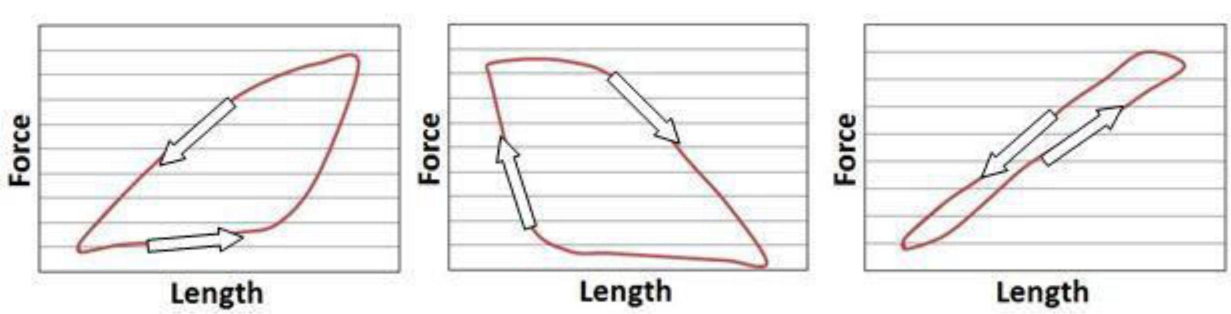

Figure 2. Theoretical work loops created by graphing muscle force by muscle length. The work loop can provide information about the work done. A work loop created with a counterclockwise direction will have a net work that is positive, or the system is providing the work to the muscle (left). If the direction of formation is clockwise, the net work is negative and the muscle (middle) is doing the work. In addition to the direction of formation, the area describes the amount of work with a work loop having a small area having a near net zero work and describing a highly efficient work loop (right).

It is possible that the stretch-shortening dynamics are present in the low back to reduce energy expenditure, a technique that would be helpful in overcoming a lack of strength and endurance.

Repetitive Lifting and Flexed Trunk Postures are Risk Factors for LBP

Lifting activities are a common occupational occurrence. Repetitive lifting has been shown by numerous researchers to be a risk factor for developing low back disorders (Frymoyer et al., 1983; Marras et al., 1995). It is possible that the risk of injury resulting from repetitive and flexed postures could be decreased by altering the mechanics of the lift. Many authors have focused on reducing spine compression by reducing the trunk moment loads as a mechanism to reduce injury risk (Bernard, 1997; Marras et al., 2001; Marras et al., 1999; McGill et al., 1996). Others have focused on issues of dynamic stability (Graham and Brown, 2012, 2014; Maduri et al., 2008; Yue et al., 2007).

Marras et al. examined how 3-dimensional trunk motion contributed to low back disorders in occupational settings involving material handling by analyzing over 400 industrial jobs in 48 industries (Marras et al., 1995). This study categorized the level of risk of low back disorder by analyzing medical records of industries and identifying which trunk motions contributed the most to low back disorders. This study identified the risk of low back disorder increased with increased maximum flexion angle in the sagittal plane, while maintaining a more upright posture during lifting significantly decreased risk of low back disorder. Additionally, load moment, lifting frequency, trunk twisting velocity, and trunk lateral velocity are factors that could accurately predict medium and high risk occupational factors. Therefore, it is important to investigate lifting tasks that involve trunk flexion.

For all trunk flexion angles, there is a range of lumbar postures that are possible. By rotating the pelvis, an individual can reach a highly kyphotic, or rounded, lumbar posture. Conversely, rotating the pelvis the other direction allows an individual to reach a lordotic, or arched lumbar posture. A lifter selects a coordination pattern within this range during a lifting task. This range can be influenced by factors such as the effects of flexion-relaxation observed during larger flexion angles associated with a more kyphotic spine (McGill and Kippers, 1994; Solomonow et al., 2003). There are also a number of factors that could influence the lumbar-pelvic coordination patterns during a lifting movement relative to an individual's range of motion.

Previously Maduri et al. examined lumbar-pelvic coordination using lumbar angle and a subject's range of motion between the most kyphotic to most lordotic lumbar postures (Maduri et al., 2008). The most kyphotic and lordotic lumbar angles were measured at multiple flexion angles to describe the lumbar angle range of motion as a function of torso flexion angle. The measured lumbar range was then used to normalize the lumbar angle as the subject performed a repetitive lifting task. It was found that subjects often perform a highly kyphotic coordination, approaching the limits of their lumbar range of motion, during the extension phase of the lifting task. The rounding of the back could stretch the muscles within the back, storing elastic energy, which is then used when performing the lift. The authors hypothesized that this coordination pattern could utilize a stretch-shortening dynamic within the lumbar musculature that could reduce the energy required as compared to a more neutral coordination to perform the repetitive lifting task. However, this coordination pattern could potentially increase the risk of injury as a result of increasing the moment loads on the intervertebral disks and the additional strain on the trunk musculature. In this dissertation, this dynamic coordination of the lumbar spine will be examined to see if it represents an energetically more efficient coordination pattern. Additionally, by comparing novice and experienced lifters, this work will seek to examine whether such a pattern may be a factor in increased injury risk.

Novice vs. Experienced Lifters

Several studies in the past have examined differences between novice and experienced lifters to improve understanding of the strategies that might be useful in avoiding injury (Authier et al., 1995; Chen, 2011; Marras et al., 2006; Plamondon et al., 2010). The belief is that as individuals gain experience in lifting they will choose better lifting strategies that help them avoid injury. It is believed that if they do not develop better lifting strategies, they may receive an injury that leads to being removed from the activity or occupations that required the repetitive lifting as a result of the injury. Both could contribute to experienced lifting population having safer lifting strategies as compared to novice lifters. As a result, many studies have identified differences between novice and experienced lifters (Marras et al., 2006; Plamondon et al., 2014; Plamondon et al., 2010).

When examining the spinal compressive loading, Marras et al. found that spinal compressive load decreased when subjects performed a lifting task a more familiar lifting frequency (Marras et al., 2006). When forced to lift at an unfamiliar frequency, novice lifters exhibited a higher simultaneous muscle contractions instead of a sequential activation pattern, a pattern which has been demonstrated to increase spinal compressive loading (Parakkat et al., 2007). Those authors hypothesized that the motor control strategies of the novice lifters could be underdeveloped. Another study, found that experienced workers seemed to focus more on maintaining torso stability to maintain total body balance as compared to novice lifters (Lee and Nussbaum, 2013).

There may be several mechanical components of lifting that influence risk of injury. Gagnon et al. observed that experienced lifters performed a knee flexion during the extension phase of a lift instead of a knee flexion (Gagnon et al., 1996). Plamondon et al. found that novice workers flexed their lumbar spine more than experienced workers while maintaining the same moments during a material handling lifting task (Plamondon et al., 2010). This finding was further supported when Plamondon observed that experienced lifters flexed their lumbar spine less than novice lifters while completing a palletizing task (Plamondon et al., 2014). All of these demonstrate differences between novice and experienced lifters with the latter studies identifying differences in the lumbar-pelvic coordination between those groups. However, only Maduri et al. has so far examined such coordination as a function of range of motion, so it is unknown how close these two groups approach their lumbar range of motion limits during the extension phase during cyclic lifting (Maduri et al., 2008). As such, this dissertation will examine range of motion normalized lumbar-pelvic coordination to see if experienced lifters avoid extremes of the range of motion (relative to novice lifters).

Vibration

Vibration has also been identified as an occupational risk factor in low back pain and injury. In addition to examining repetitive lifting, one chapter of this dissertation will examine the effects of vibration exposure on dynamic stability of low back coordination. Exposure to whole body vibration (WBV) in the occupational setting is a common event; more than 7 million workers in the United Sates experience WBV on a daily basis(Wasserman et al., 1997). As WBV has been linked to an increased risk of low back pain, a number of studies have been conducted to understand the etiology of low back pain.

Whole body vibration (WBV) exposure has been associated with a higher incidence of low back disorders in workers from a number of occupations including pilots, truck drivers, and heavy equipment operators. Low back pain and low back injury are serious health concerns affecting up to 80% of the general population (Kelsey et al., 1984; Pai and Sundaram, 2004) and are associated with significant financial costs of work-related disability (Andersson, 1999). The total annual costs of an estimated $23.51 billion (Ricci et al., 2006).

Vibration studies have demonstrated that the seated human body exposed to vertical whole body vibration will resonate at a frequency between 4 and 6 Hz based on seat to spine transmissibility (Fairley and Griffin, 1989). A vertical vibration of the seat can lead to both vertical and flexion-extension motions in the spine. Many laboratory studies have examined vibration effects using this resonance frequency as this would be the worst case scenario. It was observed that a short 20 minutes of whole body vibration resulting in increased response time following an unexpected perturbation (Li et al., 2008). Additionally, the torso flexion has been shown to remain elevated 15 minutes following the termination of vibration exposure using a reposition test (Li, 2006). Both of these conditions exhibit that there are alterations occurring resulting from vibration that inhibit the normal response of the low back with the sustained effects resulting from habituation to the vibration. The effects of vibration have also been measured from a local vibration applied during a seated sway task (Soltys, 2011).

Proprioception has also been examined in the extremities using vibration. The vibration of the muscle-tendon has highlighted the role of the muscle spindles in movement and posture control as the muscle spindles have been identified to be highly sensitive to vibration (Brumagne et al., 1999; Roll et al., 1989). Introducing vibration to the muscle spindles results in altering the output of the muscle spindle, allowing the examination of changes to movement and posture control (Brumagne et al., 2000; Wierzbicka et al., 1998). The vibration can induce a proprioceptive signal that can result in segment and postural illusions. Studies have shown that frequencies between 10 and 120 Hz can result in altered proprioception (Cordo et al., 1995; Roll and Vedel, 1982). The altering of the proprioceptive system reduces the ability to respond in the same manner as normal.

Alteration to the proprioceptive system resulting from vibration has been shown to remain even after the vibration stimulus was removed. There is a powerful post-vibration effect on the motor system (Wierzbicka et al., 1998). One study identified that 30 seconds of vibration could elicit involuntary activation of the previously vibrated muscle (Ribot-Ciscar et al., 1998). The effects were not only observed on the previously vibrated muscle, but extended to muscles away from the vibration source (Gurfinkel et al., 1989). The alterations to proprioception following vibration seemed to indicate a change in the way the central nervous system processed the proprioceptive inputs by the central nervous system (Ribot-Ciscar et al., 1996). In the low back, a series of studies in our laboratory have observed both changes in lumbar proprioception during vibration exposure and after vibration exposure (Arashanapalli and Wilson, 2008; Li et al., 2008).

Performance-based tasks have been created to measure differences in the neuromotor response. A sudden loading task was used to demonstrate that the time to peak muscle activity in the erector spinae and torso flexion following a sudden load perturbation increases during localized musclevibration compared to a baseline measurement (Arashanapalli and Wilson, 2008). A study with the same sudden loading task examining whole body vibration reported an increase in time to peak activity as well as a 1.58 fold increase in proprioceptive errors following 20 minutes of vertical seat vibration when compared to a control group (Li et al., 2008). The findings of these studies both indicate a loss in neuromotor response that could lead to poor control, which could in turn, contribute to injury.

The sudden load and proprioceptive assessments used in these experiments could be used to identify differences resulting from a short duration of vibration that individuals may experience in everyday life, particularly in occupational settings. However, the experimental setup requires a large area, is not easily transportable, and requires significant time to set up. They are, therefore, not useful to take to industry settings.

Because of portability limitations of the sudden load task, the final study of this dissertation was an effort to create a portable task, performance-based task to assess the effects of occupational vibration exposure. Although traditionally balance tasks have been used to examine standing postures, there are several studies that use seated sway protocols on a force plate to examine lumbar control of the spine. One study examined the effects of a local paraspinal vibration on the erector spinae on the mean sway speed in both stable and unstable sitting (Soltys, 2011). The results indicated a significantly increased sway speed ($p<0.05$) in the local vibration condition compared to the non-vibration condition for both the anterior-posterior and medial-lateral directions during vibration exposure. Measures of sway have long been utilized to investigate postural control while standing (Vuillerme et al., 2002; Zatsiorsky and Duarte, 1999, 2000). One reliable measure is the mean sway speed, or the total path length travelled divided by time (Raymakers et al., 2005; Silfies et al., 2003). Standing postural sway studies have been expanded to examine the neuromotor response of the trunk by incorporating seated sway protocols (Cholewicki et al., 2000; Preuss et al., 2005). The theories behind standing and seated sway studies are similar. However, seated sway removes the contribution of the joints of the lower extremities. By removing the lower extremities, any postural control necessary for the trunk to remain upright must be completed by the trunk musculature. In these studies, the subject sat on a platform positioned on a force plate. Some of the platforms are intentionally designed to provide an unstable platform to increase the level of difficulty to maintain balance (Cholewicki et al., 2000; O'Sullivan et al., 2006; Slota et al., 2008). However a recent study examining both stable and unstable seating conditions, found the task difficulty is increased through sensory stimulation, specifically vibration (Soltys, 2011). Therefore, it may be possible to determine the effects of WBV using a stable platform.

Given these results from the force plate sway task and the simplicity of the force plate setup for use in occupational settings, seated force plate measures (including sway) were selected to examine post vibration effects of whole body vibration. Because differences were observed in both seating conditions, the stable seating was determined to be more easily transported and explained to participants. A preliminary study will be presented in Chapter 7 to determine if a performance-based, seated sway protocol could identify differences resulting from WBV.

Although the stable seating task was found to be promising with local vibration during exposure to that vibration, the final study of this dissertation expands on the design by examining effects of whole body vibration following vibration instead of effects of localized vibration during exposure. Additionally the final study includes a pursuit-matching. The pursuit-matching task includes a target on a graph; which the subject attempts to match by adjusting the location of the center of pressure using biofeedback. This provided another measurement for analysis without appreciably extending the time demands on the participant.

Specific Aims and Objectives

The overall goal of the research was to improve understanding of occupational factors linked to low back pain to the further understanding of why some industries have a higher risk associated with them. One factor that was examined was repetitive lifting as both occupations of interest, material handling and truck driving, are exposed to repetitive lifting.

With the goal of working towards creating a training method that could reduce risk of injury, two studies performed. The first study (Chapter 3) had two specific aims. The first specific aim was to examine the differences between novice and experienced lifters during a self selected lifting strategy using a lumbar-pelvic measurement normalized to individual subject range of motion.   The second specific aim was to see if the patterns could be altered through training. The second study (Chapter 4) had the aim to examine how well a trained lifting strategy could be attained from a short duration of training and how well it could be maintained over time.

The next two studies were attempts to understand why the groups select different lifting strategies by investigating the energetics of lifting. In Chapters 5 and 6 the goal was to examine the energy usage during the lifting strategies to test the hypothesis of the novice group selecting a more energetically favorable strategy while also increasing the risk of injury. The first study (Chapter 5) attempts to examine energy consumption through metabolic conversion. A strategy requiring more energy would convert more oxygen to carbon dioxide. The second approach (Chapter 6) examines energy usage in a different way. This chapter examines energy usage through electromyographic (EMG) activation. A plot of EMG activation as a function of lumbar flexion angle was examined where future work could expand on this work using computational models to convert EMG to force generation and lumbar flexion angle to muscle length in order to examine energy expenditure through work loops. The specific aim for this chapter is to perform the preliminary steps that could be combined with mathematic models to create work loops to analyze the energy expenditure of lifting strategies.

The final study (Chapter 7) aimed to design a measurement task appropriate for an occupational setting to examine the effects of occupational exposure to vibration. Like the repetitive lifting studies, this study focused on dynamic coordination of the lumbar spine motion. It was hypothesized that following an occupational vibration exposure, dynamic control of the lumbar motion would be impaired due to vibration exposure. This impairment was examined both in changes in sway speed during quiet sitting and changes in lumbar motion tracking task accuracy.

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CHAPTER THREE: POSTURAL DIFFERENCES BETWEEN NOVICE AND EXPERIENCED LIFTERS DURING REPETITIVE LIFTING

Abstract

Repetitive lifting is a common occurrence in the occupational setting that has been linked to back injury; therefore, it is important to investigate techniques that might reduce injury. Maduri et al. examined the use of a lumbar-flexion envelope to normalize the lumbar posture to a subject's range of motion limits as a function of trunk lumbar flexion to examine lumbar motion in lifting and found that subjects often approached the limits of their envelope during the extension phase of lifting (Maduri et al., 2008). The current study hypothesized that, while novice lifters would approach these limits, experienced lifters would maintain a more neutral posture. Further, this study examined whether both novice and experienced lifters could be trained to different coordination strategies using a biofeedback program, specifically one maintaining near the center of the ROM envelope and another highly kyphotic strategy approaching the limits of the ROM envelope. The results show a significant difference between the lifting coordination strategies where the experienced lifters maintained a more neutral coordination even during trained strategies. Novice lifters self-selected a coordination pattern approaching the limits of lumbar ROM and were able to adjust and perform the neutral coordination pattern with the biofeedback training. The experienced lifters self-selected a more neutral coordination pattern, maintaining near the middle of their range of motion, yet they were able to adjust and perform a highly kyphotic coordination pattern with biofeedback training. Future research should examine whether the biofeedback training can influence the self-selected coordination following training.

Introduction

It has been reported that up to 80% of the general population will experience low back pain and low back injury during their lifetimes (Kelsey et al., 1984; Pai and Sundaram, 2004). Low back pain (LBP) is the leading cause of disability in individuals under 45 years old and accounts for approximately 40% of all compensation claims in the United States (Lis et al., 2007). Repetitive lifting has been identified by the National Institute for Occupational Safety and Health to be associated with incidence to low-back pain and low back injuries (Bernard, 1997).

Previously, Maduri et al. measured lumbar range of motion (ROM) to use as a normalization to compare between subjects of varying levels of lumbar flexibility. The lumbar ROM was measured by having the subject perform maximum kyphotic and lordotic postures at a few flexion angles and interpolating between those flexion angles to create a lumbar ROM envelope. Maduri et al. observed that the lumbar-pelvic coordination of a group of mostly novice lifters typically demonstrated a high lumbar flexion angle relative to the lumbar angle range of motion during the mid-extension phase of a cyclic lifting task(Maduri et al., 2008). It was speculated that this pattern of highly kyphotic lumbar postures (relative to the subject's lumbar range) might predispose these novice lifters to injury.

However, experienced lifters have been observed by other researchers to have a reduced lumbar flexion angle during lifting tasks (Plamondon et al., 2010a). Several studies have examined differences between novice and experienced lifters in repetitive lifting to identify lifting strategies that might be useful in avoiding injury (Authier et al., 1995; Gagnon et al., 1996; Marras et al., 2006; Plamondon et al., 2010b). In these studies, it has been thought that experienced lifters would avoid potentially injurious strategies.

Lifting, especially repetitive lifting, is a common and unavoidable occurrence in the occupational setting. Improved understanding of lifting strategies and how they are selected is a necessary step in designing prevention-training programs to avoid low-back pain injuries. Since experienced lifters have most likely learned strategies to avoid injury, it is therefore, important to understand the differences between experienced and untrained lifters to provide insight to decreasing risk of injury. Additionally, it is important to consider whether subjects can be trained to use other, safer, lifting strategies. The development of training that could help manual materials handling workers to avoid injury and/or low back injury patients to avoid injury recurrence would be useful.

The goal of the current study was to examine the differences between novice and experienced lifters in self-selected lifting strategy and to examine whether lifting strategy can be altered through training. Self-selected strategy was compared to two trained lifting strategies. One of the trained strategies was a highly kyphotic strategy moving through a target between 80% and 95% of the normalized lumbar ROM. The second strategy was a neutral strategy maintaining the lifting in the middle of the subjects range of motion by passing through a target between 42% and 58% of the normalized lumbar ROM. The first hypothesis is that novice lifters will exhibit a more kyphotic coordination than the experienced group during the self-selected strategy. The self-selected strategy of the novice group should resemble the highly kyphotic strategy. Additionally, it is hypothesized that using biofeedback, both groups can be trained to lift with either a kyphotic or neutral lifting strategy.

Methods

Twenty four subjects participated in this study (14 men, 10 women, age of 24.6±3.9 years, height of 1.719±0.101 m, and an average weight of 69.2±15.1 kg) with the approval of the

Human Subjects Committee from the University of Kansas Medical Center, Kansas City, KS. Subjects filled out a medical questionnaire to exclude individuals with musculoskeletal disorder or history of back pain lasting for a week or for more than a day within the past year. Another questionnaire inquired about activity levels related to specific lifting exercises to determine if a subject would be considered an experienced lifter. Individuals were classified as experienced lifters if they lifted weights at least three times a week for the last year or more. Lifting experience with any free weights was determined acceptable, but ideally they would have had experience with dead lifts, bent-over barbell rows, standing curls, squats, and/or standing military presses. Individuals that did not meet these criteria were excluded from the experienced lifters. Additionally subjects were asked if they had received any lifting training through an occupational setting. Individuals that had received lift training through an occupational setting were excluded from the novice group. All remaining subjects were considered novice lifters. The experienced group was comprised of 11 subjects, 4 female and 7 male subjects, with an average age of 25.8±3.8yrs and 23.4±3.4yrs respectively. The average height and weight for the experienced lifters was 1.622±0.051 m and 57.7±5.4kg for female lifters, while the average height and weight for male lifters was 1.774±0.091 m and 82.0±10.0kg. The novice group had 13 subjects, 6 female and 7 male subjects, with an average age of 24.3±2.5yrs and 25.3±5.5yrs respectively. The average height and weight for the experienced lifters was 1.632±0.116 m and 57.8±9.2kg for female lifters, while the average height and weight for male lifters was 1.767±0.073 m and 73.3.0±16.2kg.

Experimental Protocol:

A lifting task was created to examine the kinematics of the spine during repetitive lifting. The task involved lifting a light weight in a crate, from the floor to waist level, repeatedly, for four minutes. The weight lifted was normalized between subjects at approximately 3% of a single maximum lift. The maximum lift was determined by having the subject stand on a force plate (Bertec, Columbus, OH) and lift as hard as possible on a strap fixed to the ground. The strap was adjusted such that the hand hold was roughly shoulder width apart and required the subject to bend over to have the hand hold just below the knees. Subjects were instructed to maintain straight legs and lift with their back, not to lean backwards, pull with arms, or push with the legs. Force plate data were collected at 100hz and the mean of the highest 50 points collected during a 5 second lift was determined as the maximum lift.

The rate of the lifting task was controlled by a metronome generating a tone at 1Hz. Each lift cycle lasted 4 seconds and subjects were instructed to take two seconds to raise the milk crate from ground level to waist level and then immediately lower the crate to ground level over the next two seconds. Although the crate may have contacted the ground, at no time did the subject release the crate. In this manner, the lift task was continuous over approximately four-minute trials with a constant load.

Three electromagnetic sensors (MotionStar, Ascension Technology, VT) were used to collect position and orientation data at 100Hz using the Motion Monitor Software (Innsport, IL). These sensors have a manufacturer reported resolution of 0.08 cm and 0.1° and an RMS accuracy of 0.76 cm and 0.5°. The position sensors were attached at T10, the sacrum, and the manubrium using double sided tape (Figure 1). These three markers were used to define the lumbar ROM envelope for examining the kinematics of the spine. The lumbar ROM envelope is defined by the trunk flexion angle and the lumbar angle. The trunk flexion angle is the angle between a line connecting the T10 and S1 sensor positions and vertical. The lumbar angle is the difference between the angular orientation of the T10 sensor and the S1 sensor and reflects the curvature of the lumbar spine. These definitions were consistent with previous literature descriptions(Granata and Sanford, 2000). The lumbar ROM envelope is the range of possible lumbar angles that can be assumed by a subject as a function of the trunk flexion angle. Additionally, the vertical height of the manubrium marker was used to segment the lifts into extension and lowering phases.

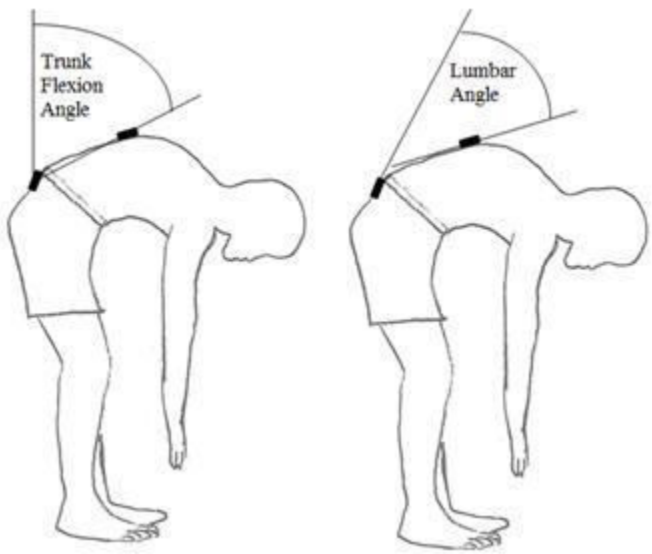

Figure 1. Sensors were located on the spine at T10 and the sacrum. These sensors were used to define the trunk flexion angle, the angle created with the vector connecting T10 to the sacrum and the vector from the sacrum extending in the vertical axis, and the lumbar angle, the angle created by the intersection of the planes extending from the sensors located at T10 and the sacrum.

A biofeedback program was created in Labview (National Instruments, Austin TX) that displayed bars and digital displays for target trunk flexion angle, the current trunk flexion angle, and lumbar angle. Subjects were asked to match current trunk flexion angle to the target flexion angle and, while holding that trunk flexion angle, flex and extend their lumbar spine to achieve their maximum (kyphotic) and minimum (lordotic) lumbar angle. This measurement of spinal range of motion was performed at trunk flexion angles of 0, 30, 60, and 80 degrees (Figure 2). The maximum and minimum lumbar angles were recorded and the average of three iterations of each extreme at each trunk flexion angle was used to normalize the lumbar angles during the remainder of the experiment. Linear interpolation between these four measured flexion angles completed the lumbar ROM envelope for all flexion angles between 0 and 80 degrees.

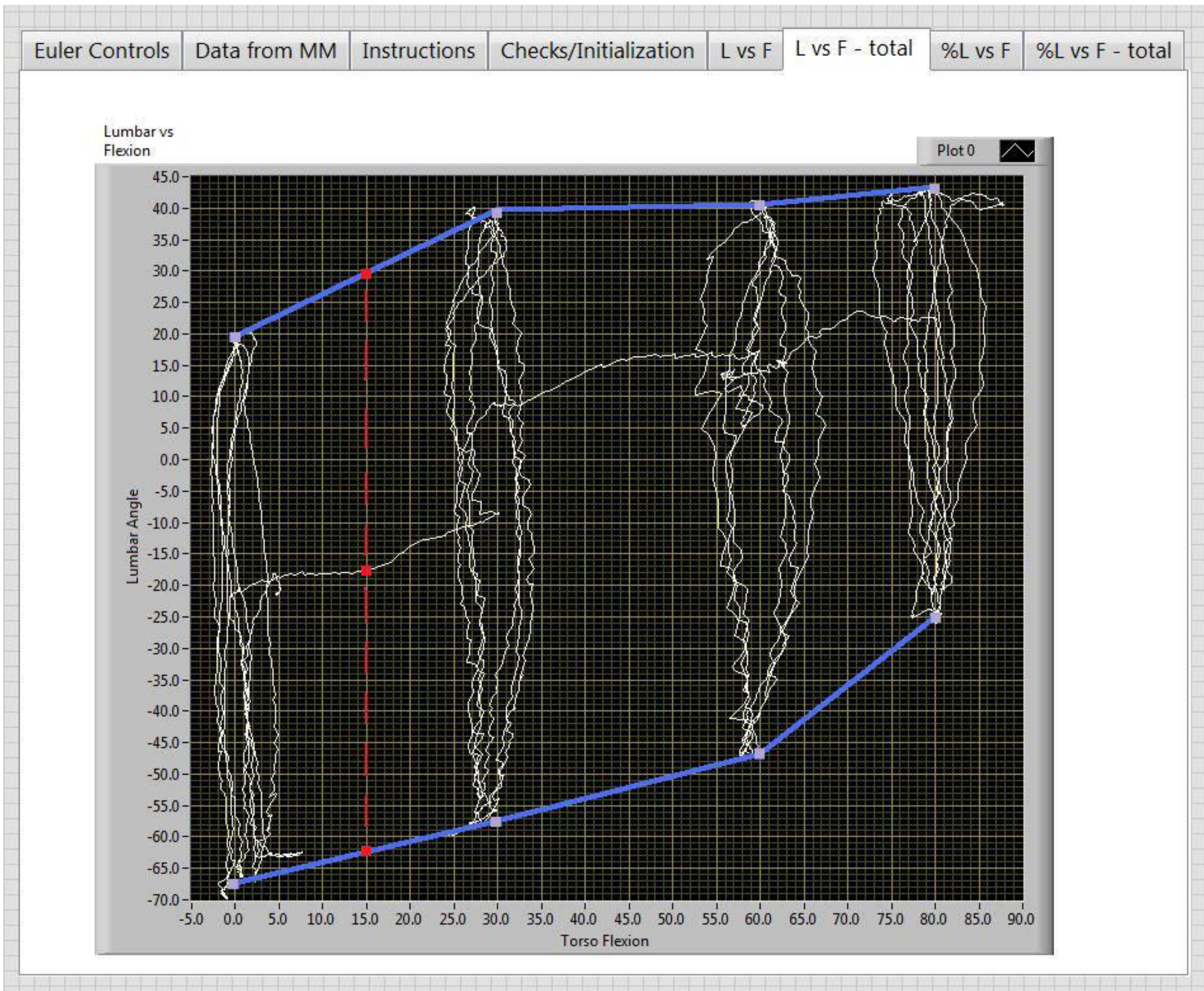

Figure 2. The range of motion envelope was created by measuring the most kyphotic and lordotic postures, or the highest and lowest lumbar angles, at 0, 30, 60, and 80 degrees trunk flexion. Linear interpolation expanded these eight values to calculate the lumbar angle at any trunk flexion angle. This envelope was used to normalize the lumbar angle as a percent of the subject's range of motion for between subject comparisons.

$$LA_{i,max} = \frac{LA_{i+1,max} - LA_{i-1,max}}{TFA_{i+1} - TFA_{i-1}} * (TFA_i - TFA_{i-1})$$

$$LA_{i,min} = \frac{LA_{i+1,min} - LA_{i-1,min}}{TFA_{i+1} - TFA_{i-1}} * (TFA_i - TFA_{i-1})$$

Extrapolation extended the lumbar ROM envelope beyond the limits to account for instances where the flexion angle extended beyond this range, commonly seen when standing fully upright. Once the maximum kyohotic and lordotic extremes were determined for all trunk flexion angles, the lumbar ROM envelope was used to normalize lumbar flexion angle using:

$$Normalized\ LA = \frac{LA - LA_{min}}{LA_{max} - LA_{min}} * 100.$$

The lifting task was performed using three strategies. The first strategy performed was always self-selected by the subject where no instructions were provided other than to perform a straight-legged lift while meeting the rate described previously. Following the self-selected trial, a biofeedback program was introduced to the subject. The subject was trained to perform a specific lifting strategy using the biofeedback. Once the subject felt comfortable with the trained strategy and consistently achieved five successive lift cycles, a rest was provided followed by the trial for that strategy. This approach of training, rest, trial was followed for the two trained strategies. The order of the trained strategies was randomized to reduce possible effects of fatigue on the experimental results.

For the trained strategy trials, a biofeedback program was introduced to the subject. The program provided visual feedback to the subject about their posture as well as a target to achieve during the lifting trials. A plot displayed the normalized lumbar angle on the y-axis and trunk flexion angle on the x-axis. Since the normalized lumbar angle was used, the y-axis was between zero and one and the x-axis was between -5 and 90 degrees trunk flexion angle. A yellow cursor provided feedback on current posture within the lumbar ROM envelope. During the trials, the visual feedback was mostly continuous throughout the trial, but was periodically removed, at intervals of every six lifting cycles for a period of approximately three cycles, to save the kinematic data. This was necessary due to memory constraints of the data acquisition system.

A target was added to the graph in the form of a red box. The target had a height of 15% of the normalized lumbar ROM for the highly kyphotic and 16% for the neutral strategy. The width spanned from 20 to 70 degrees trunk flexion angle. One strategy was a pelvis-first lifting strategy, or a highly kyphotic posture, with the target extending from 80% to 95% normalized lumbar angle (Figure 3). The other strategy was a neutral lifting strategy with the target ranging from 42% to 58% normalized lumbar angle. Subjects were instructed to pass through the target box during the extension phase of the lift. Subjects were not required to pass through the whole target range from 70 to 20 degree flexion, but were instructed to have the cursor go through the box at some time during the extension phase. No instructions were provided for the flexion phase (other than maintaining straight knees), allowing subjects to select whatever felt most natural.

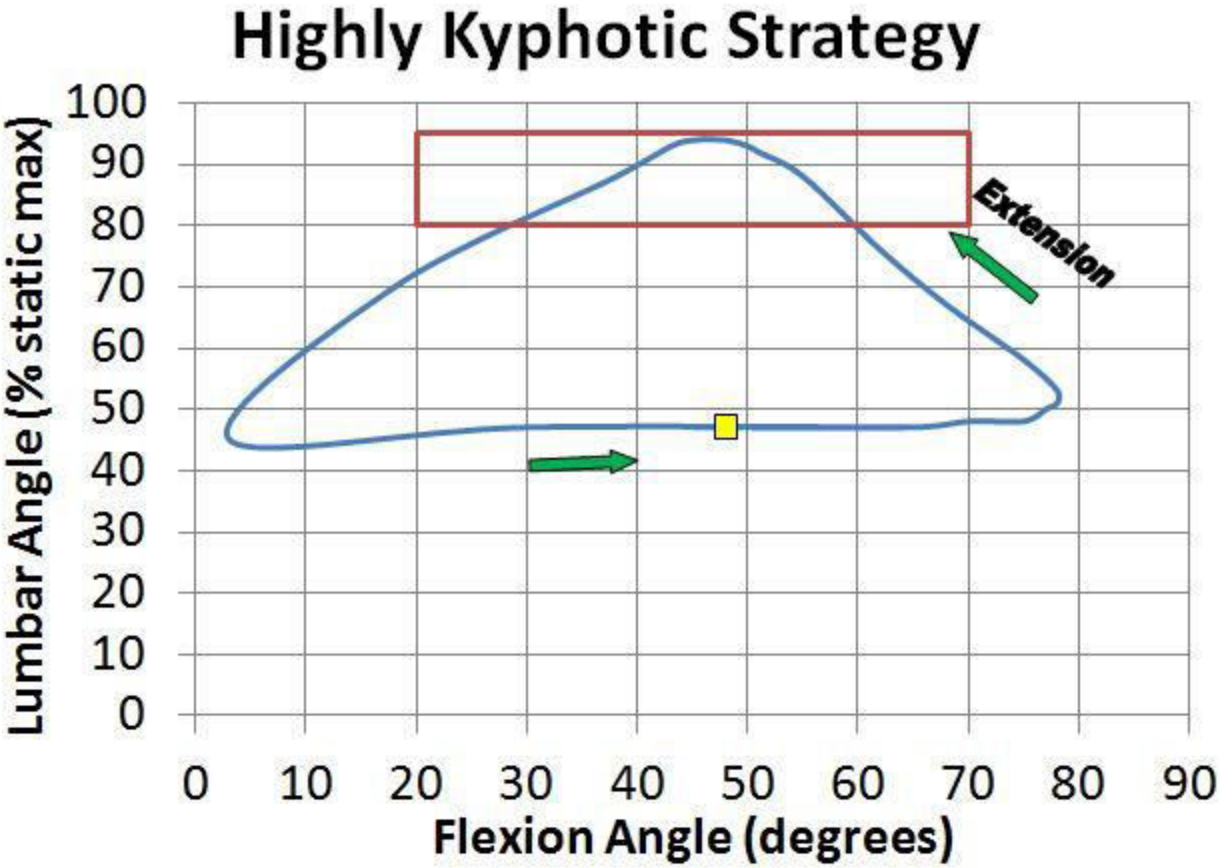

Figure 3. The visual feedback display showed the instantaneous posture with the yellow cursor and the red target box. Subjects were instructed to make the cursor enters the target box during the extension phase of the lift. The blue trail represents the cursor path and was not visible during the experiment. However, the path demonstrates the expected kyphotic path as the lumbar angle approaches the lumbar ROM limits.

Analysis:

The manubrium marker height was used to identify the indices that the lift transitioned between extension and flexion phases of each of the lifting cycles. The maximum manubrium height corresponded to upright standing, or a flexion angle ~0°, while the minimum height corresponded to the bottom of the lift, or a flexion angle ~80°. In addition to dividing the data into individual cycles of lift, the cycles were further divided into four quadrants based on the trunk flexion angle: 10-25°, 26-40°, 41-55°, and 56-70°. The average of the normalized lumbar angle during the first four cycles was determined for each quadrant and strategy. Additionally, there were a few subjects that did not flex their trunk into the fourth quadrant (56-70°), so that quadrant was removed from further analysis to maintain subject population. A mixed measures ANOVA was performed with two independent variables (repeated measures), flexion angle quadrant and strategy, and a co-variant of lifting experience. Differences were considered statistically different for $p \leq 0.05$.

Results

Novice lifters had more kyphotic lifting postures than experienced lifters during both the flexion and extension phases of the lift during all lifting strategies. The largest difference was observed when comparing the self-selected (SS) strategy (Figure 4). Novice lifters started the extension phase at normalized lumbar angle (LA) of 69.9% of their ROM compared to 42.4% for experienced lifters (Table 1). Normalized lumbar angle of both groups increased with trunk flexion angle over the three quadrants with novice lifters reaching a maximum LA of 93.4% compared to 49.0% for experienced lifters. Additionally, during both the extension and flexion phases, the SS strategy of the novice group was closer to the highly kyphotic coordination pattern (HK), or pelvis first strategy, while the experienced group had a SS strategy that more closely resembled the neutral (NU) lifting strategy.

Table 1. The average lumbar angle (% ROM) increased over the four minute trial for all flexion ranges for both the novice and experienced groups. The novice group had larger increases compared to the experienced group in all flexion ranges and lifting strategies with the exception of the flexion range of 40-55° during the highly kyphotic strategy. The increase over time followed the trend of having the greatest increase at the flexion range closest to upright posture and the smallest increase at the highest trunk flexion range.

Increase in Average Lumbar Angle Over Time

	Flexion Range	10 - 25	25 - 40	40 - 55
Nov	SS	35.4	29.1	16.2
	NU	38.3	38.1	35.4
	HK	25.9	18.6	8.7
Exp	SS	14.4	10.6	8.1
	NU	20.4	17.9	11.5
	HK	17.7	16.2	15.8

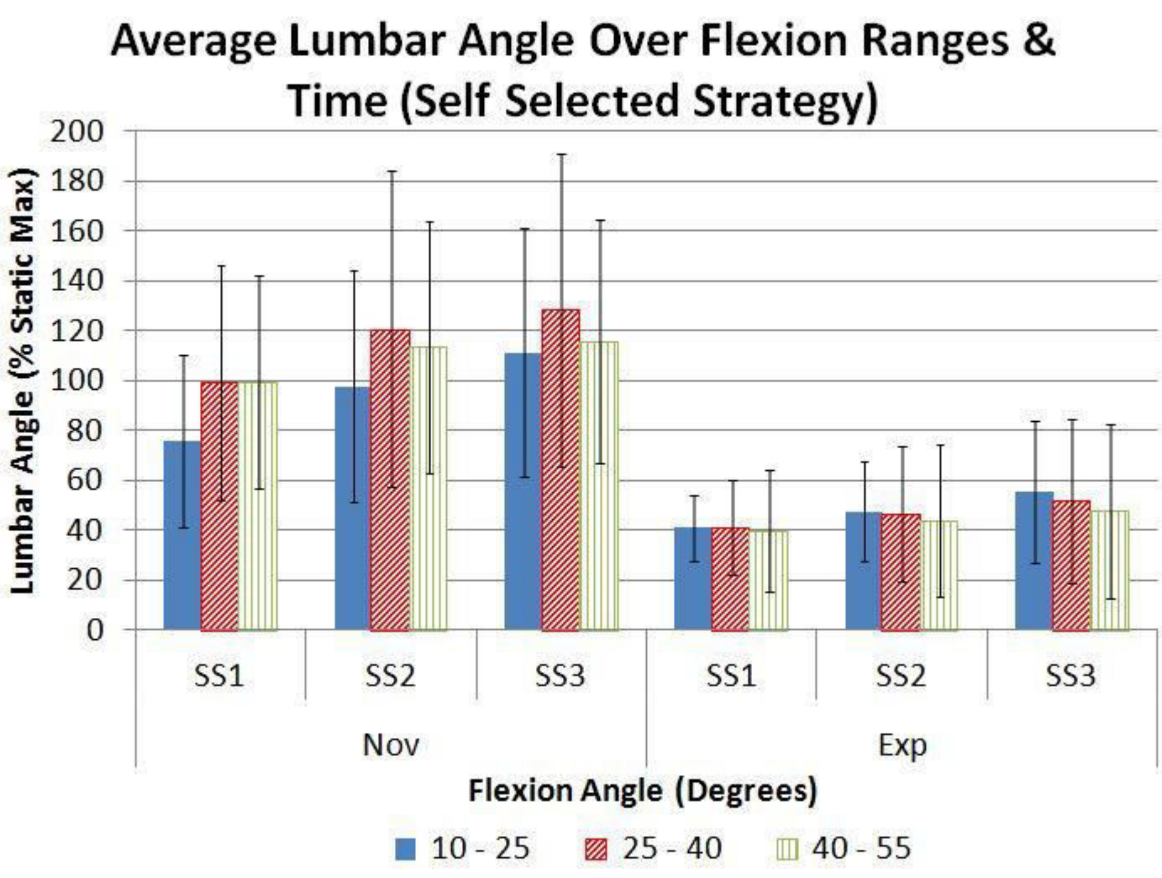

Figure 4. There is a clear difference between the novice and experienced group for the self selected strategy. The novice group select a more kyphotic posture, similar to the highly kyphotic target strategy, during the repetitive lift and increase more over time as compared to the experienced group. The experienced group maintain near the middle of the lumbar range of motion, similar to the neutral strategy, with a smaller increase over time.

A statistically significant difference ($p<0.05$) was found between novice and experienced groups. A mixed measures ANOVA showed that there was a significant difference in several variables: the strategies (SS, NU, and HK), the direction (ascending or descending phase), the quadrant, and some interactions of these main effects (Table 2).

Table 2. A mixed measures ANOVA was performed to examine the difference in lifting strategies between novice and experienced lifters. It was observed that Time, Strategy, Quadrant, Lifter category, and some cross factors were significant ($p<0.05$).

Measurement	Statistical p-value
Time	< 0.05
Strategy	< 0.05
Quadrant	< 0.05
Strategy*Direction	< 0.05
Time*Quadrant	< 0.05

Measurement	Statistical p-value
Lifters	< 0.05
Time*Lifters	0.391
Strategy*Lifters	< 0.05
Quadrant*Lifters	< 0.05
Strategy*Direction*Lifters	< 0.05

Discussion

For this study, it was hypothesized that a novice group would select a highly kyphotic (HK), or pelvis first lifting strategy, approaching the limits of their lumbar ROM, while an experienced group would select a more neutral lifting strategy, maintaining posture near the middle of their range of motion. This would agree with the lifting postures observed by Maduri et al. when subjects were not questioned about lifting experience, but were believed to be primarily novice lifters (Maduri et al., 2008). Our results demonstrate that there is a significant difference ($p<0.05$) between the lifting patterns of the two groups supporting this hypothesis. The SS strategy of the novice group more closely resembles the HK strategy, while the SS strategy of the experienced lifting group more closely resembles the NU lifting strategy (Figure 5).

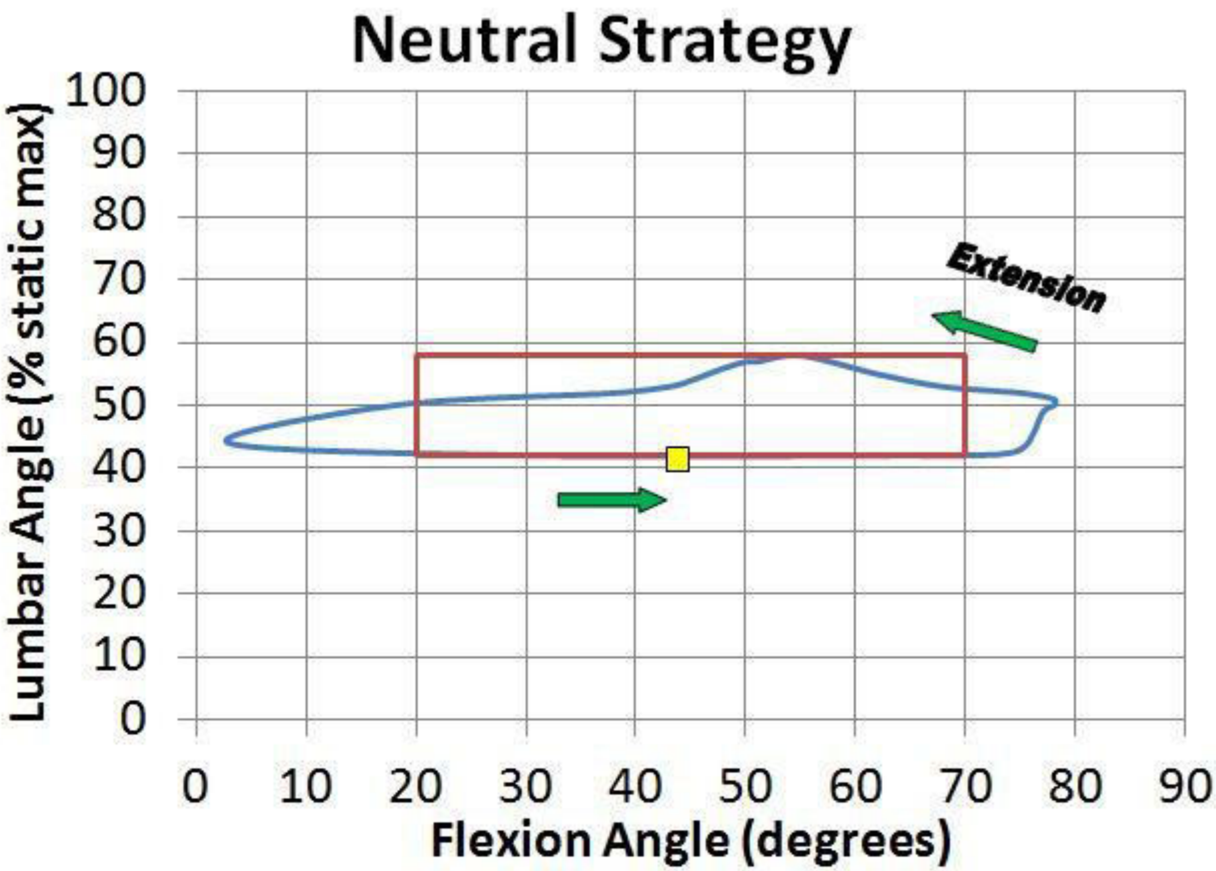

Figure 5. The visual feedback display showed the instantaneous posture with the yellow cursor and the red target box. Subjects were instructed to make the cursor enter the target box during the extension phase of the lift. The blue trail represents the cursor path and was not visible during the experiment. However, the path demonstrates the expected path for the neutral strategy as the lumbar angle remains near the center of the lumbar ROM limits.

Both groups adjusted lifting coordination to the trained strategies. The coordination of the novice lifters adjusted from the highly kyphotic coordination of the self-selected strategy to closer resemble the self-selected lifting coordination of the experienced lifters when trained to the neutral lifting strategy. However, the novice group consistently performed the lifts with a higher lumbar angle in all strategies. These results suggest that while this training can indeed change the coordination of a novice lifter, it may not bring them completely to a neutral strategy selected by a more experienced lifter. During the trained neutral lifting strategy, the novice group lowered their average lumbar angles down into the neutral strategy target range while the experienced lifters raised slight from their self-selected strategy that was near the low end of the neutral strategy target. Therefore, it is not surprising that the experienced lifters maintained a lower lumbar angle than the novice lifters as the groups reached the range while minimizing the change to their self-selected coordination strategy. During the pelvis first strategy the novice group increased lumbar angle from the self-selected coordination that was already in the target region by increasing the lumbar angle to the top of the region or even beyond at higher flexion angles.

Improved understanding of lifting strategies is a necessary step in determining prevention-training programs to avoid low-back pain injuries. Since experienced lifters have most likely learned strategies to avoid injury, it is therefore, important to understand the differences between experienced and untrained lifters to provide insight to decreasing risk of injury. Many studies have examined differences between novice and experienced lifters with the goal of identifying low risk strategies for lift training(Granata et al., 1999; Lee and Nussbaum, 2013; Marras et al., 2006; Plamondon et al., 2014a). Marras et al. examined both novice and experienced lifters for a variety of lifting frequencies and observed that spinal loads decreased when subjects lifted with a lifting frequency with which they were familiar (Marras et al., 2006). Another study examined the muscle activation patterns and observed that the spinal loading decreased with increased experience as the muscle activation pattern shifts to a sequential contraction instead of a coactivation pattern (Parakkat et al., 2007). Both of these authors suggested that with increased experience the motor control strategies become more effective at activating the appropriate muscle coordination and timing, therefore reducing the coactivation and the spinal loads. Lee and Nussbaum (Lee and Nussbaum, 2013) examined the difference between lifting experience and found that experienced lifters placed a greater emphasis on overall stability and balance. Novice workers were less focused on maintaining stability and more on maintaining consistent kinematics over a range of different task conditions. Plamondon (Plamondon et al., 2014b) reported that experienced lifters bend their spine less than novice lifters during a repetitive task. However, lumbar angles vary greatly between subjects based on individual range of motion. To the authors' knowledge, lumbar angle has not been reported as normalized values based on lumbar ROM envelope, so it is unknown if the two groups, novice and experienced, were approaching their limits of lumbar ROM.

Two parameters, lumbar ROM and the neutral zone, were suggested by Panjabi (Panjabi et al., 1982) to be necessary for understanding spinal stability. The neutral zone describes the region near the neutral posture of the spine where there is minimal resistance to intervertebral motion(Panjabi, 2003). Outside of the neutral zone there is an increased internal resistance to spinal motion and more deformation of soft tissues such as the intervertebral discs, facet joints, muscles, and ligaments begin to restrict motion. Therefore lifters going to the extremes of lumbar ROM may be moving the spine posture from the neutral zone and relying on the deformation of soft tissues to accommodate the loading.

Examination of the deformation of supraspinal ligament showed that nearby paraspinal muscles began a reflexive activation in an attempt to maintain the natural alignment of the vertebrae (Solomonow et al., 1998). Both the supraspinal ligament and the paraspinal muscles contribute to maintaining spinal stability and controlling the motion of the spine. However, during cyclic loading these ligaments become desensitized from the repeated stretching that there is a drastically decreased reflex response to 15% of the initial value within the first 8 minutes, which in turn would greatly reduce the ability to stabilize the spine (Solomonow et al., 1999). Repetitive lifting where the spine extends beyond the neutral zone could result in increased loading of the ligaments as well as reducing the reflex responses that provide spinal stability, further increasing the risk of injury.

This stretch-shortening strategy has been used in describing the mechanics of running, specifically modeling the motion of the center of mass with springs (Farley and Ferris, 1998). With the muscles acting like springs, energy is stored and then returned as mechanical work free of any additional energy cost (Bosco et al., 1987). Such a stretch-shortening strategy requires eccentric muscle contraction followed by concentric muscle contraction. It is possible that the stretch-shortening technique is also present in the low back to reduce energy expenditure, a technique that would be helpful in overcoming a lack of strength and endurance.

Stretch shortening has not been studied much in the lumbar spine. However, the coordination of stretch-shortening has been studied extensively in the extremities. This coordination has been shown to increase mechanical efficiency in such activities as drop jump exercises where the muscle actively stretches, while the knees flex, before the jump (Avela et al., 1996). The stretch-shortening coordination pattern has been learned through past experiences and studies have shown that adjusting parameters such as loading, gravity and cycle frequency can affect optimal efficiency (Avela et al., 1996; Avela et al., 1994; Bosco et al., 1987; Bosco and Rusko, 1983; Harrison et al., 2004). It is possible that the stretch-shortening technique is also present in the low back to reduce energy expenditure, a technique that would be helpful in overcoming a lack of strength and endurance. It could describe the relative lumbar flexion during trunk extension that was seen previously by Maduri et al. in novice lifters(Maduri et al., 2008).

The preference of novice lifters to lift with more kyphotic posture could possibly be because such a coordination strategy has a greater mechanical efficiency achieved through a stretch-shortening cycle. The stretch-shortening coordination would briefly store energy in the muscles during eccentric loading and returning the energy during the concentric portion of the cycle. Alternatively, novice lifters might move into highly kyphotic postures due to a lack of good neuromuscular control. The novice group in the current study had a greater variability than experienced lifters in lumbar angle at higher trunk flexion angles where the standard deviation in the third quadrant 57% higher in the highly kyphotic strategy and 72% higher for the neutral strategy. This could indicate there was increased difficulty in maintaining postural control. Conversely, experienced lifters may have reduced reliance on this more kyphotic coordination strategy based on experience as eccentric loading has repeatedly been shown to cause muscle damage (Chapman et al., 2008; Dessem et al., 2010).

The determination of the lumbar range of motion presents a limitation of this study. The procedure of collecting the limits of the range of motion involved having the subject reach and statically hold the extremes at a given trunk flexion. However, the repetitive lifting task where the lumbar ROM was used was a dynamic lift. This could help explain why during the task some subjects were able to go beyond their lumbar ROM limits. The lumbar ROM envelopes were not statistically different between the novice and experienced lifters (Figure 6). As such, the difference found in this study should not be due to difference between the group in the lumbar ROM envelope.

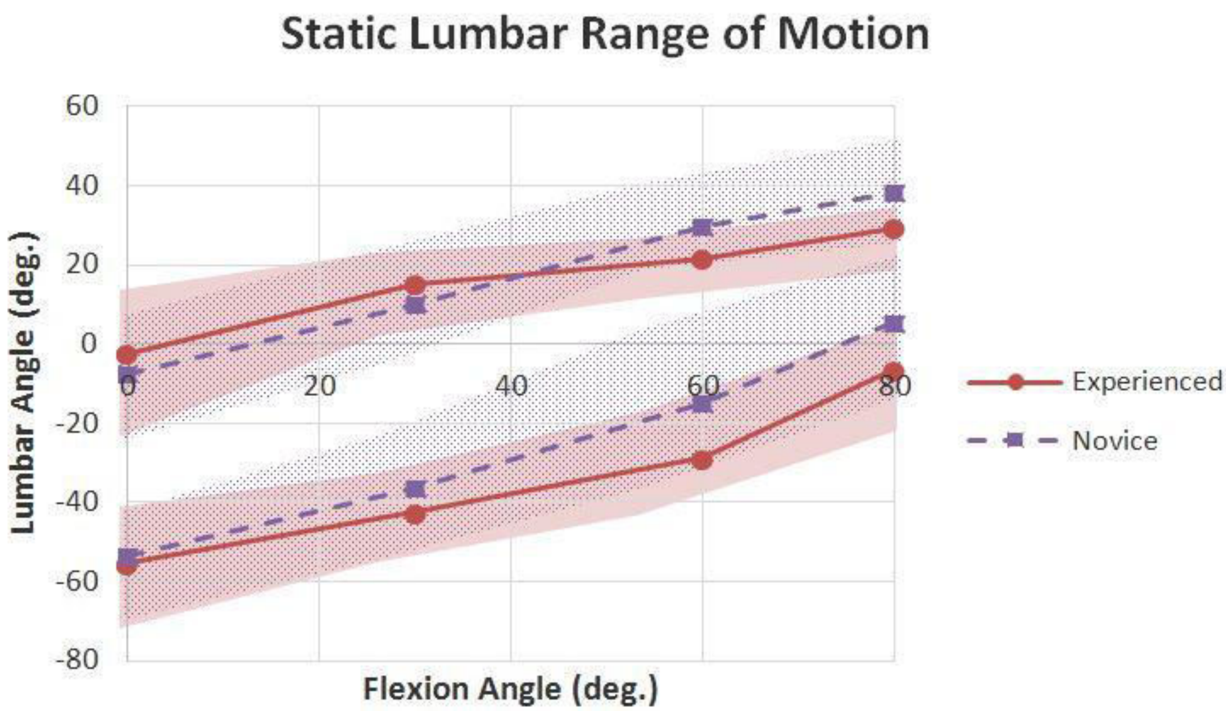

Figure 6. Examination of the ROM for the novice and experienced lifters demonstrates the ROM was similar between the lifting groups.

Future work will involve examining the compliance of the training to the new coordination strategies. The novice group not only reached, but also extended beyond the top boundary of the target during higher trunk flexion angles during the pelvis first strategy. Future work should examine whether training these alternate lifting strategies will alter a subject's preferred strategy when biofeedback is no longer available. Such research should also examine whether trained strategies are maintained over a period of time after training. Additionally, energetics during the lifting strategies should be examined to determine if the highly kyphotic posture during lifting reduces the energy required to complete the lifts. If there is an energy savings, it would strengthen the hypothesis that there is a stretch-shortening activation occurring within the back.

In conclusion, this study demonstrated that during repetitive lifting, experienced lifters maintain a neutral posture staying in the middle of their lumbar range of motion. Similarly, novice lifters select a highly kyphotic lifting posture, approaching the limits of their lumbar range of motion. Using the training protocol described in this paper, it is possible to get subjects to change their coordination strategy to one that maintains a more neutral spine. However, even with such training, novice lifters will favor a more kyphotic strategy.

Acknowledgements

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CHAPTER FOUR: LUMBAR-PELVIC COORDINATION TRAINING IN NOVICE AND EXPERIENCED LIFTERS

Abstract

Several common factors from the occupational setting have been linked to back injury, therefore it is important to examine methods to reduce risk of injury. Maduri et al. examined the lumbar-flexion coordination using a method to normalize lumbar posture to a subject's range of motion (ROM) (Maduri et al., 2008) . They demonstrated that the subjects often approached the upper limits of their ROM, reaching a highly kyphotic posture, during the extension phase of the lift. The current study hypothesizes that the lumbar-pelvic coordination patterns could be adjusted through training. Further, it was hypothesized that the coordination patterns would shift towards the preferred coordination over time when examining both novice and experienced lifters. Additionally, the ROM was examined to confirm the hypothesis that the ROM did not change over time. The results demonstrate that the lumbar-pelvic coordination patterns could be adjusted with biofeedback. There was a significant difference ($p<0.05$) in the successful completion of the trained strategies over time. Additionallya difference was observed between novice and experienced lifters in success rate as the novice group decreased over time with the experienced group remaining consistent throughout the lifting trial. The ROM was also observed to have no significant change over the collection trial. Future research should examine the combination of training duration and lasting effects to determine if a training program could be created that could address long term adjustment to lifting strategies.

Introduction

Low back pain (LBP) is a concern with great consequences on both quality of life and associated expenses. It has been estimated that 80% of the general population will experience LBP or injury during their lifetime (Kelsey et al., 1984; Pai and Sundaram, 2004). Back pain has been reported as the most common and costly reasons for filing a workers' compensation claim as occupational factors account for 37% of back pain (Guo et al., 1999; Hashemi et al., 1997; Marras, 2000; Punnett et al., 2005). The National Institute for Occupational and Health have identified several working conditions known to be associated to low back pain including repetitive lifting such as manual material handling (Bernard, 1997).

A common approach for intervention strategies to prevent LBP has included identifying differences between novice and experts that may be associated with risk of injury. By identifying the differences between novices and experts, training can be created to shift the novice group to better resemble the experienced lifters. Several studies have identified differences in loading during lifting tasks (Granata and Marras, 1999; Marras et al., 2006), while others have identified differences in torso kinematics during lifting tasks (Lee and Nussbaum, 2012, 2013). However, after identifying the differences, the next step is to create an intervention that can shift the technique of the novice individual towards the technique of the experts.

Recent reviews question the effectiveness of training programs at reducing injuries to the back (Clemes et al., 2010; Demoulin et al., 2012; Robson et al., 2012). It has been suggested that the mixed results are resulting from inconsistencies from the various studies. Interventions focusing on manual material handling have transformed over the years since "back school" sessions were developed in 1969 in Sweden where the strategy mainly involved theoretical information, demonstration, and practical exercises (Forssell, 1980). Today interventions include education as well as physical exercises, sometimes with a trainer or other form of feedback (Lavender et al., 2007). Additionally the intervention happens on varying schedules ranging from a onetime training to multiple training sessions with each training session varying from less than one hour to more than three hours (Robson et al., 2012). The question of consistency is further confused when considering the findings of Kingma et al. that observed that adjusting task conditions will adjust the recommended lifting technique (Kingma et al., 2006). The improper selection of a task may result in misleading results, such as a task that is too simple that experienced lifters cannot implement their specific skills or inexperienced lifters are too unfamiliar (Plamondon et al., 2014).

Early training methods included primarily theoretical information describing the proper technique along with demonstration of proper body mechanics and some exercises. Through the years, this has been adjusted to include videos in order to provide the information and demonstrations. Some interventions have included exercise programs as injury has been reported to decrease with increased fitness (Clemes et al., 2010). Previously an intervention with a biofeedback on spinal moment found that the approach was highly dependent on the task and that proficiency was needed more than just exposure to the training (Lavender et al., 2007).

The goal of the current study was to examine the efficacy of a relatively short training session with biofeedback in adjusting the lumbar-pelvic coordination patterns performed during a repetitive lifting task and to examine if the effects could be maintained over time. In Chapter 3, it was observed that an experienced group of lifters performed a neutral lifting coordination while a novice group performed a highly kyphotic coordination pattern. Therefore, the two lumbar-pelvic coordination strategies trained during this experiment were a neutral strategy maintaining the lumbar angle near the middle of the lumbar range of motion (ROM) and a highly kyphotic strategy where the lumbar angle approached the limits of the lumbar range of motion.

The goal would be to examine if the self-selected pattern of the experienced group is similar to a trained neutral strategy as well as if the self-selected pattern of the novice is similar to a trained strategy implementing a highly kyphotic posture. The first hypothesis was that both experienced and novice lifters could adjust lifting coordination and successfully perform the trained lifting coordination. The second hypothesis was that the success rate the trained strategy would decrease over time, as the groups' coordination reverts to their self-selected lifting coordination strategy. The experienced group is expected to reduce their lumbar angle over time during the highly kyphotic strategy returning to the neutral coordination. Similarly, the novice group is expected to increase their lumbar angle as time increases during the neutral strategy. Finally, it is hypothesized that the ROM will not change over the course of the experiment, as this would be problematic with the chosen measurement comparison.

Methods

Nineteen subjects consented and participated in this study approved by the University of Kansas Medical Center, Kansas City, KS. A medical questionnaire was used to remove individuals with history of low back pain or musculoskeletal disorder. Subjects were then classified into two groups, novice and experienced lifters, based on a self reported questionnaire about activity levels related to lifting exercises. Individuals who lifted weights at least three times per week for the past year were classified as experienced lifters. Free weights in general were accepted, but specific questions were asked about dead lifts, bent over rows, standing curls, squats, and military presses. The experienced group was comprised of 8 subjects, 2 female and 6 male subjects, with an average age of 23.7±3.0yrs. The average height and weight for the experienced lifters was 173.1±11.6 cm and 76.4±14.4kg. Subjects not meeting this criteria were classified as novice lifters. The novice group had 11 subjects, 6 female and 5 male subjects, with an average age of 25.3±4.0yrs. The average height and weight for novice lifters was 171.5±10.3 cm and 65.8±15.7kg. All individuals that received lift training or held a material handling position were excluded from the novice group.

Experimental Protocol:

A repetitive lifting task was created to examine lumbar-pelvic coordination. The lifting task cycled through raising a crate from ground level to waist level and finally returning to ground level before repeating. The weight in the crate was normalized between subjects as approximately 3% of a single maximum lift (Figure 1). The maximum lift was determined by having the subject stand on a force plate (Bertec, Columbus, OH) and performing an isometric lift by pulling up as hard as possible on a strap that was fixed to the ground. The posture of the subject had a trunk flexion such that the hands were holding the strap shoulder width apart and just below the knees. Instructions were provided to make sure the subject used their back musculature and did not push with their legs, pull with their arms, or lean backwards while performing this straight legged single max lift. The force plate data was collected at 100hz for a duration of 5 seconds. The average of the highest 0.5 seconds was considered the maximum lift.

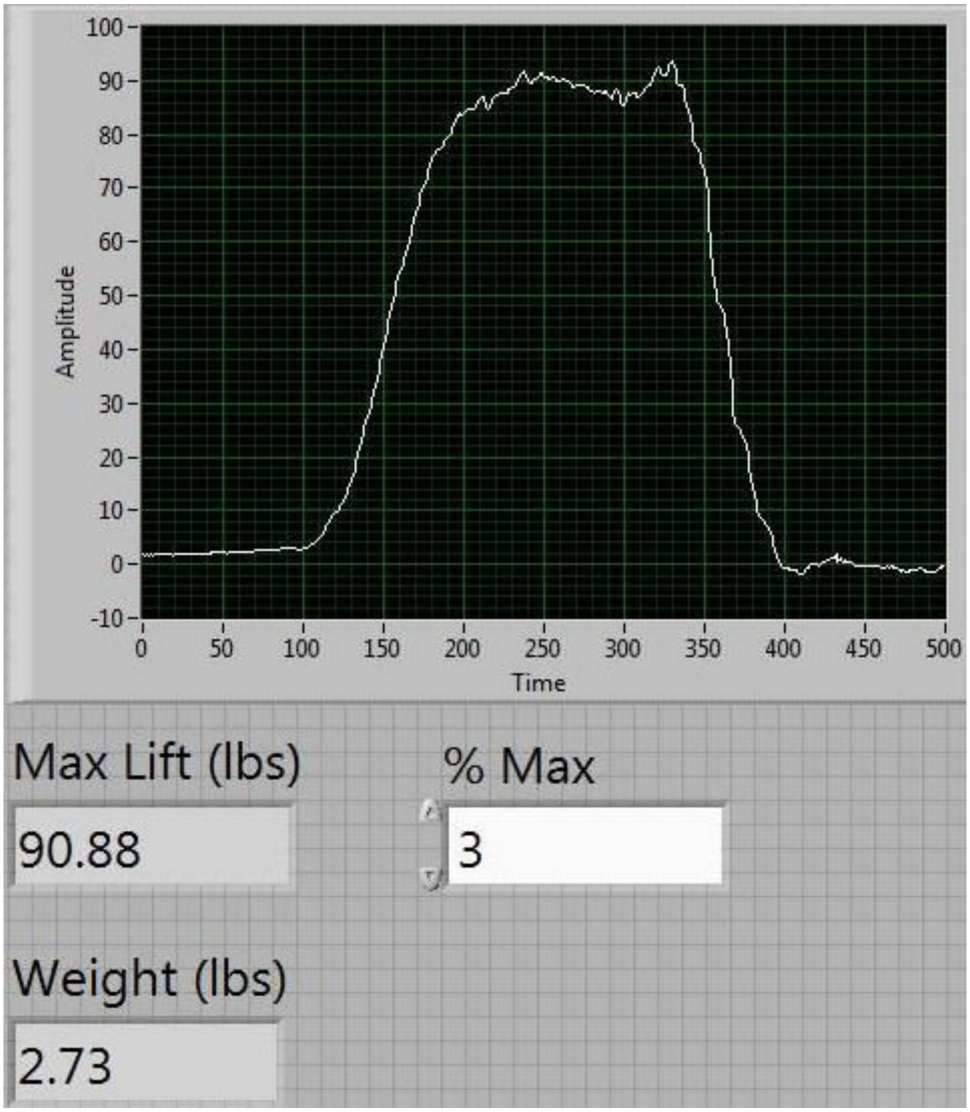

Figure 1. Subjects performed a single max lift while standing on a force plate and pulling on a strap fixed in place. The highest half second of data was averaged for the max lift and the weight lifted during the experiment was set to be ~3% of this lift to normalize between subjects.

During the repetitive lifting task, the legs remained straight to focus on the lumbar-pelvic region. For consistency between subjects throughout the experiment, the rate of the lift was held consistent using a metronome at 1Hz, where each lift cycle lasted two seconds extending the trunk to raise a crate to waist level and two seconds flexing the trunk to lower the crate to the floor level. The subject was instructed to maintain continuous motion and not to pause at any point during the lift. Additionally subjects were instructed to not release the crate and hold it throughout the lifting task. The repetitive lifting task was performed in a four-minute block resulting in approximately 60 total lift cycles. Kinematic trials recorded approximately six lift cycles at the initiation, middle, and end of the four-minute block.

The lumbar-pelvic coordination of three lifting strategies were examined. The first strategy completed was self-selected by the subject. During the self-selected lifting strategy the subject was instructed to maintain straight legs and follow the metronome, but no feedback was provided about the lumbar-pelvic motion. Following the self-selected strategy two trained strategies were performed in a block randomized order. The next strategies utilized a neutral lifting strategy and a highly kyphotic lifting strategy.

Position and orientation data were collected at 100Hz from three electromagnetic motion sensors (MotionStar, Ascension Technology, VT) using the Motion Monitor software. The sensors have a reported resolution of 0.08 cm and 0.1° and an RMS accuracy of 0.76 cm and 0.5°. Sensors were located at T10, the sacrum, and the manubrium using double sided tape. These sensors were used to define the lumbar ROM envelope for examining the kinematics of the spine during the repetitive lifting task. The lumbar ROM envelope was defined by the trunk flexion angle and the lumbar angle. The trunk flexion angle is defined as the angle created between the vectors from the position of T10 to the sacrum to the vertical axis (Figure 2). The lumbar angle is defined as the difference between the angular orientation of the sensors located at T10 and the sacrum. The definitions of these angles are consistent with previous literature descriptions by Maduri et. al. (Maduri et al., 2008).

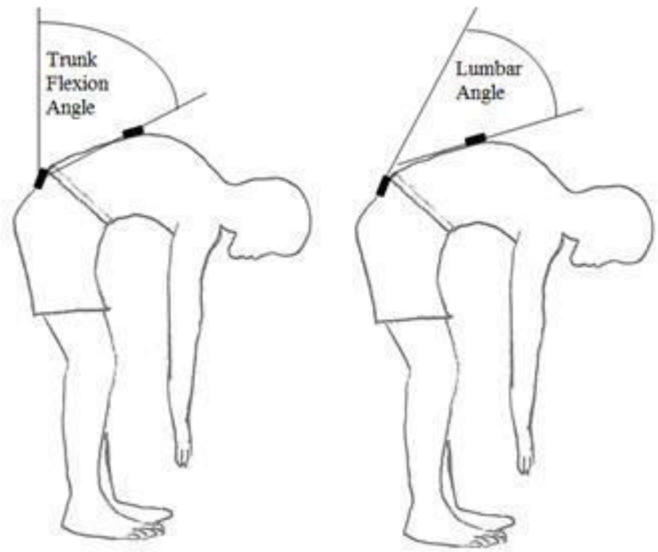

Figure 2. Sensors were located on the spine at T10 and the sacrum. These sensors were used to define the trunk flexion angle, the angle created with the vector connecting T10 to the sacrum and the vector from the sacrum extending in the vertical axis, and the lumbar angle, the angle created by the intersection of the planes extending from the sensors located at T10 and the sacrum.

The position and orientation data was exported from Motion Monitor software (Innsport, IL) in real-time through a custom Labview (National Instruments, Austin TX) biofeedback program developed specifically for this study. The initial program determined the subject range of motion (ROM) envelope. Visual feedback was provided using two bars on a plot, one was a stationary target flexion angle and the second bar was the current instantaneous flexion angle. Subjects were instructed to alternate between maximum and minimum lumbar angles while matching the target flexion angles of 0°, 30°, 60°, and 80° and hold the extreme postures while the lumbar angle was recorded. The final values of lumbar angle ROM were calculated from three iterations of the extremes for each of the flexion angles. Linear interpolation calculated the ROM envelope for flexion angles between the measured flexion angles and linear extrapolation extended the envelope below 0° or above 80° (Figure 3). This was commonly seen when subjects were standing fully upright.

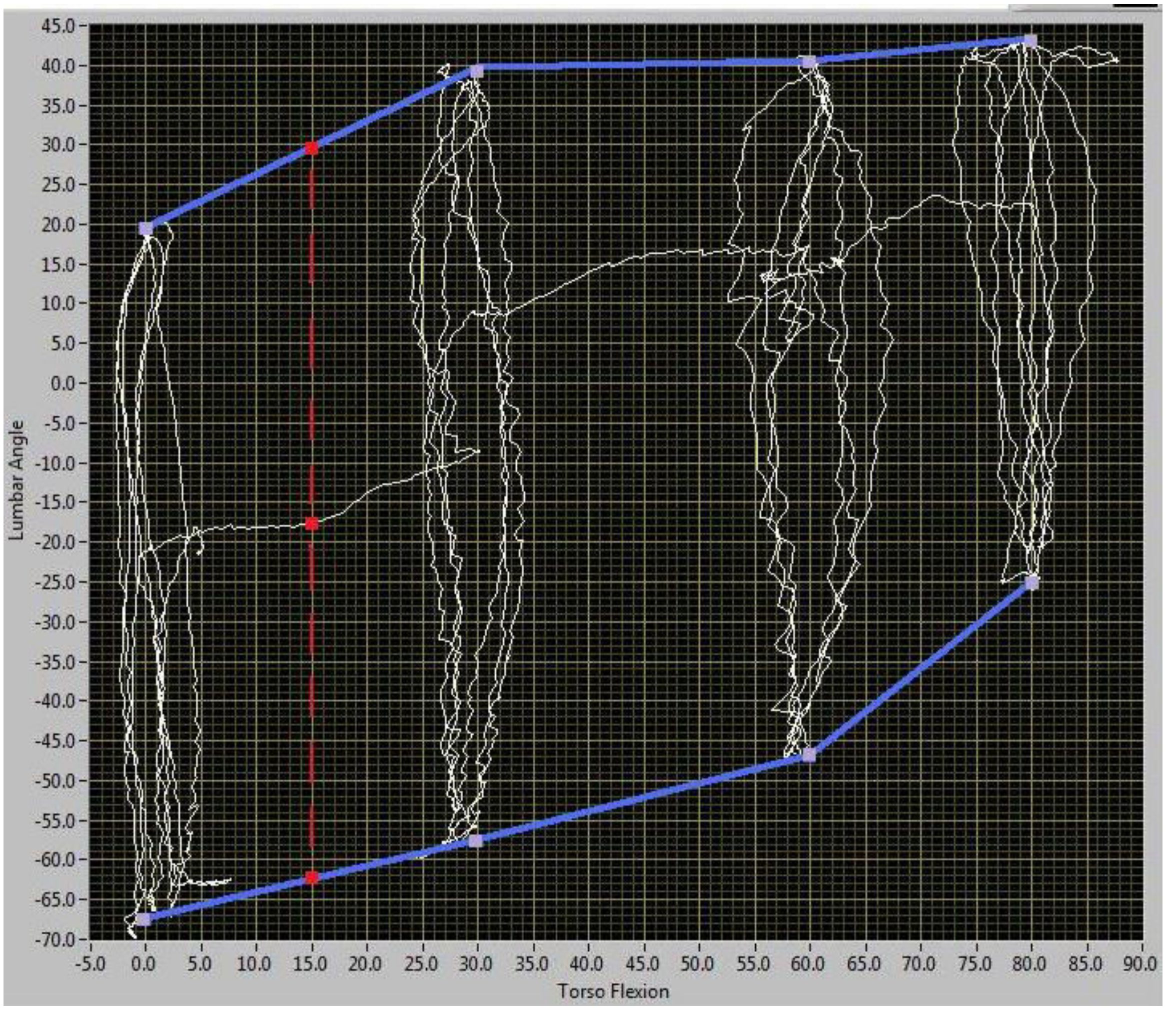

Figure 3. The range of motion envelope was created by measuring the most kyphotic and lordotic postures, or the highest and lowest lumbar angles, at 0, 30, 60, and 80 degrees trunk flexion. Linear interpolation expanded these eight values to calculate the lumbar angle at any trunk flexion angle. This envelope was used to normalize the lumbar angle as a percent of the subject's range of motion for between subject comparisons.

Three lifting strategies were performed while recording the kinematics. The first strategy performed was always the self selected strategy where no instructions were provided other than to perform a straight legged lift while following the lift rate based on the metronome. No visual feedback was provided to the subject during this trial, allowing the subject to select their preferred lumbar-pelvic coordination strategy. The subject raised and lowered the crate containing the weight for the four minutes of continuous lifting. Kinematic data during this trial was saved for analysis.

Following the self selected strategy a biofeedback program was introduced to the subject. The next biofeedback program provided visual feedback about lumbar-pelvic coordination as a function of the normalized lumbar angle. An XY-plot displayed the flexion angle on the x-axis and the normalized lumbar angle on the y-axis. The normalization was based on individual lumbar ROM envelope such that the y-axis was between zero and one hundred percent ROM (Figure 4). The flexion angles displayed were determined by a few trials such that the visual feedback maintained on the screen. The flexion angles displayed ranged from -5° to 90°. The instantaneous normalized lumbar-flexion position was marked on the plot by a yellow cursor, providing the subject with visual feedback of the current lumbar-pelvic coordination. In addition to the yellow curser identifying the subjects instantaneous normalized lumbar-flexion position, a target zone was marked on the plot. A red box was plotted to train subjects to a specific lifting strategy.

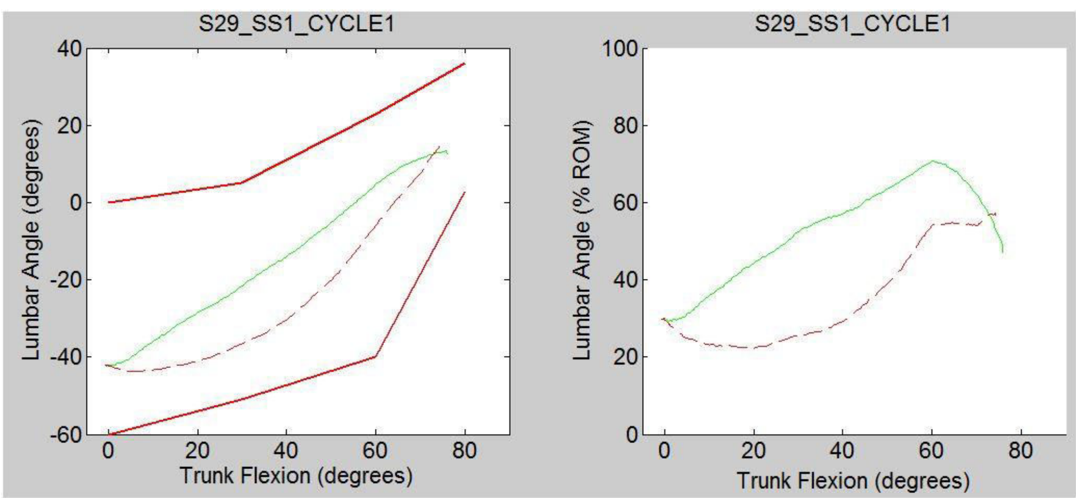

Figure 4. The raw lumbar angles of a single cycle lift are represented with the range of motion envelope surrounding it (left). The lumbar angle is normalized to the subject's lumbar ROM (right) for the analysis.

The target box was rectangular with the height of the box set to be approximately 15% of the lumbar ROM. For the highly kyphotic strategy the target was bounded between 80% and 95% of the normalized lumbar ROM (Figure 5), whereas the neutral strategy was bounded between 42% and 58% of the normalized lumbar ROM (Figure 6). In this manner, the highly kyphotic strategy reached high normalized lumbar angles while the neutral strategy maintained near the center of the lumbar ROM. The target box always ranged between 20° and 70° of trunk flexion and the order that subjects performed the different trained strategies was randomized to reduce possible effects of fatigue. Subjects were instructed to perform the lift such that the yellow curser, the instantaneous feedback, passed into the target box during the extension phase of the lift. Subjects were told that the curser did not have to pass through the entire box from 70° to 20° trunk flexion, but needed to go into the target box at some point during the extension phase. Additionally, subjects were instructed to not worry about the target during the flexion phase of the lift and were able to select the lumbar pelvic coordination that felt most natural.

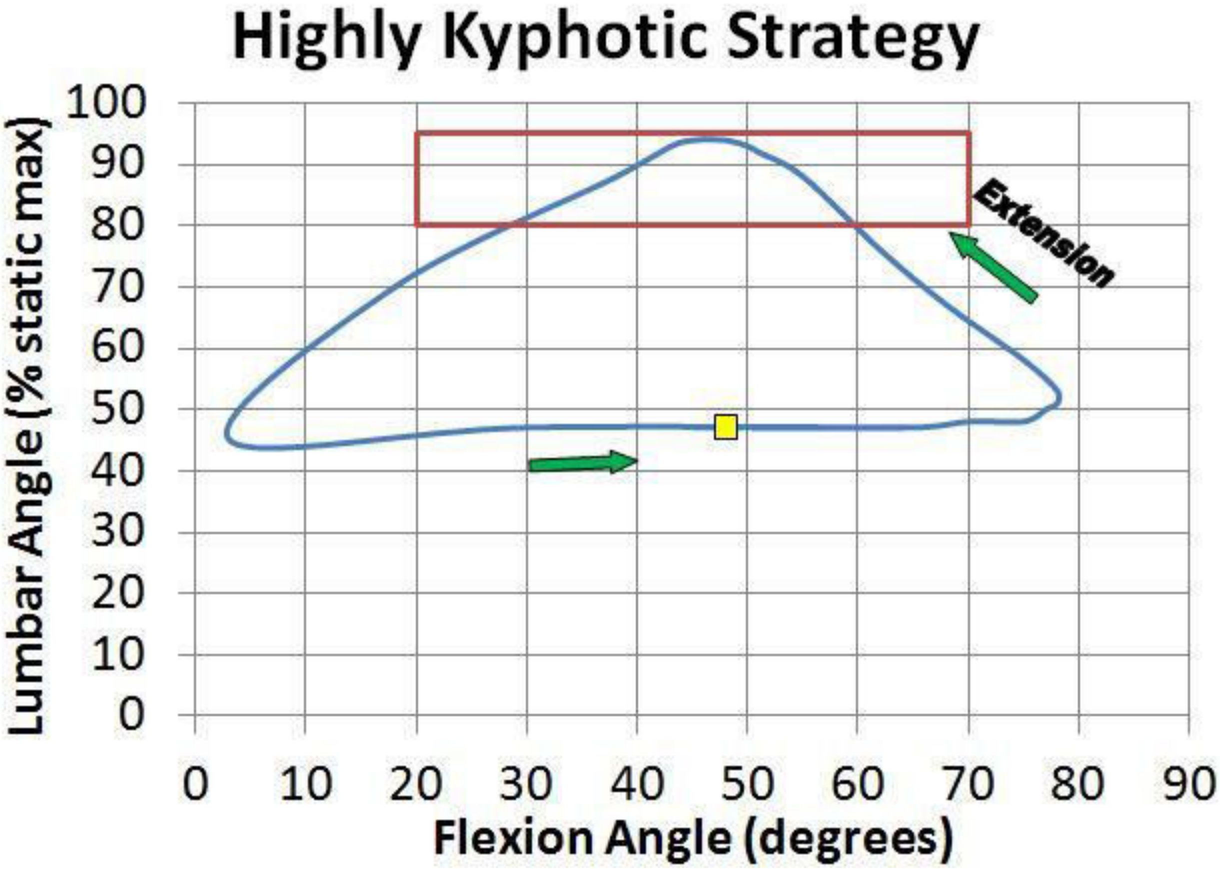

Figure 5. The visual feedback display showed the instantaneous posture with the yellow cursor and the red target box. Subjects were instructed to make the cursor enters the target box during the extension phase of the lift. The blue trail of where the cursor had been was not visible, but demonstrates the kyphotic path as the lumbar angle approaches the lumbar ROM limits.

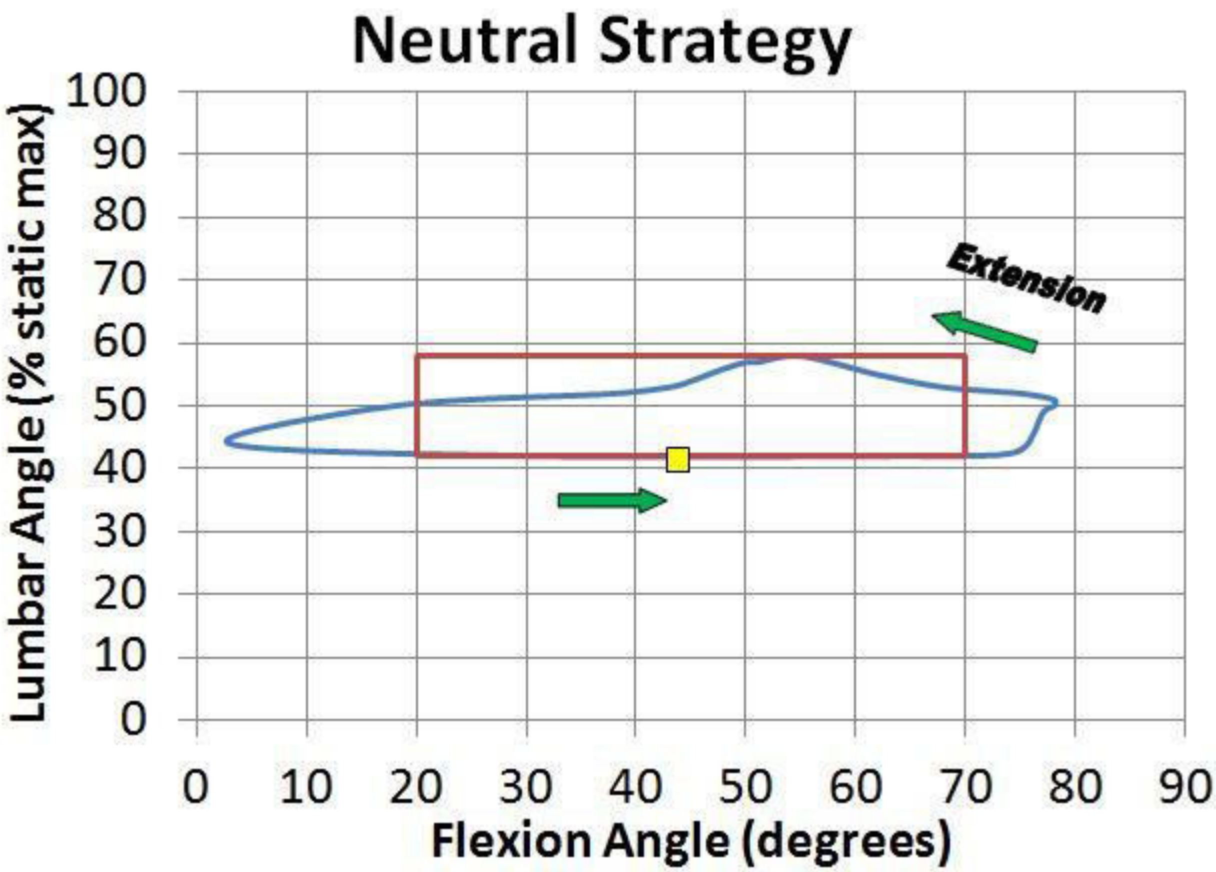

Figure 6. The visual feedback display showed the instantaneous posture with the yellow cursor and the red target box. Subjects were instructed to make the cursor enter the target box during the extension phase of the lift. The blue trail of where the cursor had been was not visible, but demonstrates the expected path for the neutral strategy as the lumbar angle remains near the center of the lumbar ROM limits.

The subject performed practice lifts to understand how to use the biofeedback program. Once the biofeedback was understood, training of the first strategy was initiated. The subject practiced performing the desired strategy absent of weight but following the metronome. Training was complete when the subject felt comfortable performing the strategy and consistently achieved five successive lift cycles. Following training the subject was offered a rest period before starting the collection trial. The sequence training, rest, collection was completed for both of the training strategies where the order of the strategies was randomized to reduce fatigue effects.

During collection of the four-minute lifting trial, the visual feedback was periodically removed to save the kinematic data. This was necessary to prevent data loss resulting from memory constraints and each kinematic recording contained approximately six lifting cycles. The visual feedback was returned as soon as possible after saving the kinematic data. Data was only collected when visual feedback was available to the subject.

Analysis:

The kinematics were divided into three time segments, starting at 0, 1.5, and 3 minutes of continuous lifting, over the four-minute repetitive lifting trial. Each cycle of these time segments was identified using the height of the manubrium sensor. The local maximum height of the manubrium corresponded to upright standing, or a flexion angle of zero degrees, while the local minimum corresponded to reaching for the floor, or the fully flexed posture approximately 90 degrees flexion. Additionally the cycles were further divided into the lifting (extension) and lowering phases. The extension phase was examined to determine the percent of successful lift cycles that executed the trained lifting strategy as a measure of the compliance to the training.

In addition to examining the compliance to the lifting strategies, the lumbar-pelvic coordination was examined over the three time segments. This was accomplished by dividing both the lifting and lowering phases of the lift cycles into three ranges of flexion angle (10-25, 25-40, and 40-55 degrees). A mixed measures ANOVA was performed on the average normalized lumbar angle for each region, 10-25, 25-40, 40-55, and 55-70 degrees of flexion. The ANOVA examined the change over time for each of the three lifting strategies in both directions, while including the between subjects comparison of lifting experience.

It was observed that the subjects were extending beyond the measured range of motion limits during the experiment so a subgroup was used to examine the change in ROM. This subgroup had 9 subjects total with 5 experienced lifters (2 male and 3 female) and 4 novice lifters (2 male and 2 female) to give an overall representation of the study population. The ROM determination procedure was completed prior to the self-selected lifting trial and immediately following the self-selected lifting trial before the rest period was provided. The maximum kyphotic and lordotic extremes were compared using a mixed measures ANOVA to determine if there was a significant change in the ROM over the self selected trial.

Results

The success rate over the first four lift cycles was examined for each of the three lifting strategies. The average success rate for the neutral lifting strategy decreased over time from 85.5% for the initial time to 48.7% for the recording at the end of the trial. Similarly, the average success rate for the highly kyphotic strategy decreased from 78.9% at the initial time to 51.3% at the end of the trial. Subjects were categorized based on the success rate for each time period in each of the trained strategies (Table 1). The success rate decreased over time for both of the trained strategies. The novice group demonstrated a decrease in success over time while the success rate of the experienced group was consistent over time. A mixed measures ANOVA was performed on the success rate over the three time periods for the two strategies recorded. There was no significant difference ($p = 0.847$) between the trained lifting strategies, whereas there was a significant difference ($p < 0.05$) over time (Table 2).

Table 1. This table lists the number of subjects that performed the trained strategy successfully. In this table the neutral strategy is identified by NU and the highly kyphotic strategy is HK. The numbers following the designation identify the timing within the four minute trial where 1 is at the beginning, 2 is the middle, and 3 is at the end of the trial. The success rate goes down over time with NU1 having the highest percent of success at 85.5% and NU3 having the lowest at 48.7% success.

Success	NU1	NU2	NU3	HK1	HK2	HK3
100%	15	9	7	12	9	7
75%	1	2	1	1	4	2
50%	1	0	1	4	0	2
25%	0	2	4	1	3	1
0%	2	6	6	1	3	7
Average	85.5%	57.9%	48.7%	78.9%	67.1%	51.3%

Table 2. A mixed measures ANOVA was performed to examine the difference in success rates in the lifting strategies between novice and experienced lifters. It was observed that Time, was significant (p<0.05). A possible trend was observed based on lifting experience and should be investigated further.

Measurement	Statistical p-value
Strategy	0.847
Time	0.003
Strategy*Time	0.234
Lifter	0.080

The difference over time was also significant when considering between subjects factor of lifting experience. The experienced group was more successful at completing the neutral strategy over time with a success rate remaining above 78% throughout the four minute trial. In addition to maintaining a higher success rate over time, the experienced group had a consistent success rate over time in both strategies. The novice group however decreased over time to a success rate of 27.3% by the end of the neutral trial. However, the novice group had the highest success rate for the initial time period in both of the trained strategies (Table 3).

Table 3. The experienced group was more successful at completing the neutral strategy over time with a success rate remaining above 78% throughout the four minute trial. The novice group however decreased over time to a success rate of 27.3% by the end of the trial. At the same time, the novice group had the highest success rate for the initial time. This pattern was consistent with the highly kyphotic strategy as well. The experienced group maintained a higher success rate over time after starting at a lower success rate during the initial time period as compared to the novice group.

	Novice					
Success	**NU1**	**NU2**	**NU3**	**HK1**	**HK2**	**HK3**
100%	9	3	2	8	4	2
75%	1	2	0	0	2	2
50%	0	0	0	2	0	0
25%	0	1	4	0	2	1
0%	1	5	5	1	3	6
Average	**88.6%**	**43.2%**	**27.3%**	**81.8%**	**54.5%**	**34.1%**

	Experienced					
Success	**NU1**	**NU2**	**NU3**	**HK1**	**HK2**	**HK3**
100%	6	6	5	4	5	5
75%	0	0	1	1	2	0
50%	1	0	1	2	0	2
25%	0	1	0	1	1	0
0%	1	1	1	0	0	1
Average	**81.3%**	**78.1%**	**78.1%**	**75.0%**	**84.4%**	**75.0%**

The normalized lumbar angle increased in all quadrants over the four-minute trials for both novice and experienced lifters. During the self-selected strategy the average normalized lumbar angle increased 8.1% for the third quadrant, 10.6% for the second quadrant, and 14.4% for the first quadrant for the experienced group. Similarly, the average normalized lumbar angle increased 16.2% for the third quadrant, 29.1% for the second quadrant, and 35.4% for the first quadrant for the novice group. The increase was observed for all three lumbar ranges in all three strategies including the trained strategies where a target range was provided. The experienced group maintained a lower average than the novice group for all ranges in all strategies with the largest differences observed during the self-selected strategy (Figure 7). The averages for the novice group ranged from 52.4% ROM in the initial time segment of the neutral strategy in the lowest flexion range to 122.2% ROM in the final time segment of the self-selected strategy in the second flexion range. The experienced group averages ranged from 40.1% ROM in the initial time segment of the self-selected strategy to 99.4% ROM in the final time segment of the kyphotic strategy.

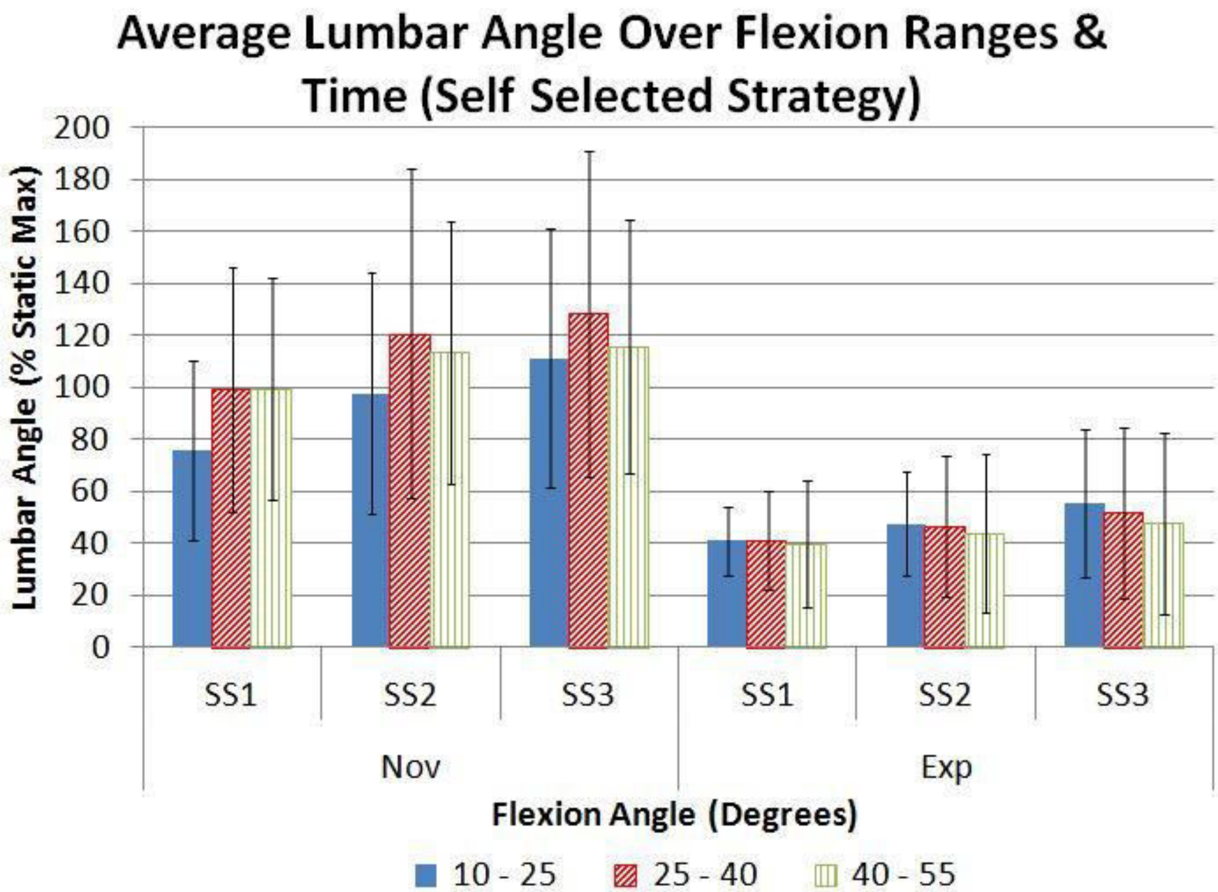

Figure 7. There is a clear difference between the novice and experienced group for the self selected strategy. The novice group select a more kyphotic posture, similar to the highly kyphotic target strategy, during the repetitive lift and increase more over time as compared to the experienced group. The experienced group maintain near the middle of the lumbar range of motion, similar to the neutral strategy, with a smaller increase over time.

During the trained strategies the novice group increased lumbar angle more than the experienced group. During the neutral strategy the experienced group increased from the initial time period to the middle of the trial and maintained near that same lumbar angle for the remainder of the trial while the novice group continued increasing the lumbar angle into the third time period (Figure 8). This trend of the novice group to continue increasing lumbar angle was also present in the highly kyphotic strategy even as the initial time period had the lumbar angle near the limits of the range of motion (Figure 9). By the end of the four-minute trial the lumbar angle had extended well beyond the limits of the static lumbar range of motion for the novice group. Even the experienced group was reaching the limits of the static range of motion by the end of the trial, although not extending well beyond the limit as the novice group had demonstrated.

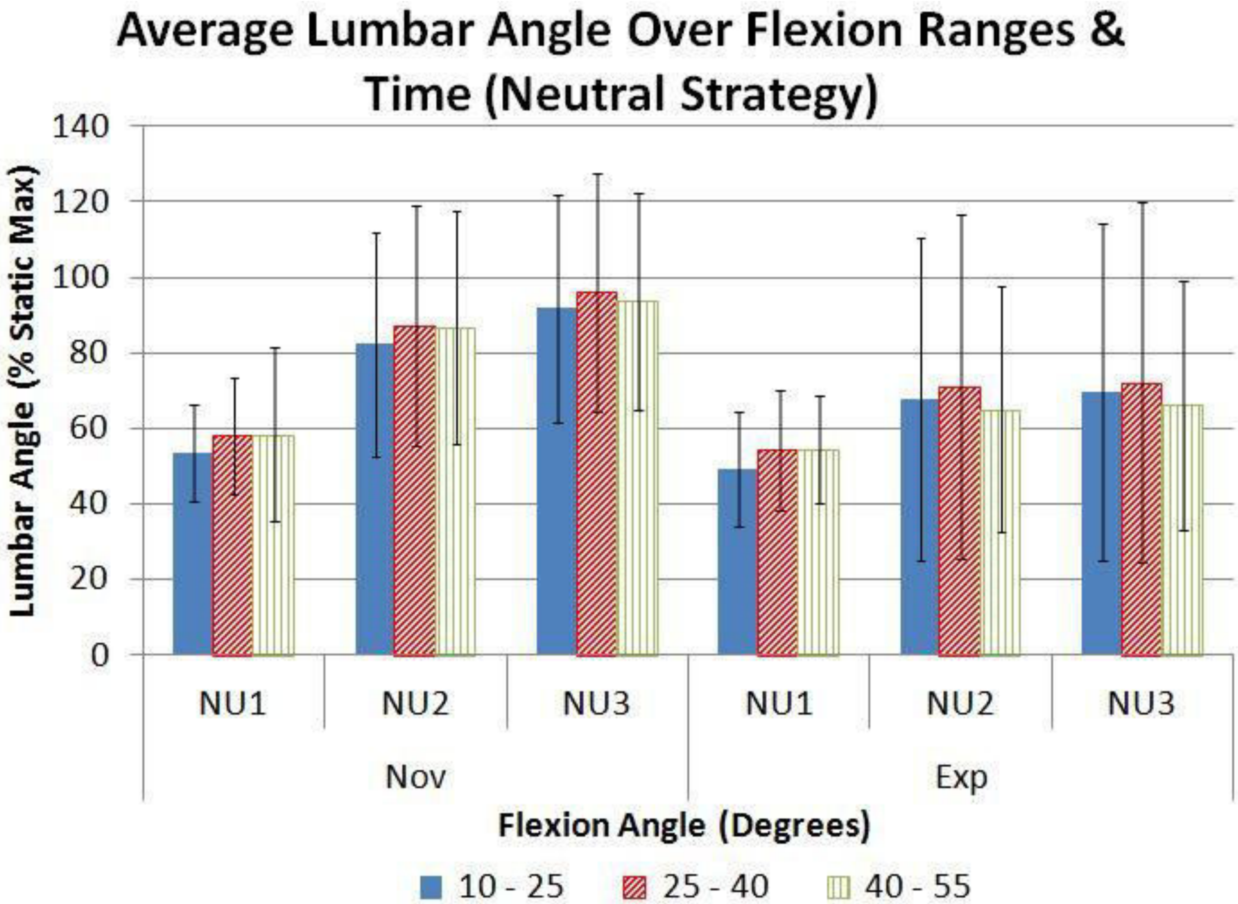

Figure 8. The novice group had more difficulty than the experienced group at maintaining the neutral strategy over time. The novice group average was within the target for the initial recording, but by the middle of the four minute trial the novice group average was well above the target lumbar range and continued higher for the end of the trial. A similar upward trend is observed with the experienced group with the middle of the trial above the target range, but there is no real change in lumbar angle for the experienced group between the middle and the end of the trial. Both groups demonstrate an increase in variability from the initial time to the middle of the trial.

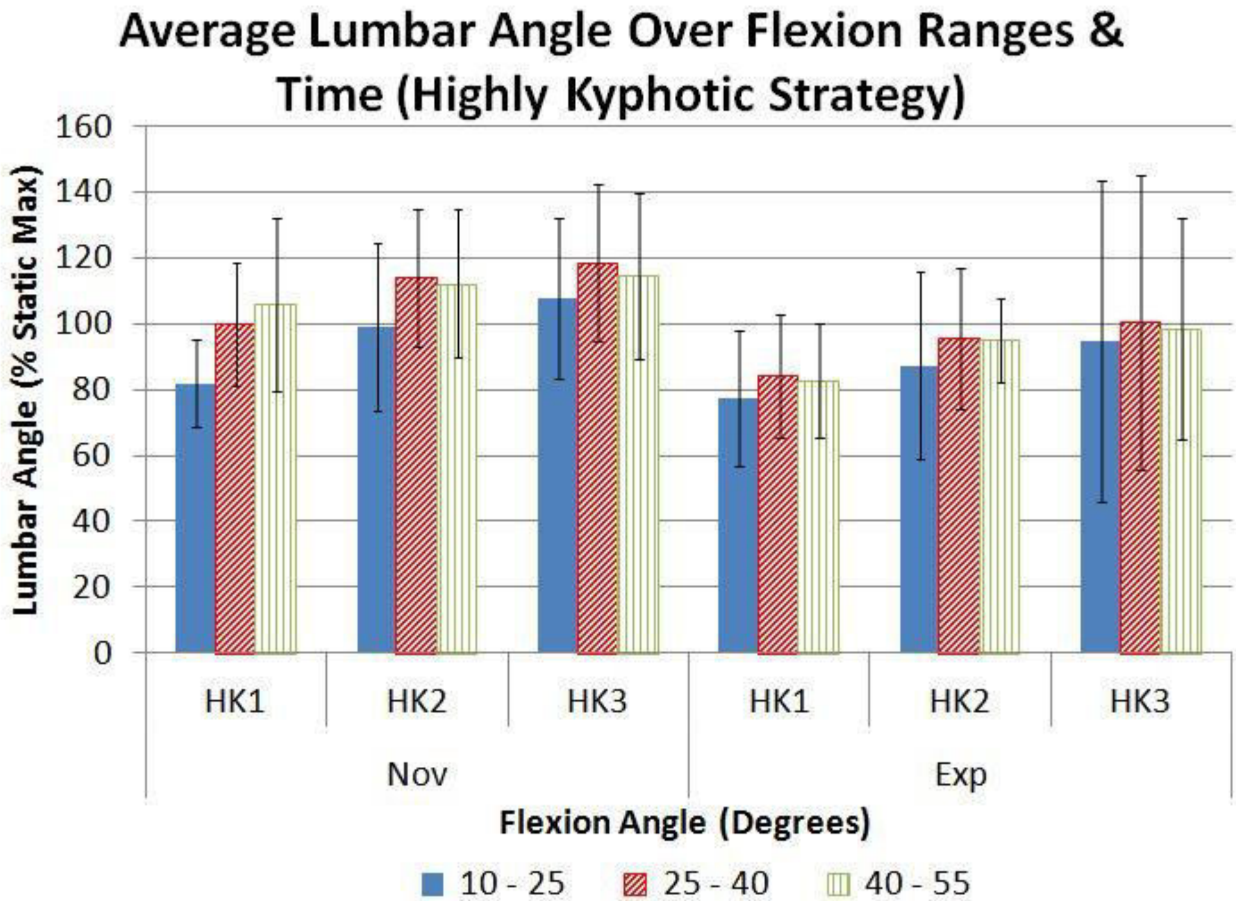

Figure 9. During the highly kyphotic strategy both the novice and experienced lifters demonstrated an increase in lumbar angle over time. However, the novice group extended beyond the static range of motion limits starting at the middle of the four minute trial. Although the experienced group appears to remain closer to the target range for lumbar during the end of the trial, there was a large variability in this final time segment.

The normalized lumbar angle extended beyond 100% of the ROM in preliminary analysis so the ROM envelope was examined to determine if the ROM was changing during the experiment in nine of the subjects. The ROM was measured prior to and directly following the self-selected lifting strategy. The change in ROM did not vary over time as illustrated in (Figure 10).

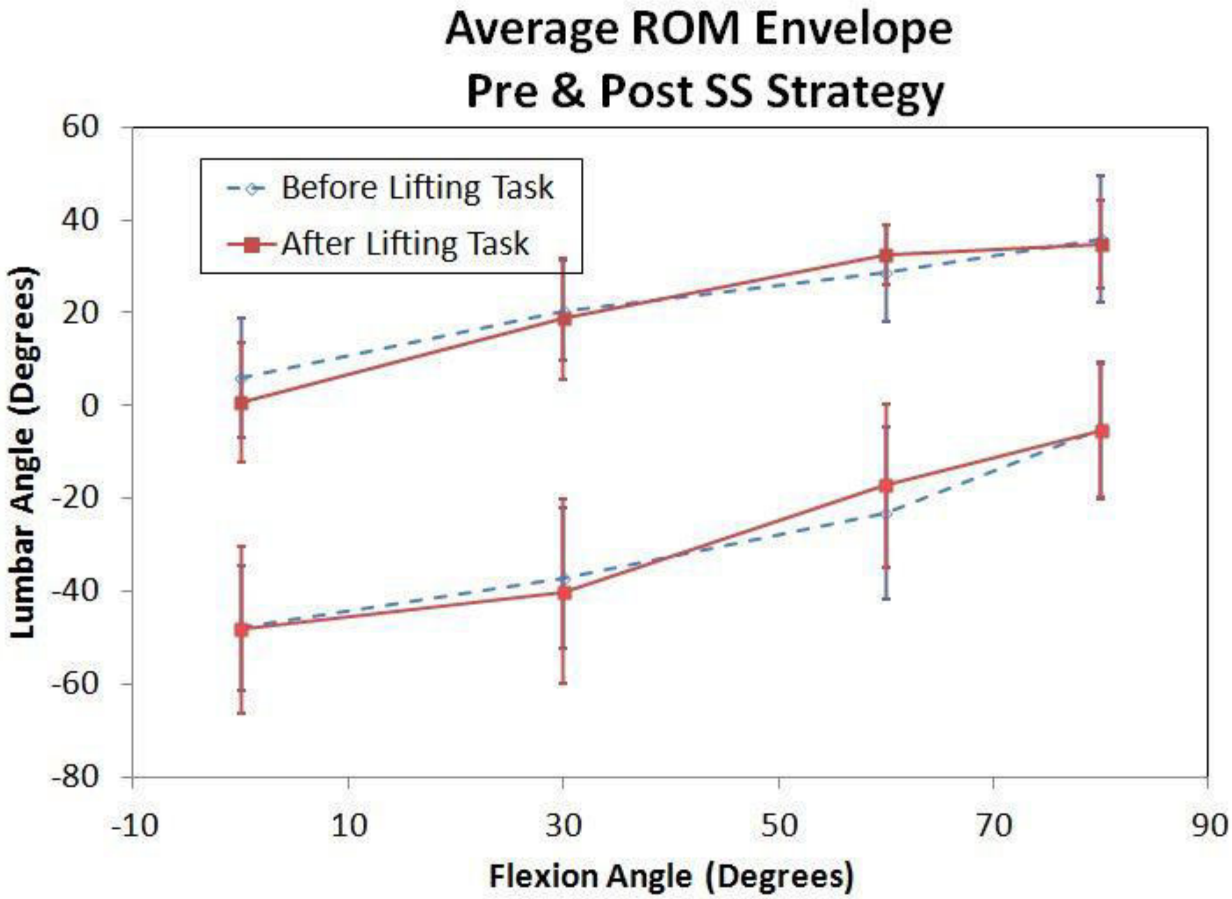

Figure 10. It was observed that there were a number of subjects extending beyond the limits of the lumbar range of motion. Therefore, a sub group of 9 subjects performed the ROM determination procedure to examine if the ROM limits changed following the self-selected lifting strategy. The results demonstrate that there is almost no change in the ROM limits measured.

Discussion

Both the novice and experienced lifters were able to achieve the trained lifting strategies following the short training period. The overall success rate for the neutral lifting strategy was higher than the highly kyphotic strategy with a success rate initially at 85.5% compared to 78.9%. However, by the end of the four-minute trial the highly kyphotic strategy had a higher success rate at 51.3% compared to 48.7%. The success rate was consistent for both the strategies examined as there was no statistical difference when comparing the two trained strategies.

However, the effects of time on the success rate was significant ($p<0.05$). The change over time could be due to fatigue, resulting in increased difficulty in continuing to perform the specified task. With increased difficulty in performing the specific task, it is possible that subjects reverted back to their preferred lifting strategy.

Although both groups were successful in achieving the desired lifting coordination, the success rate of the experienced group was higher for both of the trained strategies over time. The experienced group maintained a success rate ranging from 84.4% down to 75% for all times examined whereas the novice group ranged between 88.6% down to 27.3% over the four minute trials. Experienced lifters have been examined in numerous studies to identify lifting kinematics to reduce risk of injury. This observation demonstrates that all individuals could be trained to perform a lumbar-pelvic lifting coordination different from their preferred strategy. There was however, a significant difference observed with the compliance to the trained strategies over time.

The experienced lifters had lower average normalized lumbar angles for all conditions compared to the novice lifters. As the self-selected strategy for the experienced lifters was a more neutral coordination, this observation is not unexpected as it minimizes the adjustment from the natural lifting strategy. Similarly, the novice group selected a coordination pattern that had a highly kyphotic pattern so the higher normalized lumbar angles observed were closer to the natural pattern exhibited by the novice group. It was interesting to observe that the novice group naturally performed a lifting strategy attaining the highly kyphotic strategy target yet when performing the highly kyphotic trained strategy the novice group exaggerated the lumbar-pelvic coordination often extending higher than the target range. It is possible that the novice group subjects have greater difficulty controlling their lumbar posture.

Subjects were observed to extend beyond the ROM during the lifting tasks. This may be due to changing properties as the subjects warmed up and stretched during the lifting task. To test this theory, data was collected on a subset of subjects to examine if the ROM was changing throughout the experiment. Comparison of the ROM of nine subjects identified no significant difference in ROM collected prior to and directly following the self-selected lifting strategy. Another possible explanation of exceeding limits of ROM could be the difference in the measurement of the ROM and the dynamic lifting motion. The ROM was determined by having the subject reach and hold a static posture to identify the limits whereas the activity itself was dynamic in nature with the subjects continuously moving during the lifting strategy. Subjects may have a greater ROM dynamically than statically.

It has been identified that there are complications relating different lifting studies as there is little consistency in training between studies (Demoulin et al., 2012). The duration of training has varied along with the method of prevention. Our study had a few minutes of training with constant feedback during the training. Others have incorporated multiple personal training sessions over the span of the study (Lavender et al., 2007).

This study has a few limitations including some limitations regarding the biofeedback. The visual feedback was not shown during the self-selected strategy and therefore it is possible that the visual feedback itself has led to a change in the control of the lifting strategy. It might have been beneficial to include visual feedback during the self-selected lifting strategy even though no description of how to control the coordination would be provided.

In addition, the parameters regarding the training were very short. Although it was observed that the intervention could adjust the lumbar-pelvic coordination strategy for all subjects, independent of experience with lifting, there was no investigation to the duration that compliance would continue. As seen with the differences over time, the success of subjects in achieving the target lowered as they became fatigued and returned to patterns closer to their self-selected. This may have been a result of the limited training received and could possibly be improved with additional training.

Finally, there is the limitation involving experienced lifters. For this study, individuals with experience lifting weights and doing so over a specific period were defined as experienced lifters. However, the definition of experienced lifters can vary widely between studies. Some studies examine individuals in the occupational setting that may have a year or more experience working in a position that involves lifting (Chany et al., 2006). Additionally, there may be considerations to the specific type of lift as it relates to the workers as no single lifting technique can be described as optimal for different lifting tasks (Plamondon et al., 2014).

The success of the intervention strategy was observed to decrease over time when examining the short training and assessments of this study. This study examined the ability of training to a new strategy when biofeedback was present, but the goal would be to create a training program that would allow the alterations to continue following the removal of biofeedback. Future work should examine the lasting effects of training in both the short term as well as long term duration. The training duration could be examined to compare the lasting effects of the training when over a single training session to multiple training sessions. Additionally, the duration between training and assessment should be investigated to determine an appropriate frequency for training efficacy.

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CHAPTER FIVE: VARIABILITY OF VO_2 INCREASES DURING A TRAINED LIFTING STRATEGY COMPARED TO A SELF SELECTED STRATEGY

Abstract

Several occupational factors have been linked to low back injury including repetitive lifting. Several studies have investigated techniques that might reduce risk of injury by comparing experienced and novice lifters with the belief that the experienced lifters will demonstrate a better technique. Maduri et al. examined a repetitive lifting task using a normalized lumbar-flexion envelope to examine coordination patterns relative to subject lumbar range of motion (Maduri et al., 2008) . That study observed that a group of novice lifters performed a lifting coordination that approached the kyphotic limits of range of motion during the middle of the extension phase of the lift. The current study hypothesized that this strategy could be an attempt by novice lifters to reduce the energy required to perform the lift. The novice group could be implementing a stretch-shortening cycle within the back musculature as a way to reduce the energy requirements. Alternatively, the experienced group select a more neutral coordination as they seem to be placing a higher priority on maintaining spinal stability. Novice and experienced lifters were trained to perform two lifting strategies, a highly kyphotic (HK) and a neutral (NU) lifting strategy, using a custom biofeedback program. The results show that there was no significant difference in the average volumetric oxygen uptake between the different lifting strategies. There were also no differences observed between the novice and experienced groups. There was however a significant difference over time. It was observed that

there may be a gender difference as the experienced women lifters demonstrated a slightly lower oxygen consumption during the NU strategy compared to the HK strategy, the experienced men demonstrated the opposite trend.

Introduction

Low back pain is a leading cause of disability for individuals under 45 years in the United States and accounts for 40% of all workmen's compensation claims (Lis et al., 2007). Several studies have identified risk factors for low back pain and low back injuries including torso flexion and repetitive lifting and the National Institute for Occupational Safety and Health has particularly identified repetitive lifting as a risk factor for back disorders (Bernard, 1997; Health, 1981; Hoogendoorn et al., 1999). As repetitive lifting is a common occurrence that is unavoidable in the workplace, it is important to examine strategies that could reduce risk of injury resulting from repetitive lifting.

A number of studies have attempted to improve understanding of lifting strategies by examining the differences between novice and experienced lifters (Clemes et al., 2010; Lee and Nussbaum, 2012, 2013; Marras et al., 2006; Plamondon et al., 2014; Plamondon et al., 2010). The differences between novice and experienced lifters has been examined as it is believed that the experienced lifters have been conditioned to avoid strategies that have a greater risk of injury as the strategy has resulted in pain previously. As a result, there have been a number of differences in lifting strategies observed between novice and experienced lifters. One study identified that experienced lifters perform a lifting task utilizing a lower flexion angle as compared to novice lifters (Plamondon et al., 2010). In Chapter 3 it was observed that novice lifters select a highly kyphotic posture approaching their limits of range of motion when performing a repetitive lifting task while an experienced group select a posture maintaining near the middle of their range of motion.

The definition of experienced lifters has varied between studies. Some ergonomic studies have examined specific lifting tasks with a minimum number of years in a manual material handling position (Marras et al., 2006). The focus of this work is interested in fundamental lifting biomechanics and not focused on a specific occupational setting. As such, we selected a definition for experienced lifters that was more encompassing to the general population. Experienced lifters were defined as individuals having lifted weights at least three times per week for a minimum of a year.

Previously it was observed that the lumbar-pelvic coordination of lifters relied on a highly kyphotic lifting pattern approaching the limits of their range of motion(Maduri et al., 2008). This study measured the lumbar range of motion by having subjects move to their maximum and minimum kyphotic lumbar postures while maintaining a torso flexion angle relating to an upright torso posture. This process of measuring lumbar angles was repeated at four different levels of torso flexion angles including 0, 30, 60, and 80 degrees torso flexion. The ranges of lumbar angles were used to normalize the lumbar angles at all torso flexion angles. That study observed that during the extension phase of a lifting task the subjects often approached the kyphotic limits of their lumbar range of motion. This study hypothesized that the highly kyphotic coordination could be an attempt at reducing energy expenditure as compared to maintaining a strategy near the middle of their range of motion. The belief was that a stretch-shortening dynamic in the lumbar musculature could reduce the energy expenditure through improved mechanical efficiency (Bosco et al., 1987). However, it is believed that this coordination could increase risk of injury to the torso musculature by increasing the strain and moment loads experienced within the torso.

Several studies have researched a stretch-shortening dynamic within the extremities, including running and drop jump exercises (Avela et al., 1996; Bosco and Rusko, 1983; Farley and McMahon, 1992; Fleischmann et al., 2010; Harrison et al., 2004; Liu et al., 2006; McMahon, 1984). The muscle tendon unit seems to increase the mechanical efficiency of human muscle when the muscle lengthens followed by shortening. This phenomena is evident in such tasks as the jump exercise where children at an early age have learned that they can jump higher if the first flex their knees and squat prior to jumping. It has been suggested that the cyclic stretch-shortening dynamic allows the muscle tendon unit to perform like a spring. Storing energy during the stretch and releasing the stored energy during the shortening phase directly following the stretch (Liu et al., 2006). Oxygen consumption could identify the presence of such stretch-shortening through a decrease in oxygen consumption as the mechanical efficiency is increased (Heglund and Cavagna, 1987; Saibene, 1990).

In Chapter 3, it was observed that novice lifters performed a highly kyphotic lifting coordination approaching the limits of their range of motion while an experienced group performed a relatively neutral lifting coordination maintaining near the middle of their range of motion. It is hypothesized that the novice group was incorporating a stretch-shortening pattern within the torso musculature that would decrease the energy required for the task. This study examines the metabolic energy expenditure of the neutral and highly kyphotic lumbar-pelvic coordination strategies. It was hypothesized that the highly kyphotic lifting strategy preferred by novice lifters would require less energy expenditure observed through the metabolic data, which would support the idea that a stretch-shortening cycle was occurring.

Methods

Twenty-seven subjects (16 male and 11 female) with ages between 19 and 33 years old and an average height and weight of 149.8 ± 59.4 centimeters and 61.1 ± 27.7 kilograms participated in this study with the approval of the Human Subjects Committee from the University of Kansas Medical Center, Kansas City, KS. Subjects performed a repetitive lifting task at the University of Kansas Medical Center Research in Exercise and Cardiovascular Health Laboratory, controlling the lumbar-pelvic coordination using visual biofeedback to examine the energetics of lifting strategies. Individuals with a history of low back disorder or musculoskeletal issues were removed using a medical questionnaire (see appendix A7). Subjects were classified into groups based on their responses to an activity level questionnaire. Individuals who lifted weights at least three times per week for the past year were classified as experienced lifters. Specific questions were asked about dead lifts, bent over rows, standing curls, and military press, but in general free weights were accepted. Individuals that did not meet the criteria of the experienced group were classified as novice lifters. The experienced group consisted of 13 subjects, 4 female and 9 male subjects, with an average age of 24.7±4.2yrs. The average height and weight for the experienced lifters was 173.0±10.2 cm and 74.9±14.6kg. Similarly, the novice group had 14 subjects, 7 female and 7 male subjects, with an average age of 24.6±4.1yrs. The average height and weight for novice lifters was 171.1±10.1 cm and 65.8±14.4kg.

Three straight legged lifting strategies were examined including a self-selected strategy, a neutral strategy remaining in near the center of the lumbar range of motion, and a pelvis-first strategy that was highly kyphotic compared to the ROM. During the self selected strategy there was no visual feedback provided on the lumbar-pelvic coordination, subjects were only instructed to maintain straight legs and perform the repetitive lift following a metronome controlling the rate to 15 lifts per minute.

Following the self-selected strategy, the two trained strategies were randomized in order. The trained strategies also used a metronome to control the rate to 15 lifts per minute, but introduced a biofeedback program to train subjects to a specific posture coordination. One of the trained strategies utilized a neutral posture coordination maintaining the lumbar angle near the middle of the range of motion. The other trained strategy utilized a highly kyphotic strategy such that the lumbar angle approached the limits of the lumbar range of motion.

The lifting task involved repeatedly raising and lowering a crate between ground level and waist level. The crate contained a weight that was normalized between subjects using a single maximum lift. The single lift max was performed by having the subject pull a stationary strap fixed to the ground while standing on a forceplate. Subjects were instructed to lift with their back and not lean backwards, pull with their arms, or push with their legs. The subject's hands were shoulder width apart and located just below their knees, which required that subject bend over to maintain straight legs. The average of the highest half second (50 points of the 100hz data) was determined as the maximum lift and three percent of the maximum was used for the study (Figure 1). The weights ranged between 0.6 kg to 3.4 kg with an average of 1.5 ± 0.8 kg.

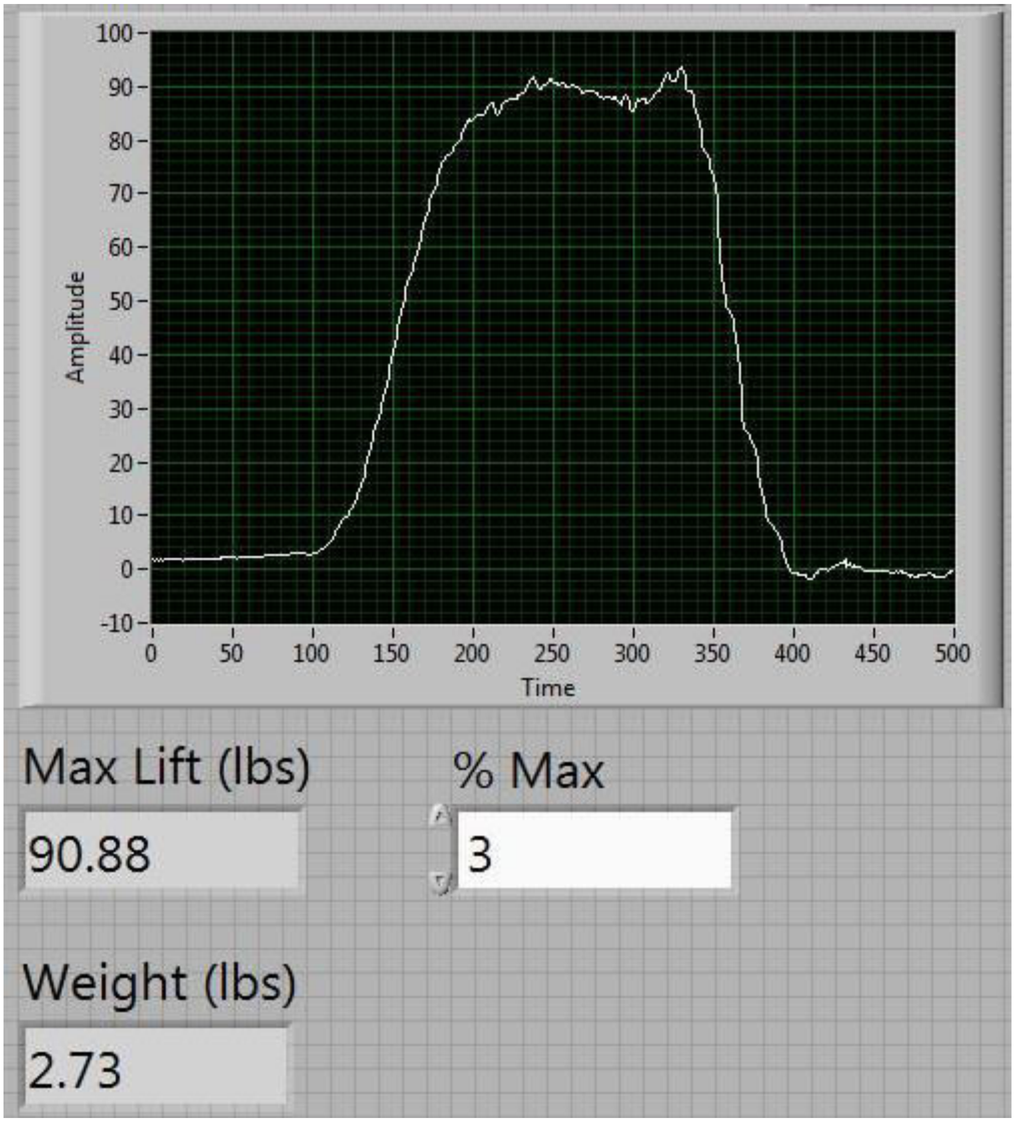

Figure 1. The weight lifted was normalized using a single lift maximum.

The energy expenditure for the lifting task was measured and analyzed through the collection of expired gas composition using a metabolic cart (Parvo Medics Inc, Sandy UT). It has been demonstrated that the system accurately measures metabolic variables over a wide range of intensities (Bassett et al., 2001). Gas and flow meter calibrations were performed on the metabolic cart following manufacturer specifications and were performed by the same individual when possible to prevent the likelihood of operator error. The calibrations were performed before each subject. A headgear held the mouth piece attached to a two-way non-rebreathing valve directing expelled gasses to the metabolic cart. A nose clip was worn preventing the loss of gases through the nose. Additionally, subjects did not consume food or drink (except water) in the hour prior to data collection. Expired gases were collected continuously with oxygen uptake (VO_2) and carbon dioxide (VCO_2) production averaged using a five-second window to smooth out the variability resulting from individual breaths. Each trial started with a baseline reading prior to the initiation of the lifting task.

Three electromagnetic sensors (Ascension Technology, VT) collected motion data at 100Hz. The position sensors were located at T10, the sacrum, and the manubrium (Figure 2). These three markers defined the lumbar flexion envelope for examining the kinematics of the spine. This was accomplished by determining the flexion angle, the angle created between T10 – sacrum – vertical, identifying the angle the subject was bending over at the waist. Also determining the lumbar angle, the angle created at the intersection of the planes extending through the markers placed at T10 and sacrum, identifying the curvature of the back. The lumbar angle was normalized using the average of three maximum and minimum voluntary static kyphotic postures at flexion angles of 0, 30, 60, and 80 degrees (Figure 3). Linear interpolation between these four measured flexion angles filled in the range of motion (ROM) envelope for all flexion angles between 0 and 80 degrees. Extrapolation extended the envelope beyond the limits to account for instances where the flexion extended beyond this range, commonly seen when standing fully upright.

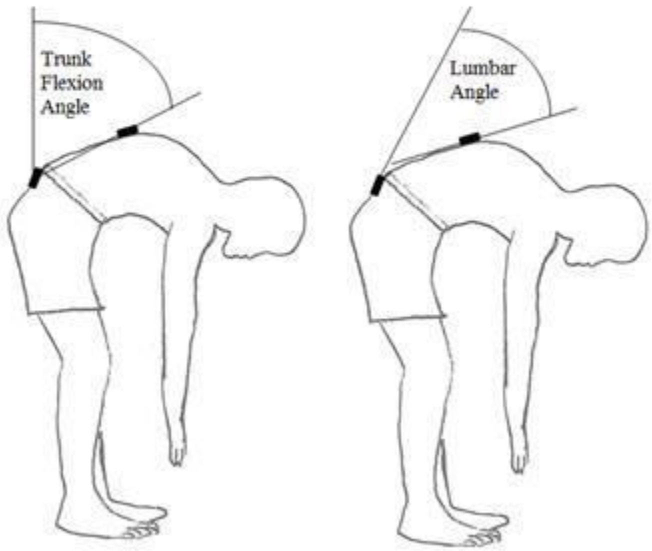

Figure 2. Sensors were located on the spine at T10 and the sacrum. These sensors were used to define the trunk flexion angle, the angle created with the vector connecting T10 to the sacrum and the vector from the sacrum extending in the vertical axis, and the lumbar angle, the angle created by the intersection of the planes extending from the sensors located at T10 and the sacrum.

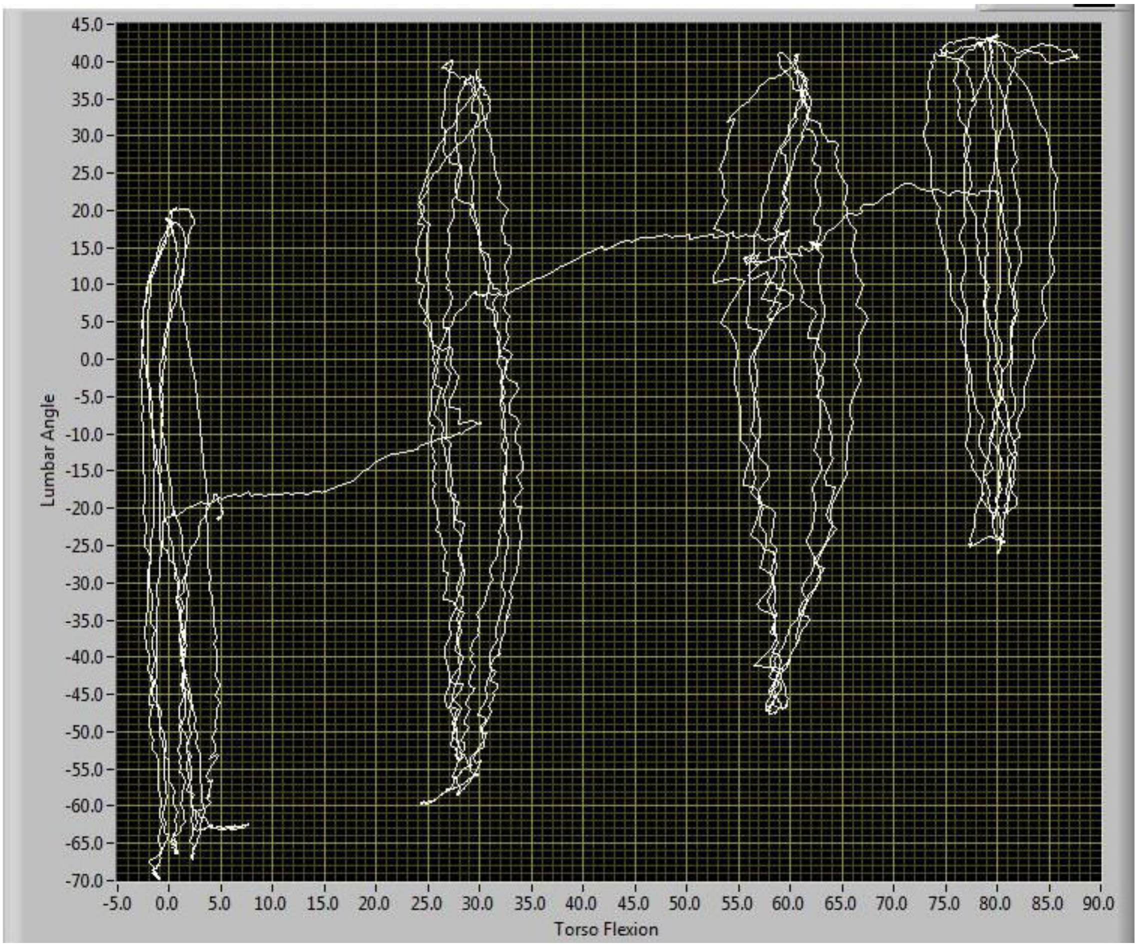

Figure 3. The lumbar range of motion was measured at 0, 30, 60, and 80 degrees of flexion with the average of three iterations saved for defining the range of motion envelope.

Subjects were instructed to perform the repetitive lift using straight legs. This reduced the focus to the lumbar-pelvic region. The lifting task was normalized between subjects by controlling the rate of lifts using a metronome at 1 Hz with each lift cycle lasting a total of four seconds such that there were two seconds extending up and two seconds descending down. Subjects were instructed to continuously perform the lift and not to pause at any point during the lift. Additionally subjects were instructed to never release the crate holding the weight throughout the duration of the lifting trial. Each trial lasted a total of four minutes with the first 45 seconds as the baseline metabolic reading with the lifting task starting at that point.

Biofeedback programs written in Labview (National Instruments, Austin, TX) interacted with position and orientation data exported from Motion Monitor Software (Innsport, IL) to provide visual feedback on the lumbar-pelvic coordination. The initial program displayed two bars representing the torso flexion angle and a target torso flexion angle. The subjects were instructed to match their instantaneous torso flexion angle bar to the stationary target torso flexion angle bar while alternating between an arched and rounded posture where the maximum and minimum lumbar angles were recorded. These extremes were recorded with the average of three extremes for each of the flexion angles defining the subject's lumbar range of motion envelope. The ROM envelope was expanded between the recorded flexion angles using linear interpolation and expanded outside the recorded flexion angles using linear extrapolation (Figure 4). This allowed for the calculation of the lumbar angle at any given flexion angle. This ROM envelope was normalized between 0 and 100% range of motion for comparison between subjects.

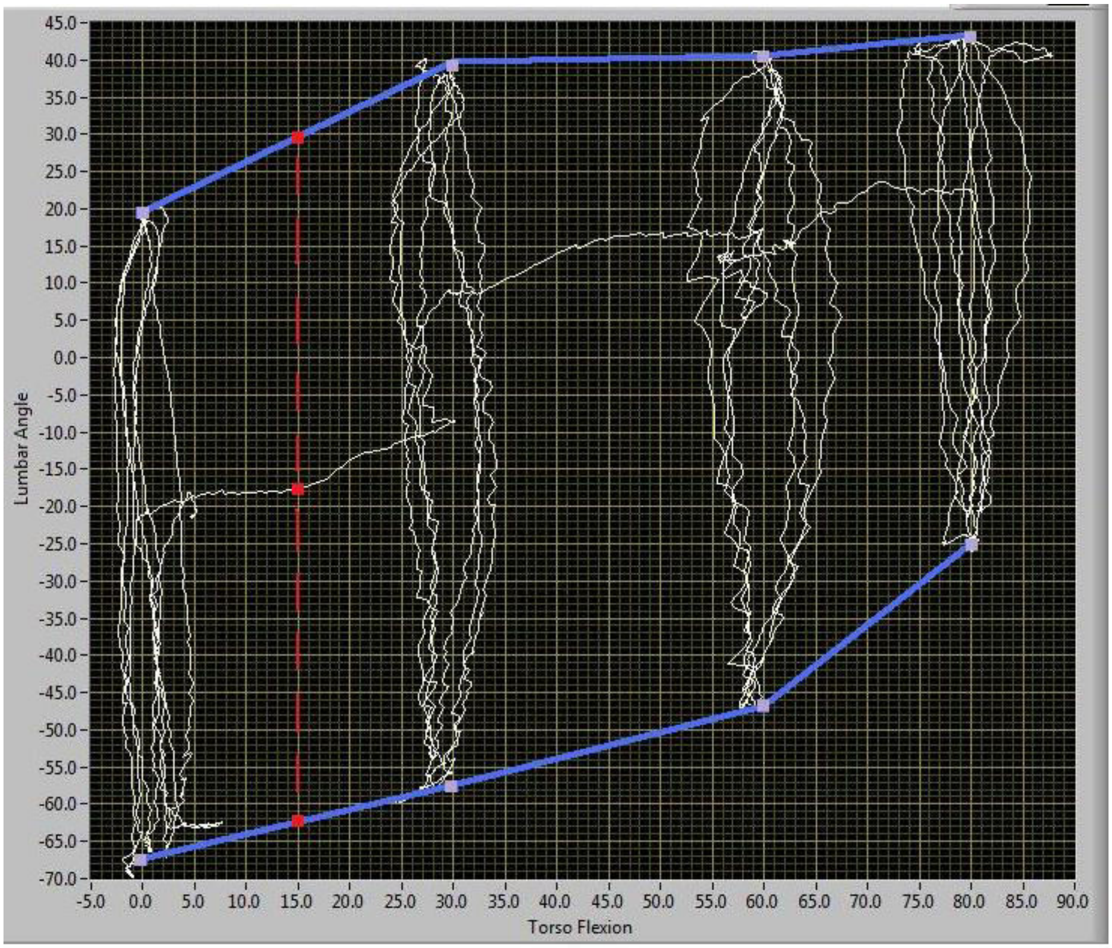

Figure 4. The range of motion envelope was created to calculate the lumbar angle at all flexion angles, using linear interpolation. This envelope was used to normalize the range of motion for between subject comparisons.

The next biofeedback program was provided during the trials and consisted of an XY plot with information about the lumbar-pelvic coordination as a function of the normalized lumbar angle. The XY plot displayed the instantaneous torso flexion angle on the x-axis and the normalized lumbar angle, as determined by individual subject range of motion, on the y-axis. The normalized lumbar angle ranged between 0 and 100% ROM. The torso flexion angles displayed ranged from -5 to 90 degrees and was determined experimentally such that the visual feedback would not extend beyond the limits of the plot. A yellow curser identified the instantaneous normalized lumbar – torso flexion position providing the information to the subject on the current lumbar-pelvic coordination. Additionally a red target box was displayed on the graph creating a target zone that the subject was instructed to pass through to control their lumbar-pelvic coordination.

The red target box extended between 20 and 70 degrees torso flexion on the x-axis for both lifting strategies. The height of the box was set to be approximately 15% of the lumber ROM with the highly kyphotic strategy target ranging between 80% and 95% of the normalized lumbar angle (Figure 5). The target range for the neutral coordination strategy ranged between 42% and 58% of the normalized lumbar angle (Figure 6). These target ranges allowed the neutral strategy to remain near the middle of the normalized lumbar ROM and the highly kyphotic strategy required reaching a high normalized lumbar angle. Subjects were instructed to have the yellow curser pass through the target box during the extension phase of the lifting task. Subjects were told that the length of time the curser remained inside the target box was not a concern as long as the curser passed through the box at some point. Therefore the curser was not required to enter from one side passing through the entire target box and exit on the opposite side. Additionally subjects were instructed that there is no desired target for the descending phase of the lifting task, allowing subjects to select any coordination that they wish during the descending phase.

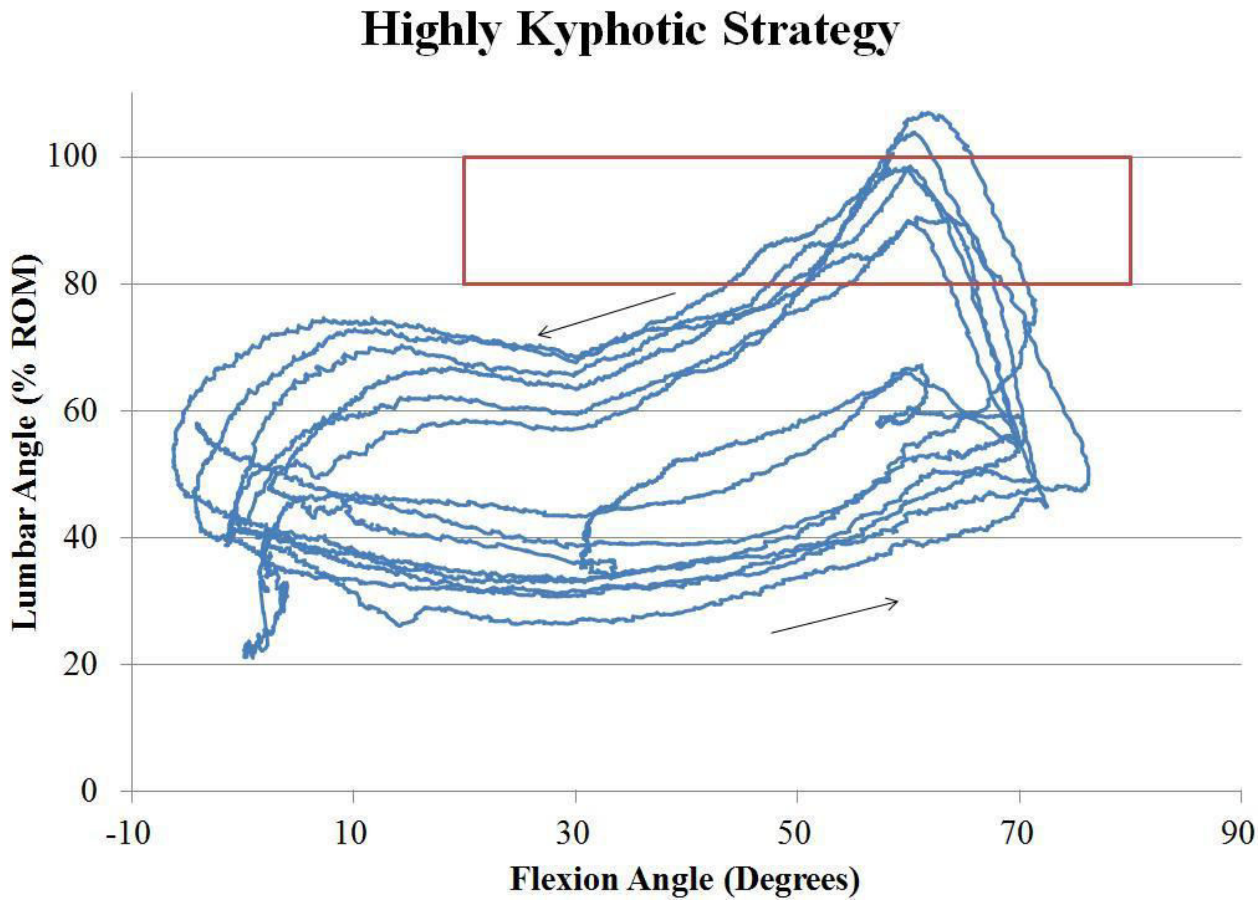

Figure 5. The highly kyphotic strategy required a lumbar pelvic coordination approaching the limits of the subject's range of motion.

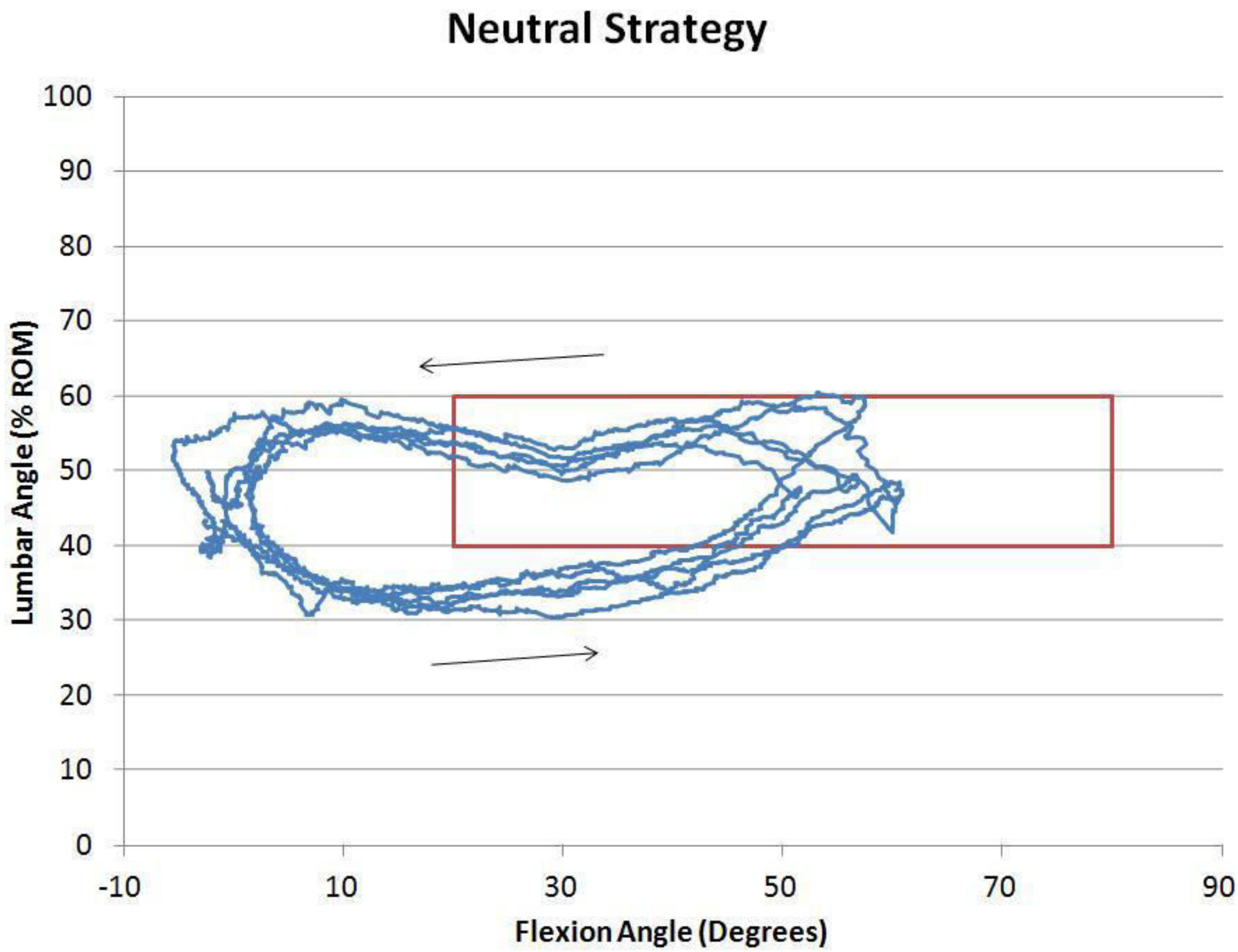

Figure 6. The neutral lifting strategy maintained near the middle of the subject's lumbar range of motion. The target box is indicated in red and the arrows identify the phase of the lift where the extension phase, or moving from highest to lowest flexion angle during a cycle, was examined.

Following the self-selected strategy, the biofeedback program was introduced to the subject. Subjects practiced lifts with the biofeedback to understand to how to use the biofeedback and once a basic understanding was observed, the first strategy was trained. Training of the strategies was completed using the metronome, but in the absence of any weight in the crate. The subject practiced lifting the crate at the specified rate focusing on the biofeedback program while attempting to have the instantaneous feedback pass through the target box. The subject was instructed to think about the sense of posture as the visual feedback would disappear momentarily throughout the trial while they continued to perform the desired lift. The training continued until two conditions were met. First, the subject had to feel comfortable that they could perform the lifting task while consistently attaining the target. The second condition was consistently achieving five successful lift cycles. Following the training, a rest period was offered prior to the trial collection to reduce the possibility of fatigue. The sequence of training, rest, trial was completed for both strategies with the order of strategy selected at random.

The four minute lifting trial was continuous for the metabolic data, but the kinematic data was saved periodically throughout the trial to prevent the loss of data. As a result, the biofeedback was absent for short periods until the system was returned after saving the data. This was necessary due to limitations with the amount of data being collected and the available memory.

Analysis:

Preliminary analysis of the metabolic data identified the average time for subjects to reach the plateau region was approximately 1.6 minutes into the trial. The data was divided into three time segments lasting 30 seconds each resulting in an average volumetric oxygen uptake for the ranges of 1.6 – 2.1, 2.1 – 2.6, and 2.6 – 3.1 minutes. Additionally the standard deviation was calculated for these time segments. A repeated measures ANOVA was performed on the average and standard deviations for these time segments.

In addition to examining the oxygen consumption ($\dot{V}O_2$), the oxygen uptake efficiency slope (OUES) was determined using the equations below where “a” is the rate of change in

$$\dot{V}O_2 = a * log_{10}\dot{V}E + b$$

$$\frac{d\dot{V}O_2}{d\dot{V}E} = \frac{a * \frac{1}{log_e 10}}{\dot{V}E}$$

oxygen uptake in response to the ventilation, or OUES. (Baba et al., 1996) A higher OUES indicates improved oxygen uptake during the exercise and allows an estimation of the VO_{2max} from a sub maximal exercise.

Results

Over time, there was an increase in oxygen uptake increasing from 9.4 to 11.9 ml/kg/min for the average of all subjects (Figure 7) (Table 1). This pattern was observed when dividing into groups based on experience. The novice group average increased from 8.8 to 11.7 ml/kg/min and the experienced lifting group increased from 9.5 to 12.3 ml/kg/min (Figure 8) (Table 2). No significant differences were observed in the average volumetric oxygen uptake for the different strategies ($p = 0.25$). Over time there was highly significant ($p < 0.001$) difference in the oxygen uptake (Table 3).

Table 1. The average oxygen consumption for all subjects increases over time.

	1.6 min	2.1 min	2.6 min
SS	9.489	10.732	11.148
NU	9.366	11.003	11.948
HK	9.553	11.042	11.740

Table 2. The consumption of oxygen increases over time for both groups. It appears that the experienced group increases rapidly and reaches a plateau whereas the novice group linearly increases over time.

	EXP			NOV		
	1.6	2.1	2.6	1.6	2.1	2.6
SS	9.527	11.256	11.083	9.453	10.245	11.209
NU	9.986	11.171	12.255	8.790	10.847	11.663
HK	9.534	11.297	12.146	9.571	10.805	11.364

Table 3. An ANOVA of the oxygen consumption did not identify lifting strategy as significantly different.

Measurement - VO2	p-value
Strategy	0.250
Time	0.000
Strategy x Time	0.673
Lifter	0.235

Measurement - STD (VO2)	p-value
Strategy	0.021
Time	0.090
Strategy x Time	0.207
Lifter	0.129

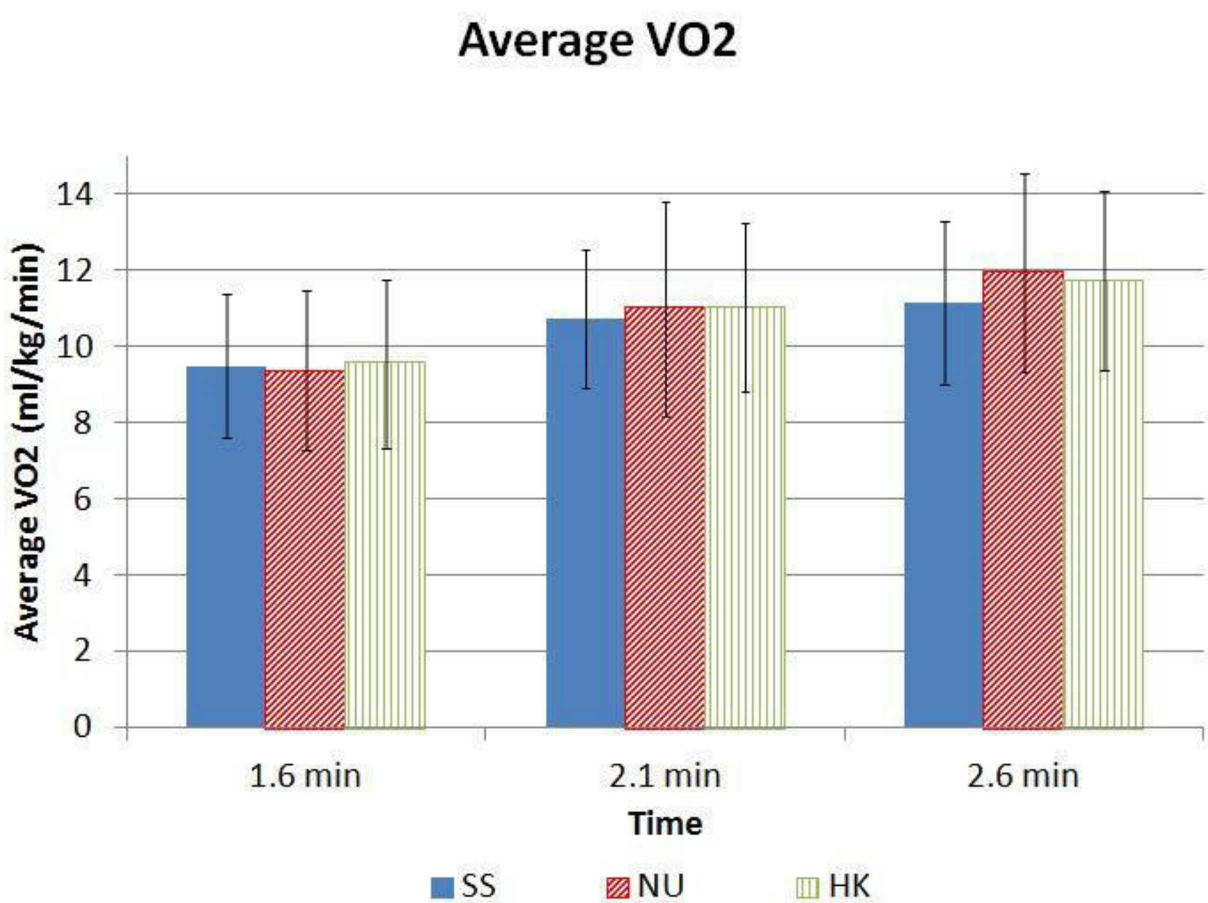

Figure 7. The average oxygen consumption of the composite group increased over time with no difference observed between the different lifting strategies.

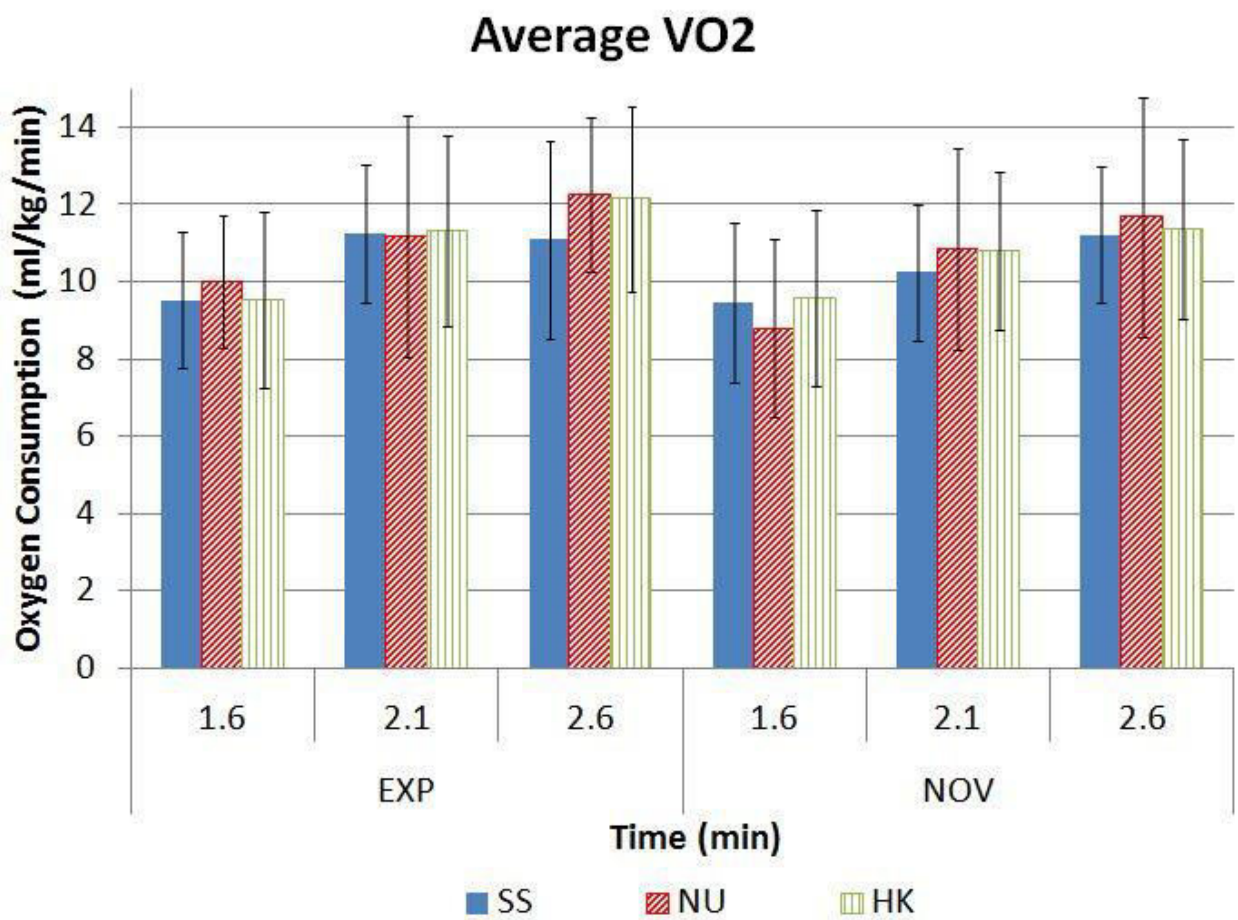

Figure 8. The oxygen consumption increased over time for both the experienced and novice groups for the trained strategies. It appears that the experienced group increases rapidly and reaches a plateau whereas the novice group linearly increases over time.

The standard deviation of the oxygen uptake varied between the groups. The novice group had standard deviations in the oxygen uptake between 1.7 and 3.6 ml/kg/min whereas the experienced group had lower variability at 1.5 to 2.1 ml/kg/min although this difference was not statistically significant. The standard deviation did display a significant difference with strategy ($p < 0.05$) (Table 4) (Table 4). It can be observed that the standard deviation is higher in the trained strategies (1.5-3.6 ml/kg/min) than in the self-selected lifting task (1.7-1.9 ml/kg/min).

Table 4. Standard deviation of the average volumetric oxygen uptake VO2 (ml/kg/min) normalized by subject weight.

	1.6 min	2.1 min	2.6 min
SS_NOV	1.8 ± 1.1	1.7 ± 1.0	1.8 ± 1.0
NU_NOV	2.0 ± 1.6	2.4 ± 1.5	3.6 ± 2.4
PF_NOV	2.0 ± 1.5	2.2 ± 1.2	2.5 ± 1.2
SS_EXP	1.9 ± 0.9	1.8 ± 1.7	1.7 ± 0.9
NU_EXP	2.1 ± 1.2	1.8 ± 0.9	2.1 ± 1.1
PF_EXP	1.5 ± 0.7	1.8 ± 0.5	1.9 ± 0.8

The group average of the oxygen uptake efficiency slope for the novice group was between 1.5 ± 0.6 in the self selected strategy to 1.7 ± 0.6 for the highly kyphotic strategy. The experienced group averages were between 1.8 ± 0.6 in the self selected strategy to 1.9 ± 0.5 for both the trained strategies (Table 5).

Table 5. Examination of the oxygen uptake efficiency slope indentified no differences based on lifting experience or between the lifting strategies.

	SS	NU	HK
NOV	1.5 ± 0.6	1.6 ± 0.7	1.7 ± 0.6
EXP	1.8 ± 0.6	1.9 ± 0.5	1.9 ± 0.5

Discussion

This work does not support the hypothesis that the highly kyphotic lifting strategy preferred by the novice lifters would require less metabolic energy consumption. A significant difference in metabolic energy consumption was not observed between the lifting strategies. Previous studies have identified that metabolic energy cost minimization is an important factor in selection of neuromuscular strategy within a cyclic task such as running (Farley and Ferris, 1998). Cyclic activities such as running have identified a decrease in oxygen consumption, suggesting a decrease in metabolic energy.

Although not significant, the experienced lifters had a higher average oxygen consumption than the novice lifters for all time segments. This was most likely a result of the experienced lifters performing the experiment with heavier weights. The experienced group lifted a average of 4.0 + 1.5 lbs while the novice group lifted 2.7 + 1.8 lbs during the experiment. The additional weight resulted in increased energy required while completing the lifting task. There was no significant difference in the weight lifted between the experienced and novice groups (Figure 9).

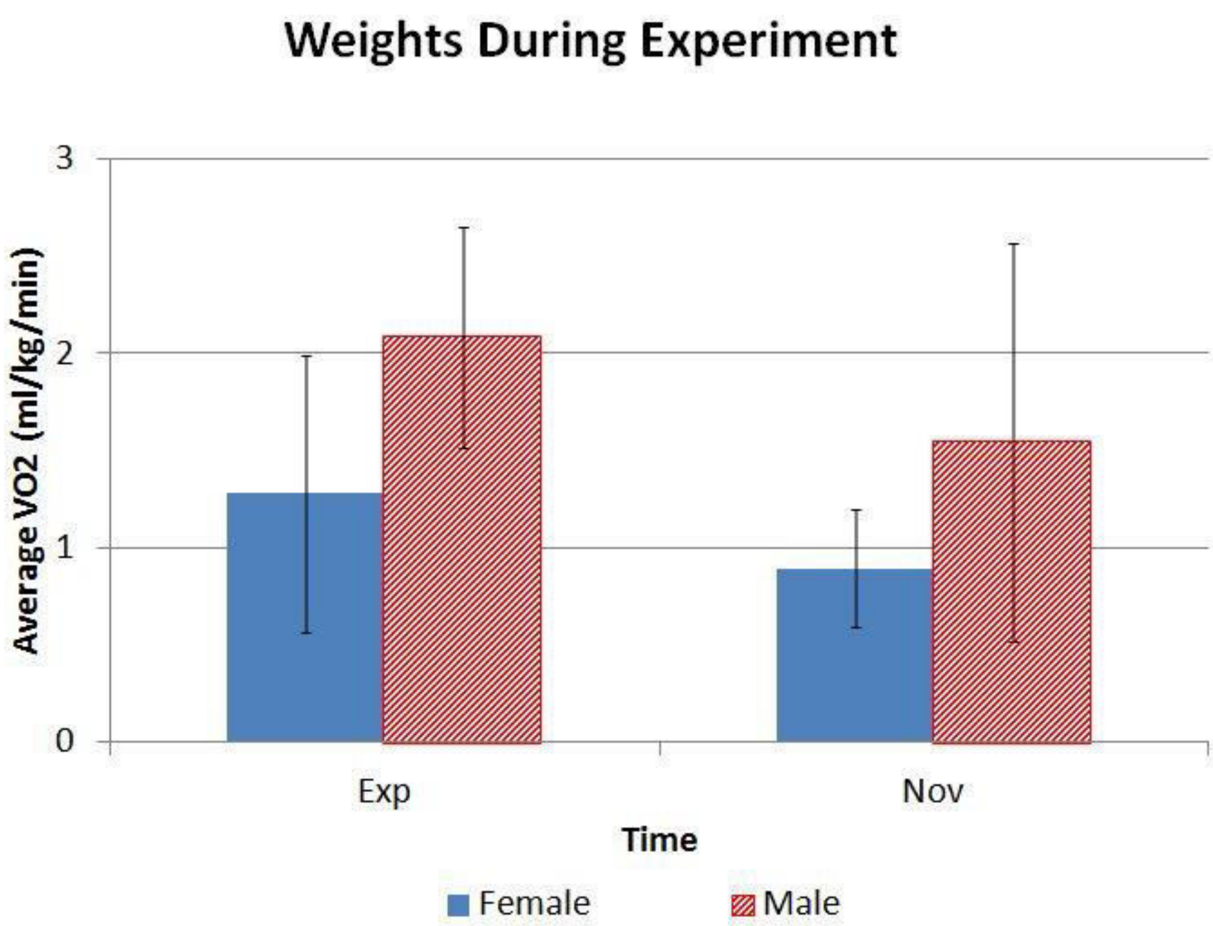

Figure 9. A two-way ANOVA of the weights lifted did not identify a significant difference between the novice and experienced groups.

The time regions were selected such that we could examine the oxygen uptake occurring once the lifting task had stabilized oxygen consumption and before effects of fatigue may be present. The preliminary investigation identified that most subjects would reach the plateau region by 1.6 minutes into the trial, which corresponds to 50 seconds after the lifting task begins (Figure 10). To reduce the likelihood of including effects of fatigue, the time segments were set to 30 seconds in duration.

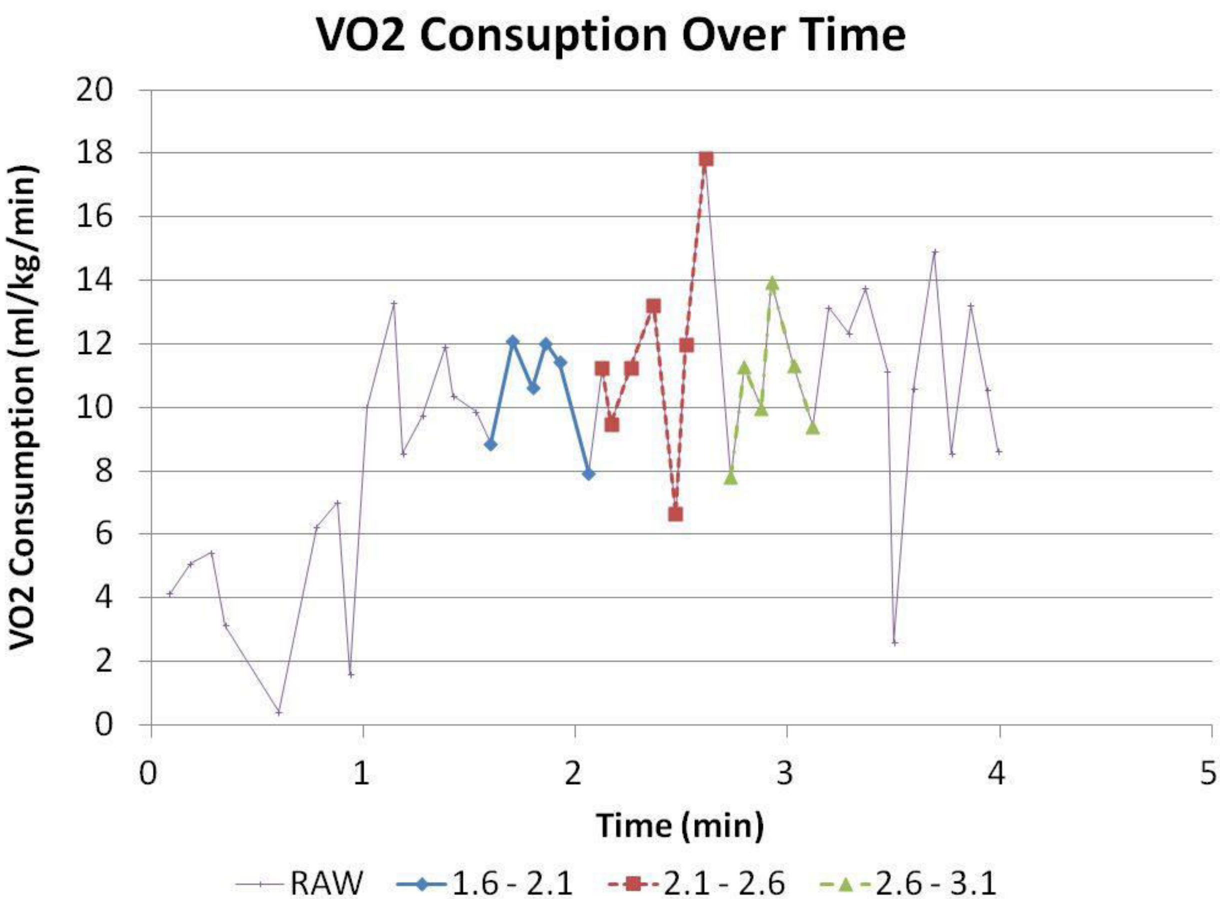

Figure 10. Several trials were examined to determine the time blocks to analyze. Most subjects were passed the initial ramp up characteristic going from rest to lifting by 1.6 minutes into the trial when lifting began at 0.75 minutes. Additionally the final time segment needed to be concluded prior to erratic characteristics began occurring at the end of the lifting trial. The time segments selected were 1.6 - 2.1, 2.1 - 2.6, and 2.6 - 3.1 minutes and are shown with a sample trial.

The difference observed over time could be a result of selecting consistent time segments for analysis for all subjects. It is possible that some of the subjects had not reached a steady state oxygen consumption for the entire first segment resulting in lower VO_2 while the subjects respiratory system was adjusting to the increased oxygen requirements of the lifting task. Similarly, the final time segment could have seen higher values of VO_2 an indication that subjects were becoming fatigued.

The timing of the lift was a limitation of the study as there were multiple data collection systems with no synchronization between them. The metabolic data was collected separately from the kinematic data without the use of a sync signal. This was deemed acceptable as the metabolic data was an average over five seconds and the small amount of error that this introduced was deemed acceptable. However, there were times that the subject did not begin the lifting task on cue and would wait an unrecorded amount of time. This delay in task initiation could have played into the difficult in identifying the best time segments to analyze and there was no way to realign the data based on the kinematics.

Future work will examine lift strategy training to determine a proper regiment for training a specific coordination. This could include duration of lift training sessions as well as the frequency and duration that training sessions should be completed. The goal would be to identify a training program that will have lasting effects well beyond the time that feedback is provided.

Acknowledgements

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CHAPTER SIX: EXAMINATION OF LIFTING ENERGETICS USING EMG ACTIVATION

Abstract

Repetitive lifting is a common occurrence in several occupational settings and has been linked to low back injury by the National Institute of Health and Safety (Bernard, 1997a). As a result, several studies have investigated techniques of lifting with the goal of reducing risk of injury with a common approach of comparing novice and experienced lifters. Maduri et al. observed that a novice group of lifters performed a lumbar-pelvic coordination strategy that approached the limit of their range of motion (Maduri et al., 2008). Those authors hypothesized that a possible reason the novice lifters selected that coordination strategy was to implement a stretch-shortening pattern within the musculature of the back that would reduce the energy necessary to perform the task. The current study examines the energy expenditure for novice and experienced lifters while performing a trained strategy approaching the kyphotic limits of the range of motion as well as another neutral strategy maintaining near the middle of the range of motion. It was hypothesized that the highly kyphotic strategy will require less energy than the neutral strategy as demonstrated by lower EMG activations when plotting the normalized EMG signal verses the flexion angle. The general curves demonstrate that over time the activation decreases at higher torso flexion angles. However, the observations do not support the hypothesis that the highly kyphotic strategy is energetically favorable. The EMG activation curves are the rpelimanry step towards examining the energy expenditure through the

examination of work loops using models to simulate both the muscle force from EMG activation and muscle length from the kinematics would be the next steps.

Introduction

Several factors have been identified as risk factors for low back pain and injury, including torso flexion and repetitive lifting, and are commonly seen in the occupational setting involving manual materials handling (Bernard, 1997b; Hoogendoorn et al., 1999; Marras and Granata, 1995; Marras et al., 1995). A previous study examined automobile workers and found tasks involving both extreme and mild torso flexion were associated with low back disorders(Punnett et al., 1991). As it is impossible to remove all tasks involving torso flexion and repetitive lifting from the occupational setting, it is important to examine lifting techniques to identify methods that could potentially reduce risk of injury.

Previously Maduri et. al.(Maduri et al., 2008) created a normalization method to examine torso flexion by determining the subject's lumbar range of motion (ROM), starting at the most lordotic to the most kyphotic lumbar postures. The ROM was measured while maintaining specific torso flexion angles such that the lumbar angles could be normalized between the subject's individual lumbar ROM. Once normalized the subjects performed a repetitive lifting task where it was identified that the subjects perform highly kyphotic motions, approaching their ROM limits during the extension phase of the lifting cycle. This work hypothesized that the highly kyphotic pattern could be an attempt to decrease energy expenditure, as compared to remaining near the middle of the ROM, during the lifting made possible through the implementation of a stretch-shortening dynamic within the lumbar musculature. However, it was also speculated that this pattern within the torso could result in higher moment loading on the spine as well as increasing the strain on the extensor musculature and posterior ligamentous structures of the spine. Both of which could increase the risk of injury.

To improve understanding of lifting strategies that could be useful in avoiding injury, several studies have examined differences between novice and experienced lifters (Authier et al., 1995; Gagnon et al., 1996; Marras et al., 2006; Plamondon et al., 2010). It is believed that experienced lifters will select a strategy with a lower risk of injury as they will have been conditioned to avoid strategies that have led to pain through past experiences. As such, several studies have demonstrated that experienced lifters exhibit strategies that are different from those observed by novice lifters (Authier et al., 1995; Gagnon et al., 1996; Marras et al., 2006; Plamondon et al., 2010). One study identified that novice lifters performed a lifting task with a higher flexion angle as compared to experienced lifters (Plamondon et al., 2010). In Chapter 3 it was observed that experienced lifters self select a lifting coordination maintaining near the middle of their lumbar ROM while novice lifters select a highly kyphotic coordination during the extension phase of a repetitive lifting task. A highly kyphotic pattern was suggested to save energy at the expense of increasing risk of injury and therefore the energetics of lifting strategies was examined.

Stretch-shortening dynamics have been well documented in research on the extremities, including running and drop jump exercises (Avela et al., 1996; Fleischmann et al., 2010; Harrison et al., 2004; Jacobs et al., 1993; McMahon, 1984; Nicol et al., 1996). Stretch-shortening seems to increase mechanical efficiency as the muscle-tendon lengthens followed by shortening. An example would be how a person squats prior to jumping when attempting to jump as high as possible. It has been suggested that the cycle of stretching the muscle tendon unit stores elastic energy, which is then released during muscle contraction similar to the compression and release of a spring(Liu et al., 2006). Novice lifters could be implementing this stretch-shortening cycle to save energy at the expense of increasing risk of injury while experienced lifters may have learned to avoid such lifting patterns.

The goal of the current study was to examine the activation of the erector spinae muscle along with the flexion angle as an estimation of energy expenditure resulting from different lifting strategies. It was hypothesized that the self-selected strategy of the novice group, a highly kyphotic lifting strategy, would demonstrate a lower energy expenditure. Conversely, the self-selected pattern from the experienced lifters, a lifting pattern maintaining near the middle of the lumbar ROM, would require less energy. This was to be examined through the EMG activation curves using the EMG and flexion angle. A sustained higher activation over the flexion angles would represent greater work required and therefore more energy expenditure. This will be a precursor to future work creating a work loop using models estimating muscle force and muscle length.

Methods

Subjects:

Seventeen subjects provided informed consent and participated in this study approved by the human subjects committee at The University of Kansas Medical Center. There were nine men and eight women with an average age, height, and weight of 24.1±4.2 years, 1.70±0.1 meters, and 66.4±12.7 kilograms (Table 1). Subjects filled out a questionnaire to remove individuals with a musculoskeletal disorder or history of low back pain. Individuals reporting an existing musculoskeletal injury or disorder were excluded. Additionally, individuals reporting back pain lasting for more than a day within the previous year or lasting more than a week were also excluded.

Table 1. Seventeen subjects provided informed consent and participated in this study. Subjects were divided into novice and experienced lifters with a total of nine men and eight women between the two groups. This table provides the gender distribution and the average age, height, and weight for each group.

	Experienced	Novice
Sex	3 Women, 5 Men	5 Women, 4 Men
Age (Years)	24.8±4.1	23.6±4.4
Height (m)	1.71±0.11	1.70±0.09
Weight (kg)	70.9±14.6	62.3±9.8

An additional questionnaire provided information to categorize subjects into two groups based on lifting experience. An individual was classified as an experienced lifter if they had lifted weights for at least three times a week for the last year or more. Specific weight lifting exercises were sought out including dead lifts, bent over rows, standing curls, squats, and standing military presses, but in general most forms of free weights was considered acceptable. Subjects that did not meet the criteria of the experienced group were considered novice lifters. However, subjects that did not meet the criteria for the experienced group and had been employed in a position involving lifting or material handling, of at least one hour a day for four days a week over the span of three months, were excluded from the study. This resulted in an experienced group consisting of five men and three women with average age, height and weight of 24.8±4.1 years, 70.9±14.6 kilograms, and 1.71±0.11 meters. The novice group had four men and five women with average age, height, and weight of 23.6±4.4 years, 62.3±9.82 kilograms, and 1.70±0.09 meters.

Experimental Protocol:

A repetitive lifting task was examined with three different lifting strategies. The three strategies examined included the self-selected strategy and two trained strategies described in

Chapter 3. One trained strategy consisted of a highly kyphotic motion approaching the range of lumbar motion, a pattern observed in a novice group of lifters. The second trained strategy was a neutral lifting pattern remaining near the middle of lumbar range of motion, a pattern observed within a group of experienced lifters.

Motion data were collected with three electromagnetic motion sensors (MotionStar, Ascension Technologies, VT) collecting at 100Hz using the Motion Monitor software (Innsport, IL). Electromyographic sensors (Delsys, Natick, MA) were also used and were positioned over the erector spinae at the L2-L3 level and were collected at 1000Hz again using an analog to digital board on the Motion Monitor system. Additionally, a force plate (Bertech, Columbus, OH) was used to determine a single maximum lift using a custom Labview program (National Instruments, Austin, TX).

Participants performed the lift with a crate containing a weight. The weight was standardized from a single maximum lift trial. The maximum lift was determined by having the subject stand on a force plate and pull up on a strap that was fixed to the ground. The strap was positioned such that the subject's hands would be shoulder width apart and just below the knees when holding the strap. This positioning required the subjects to be slightly bent over while maintaining straight legs for the lift. Force data was collected at 100Hz using a custom program created in Labview. A total of 5 seconds was collected with the highest 0.5 seconds being averaged for the maximum lift weight (Figure 1). For the experimental trials, a weight of approximately 3% of this maximum lift was placed in the crate.

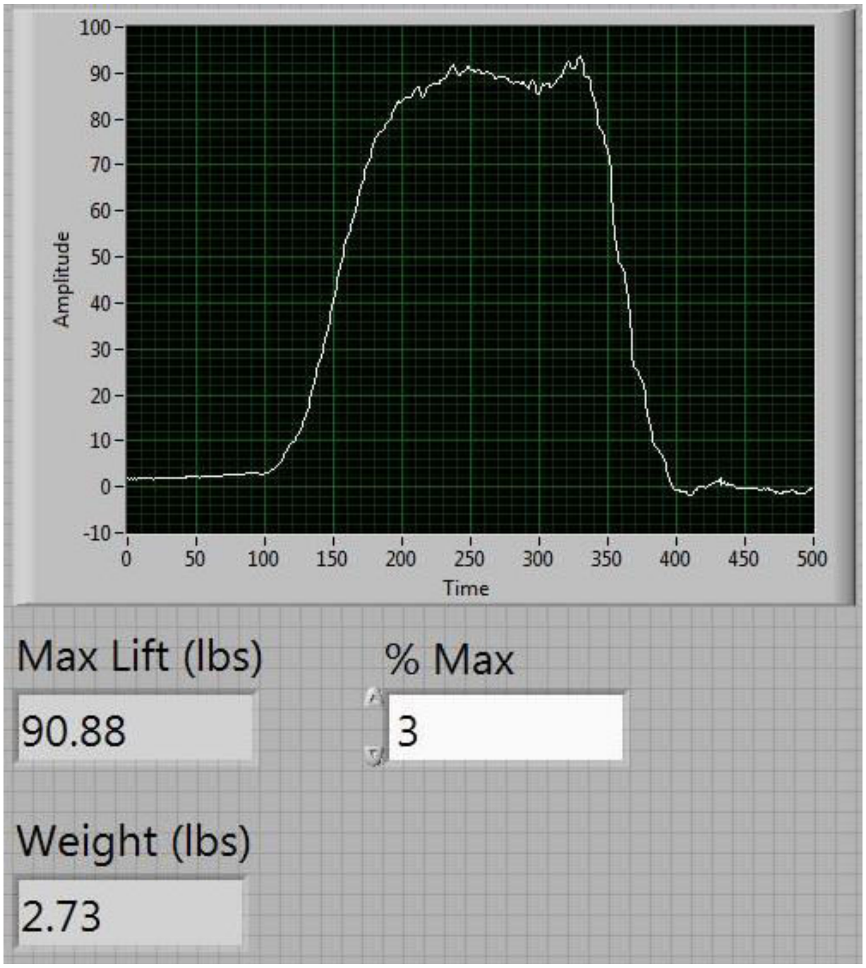

Figure 1. The weight lifted was normalized using a single lift maximum.

Training for the lifting strategies was possible using a custom biofeedback program created in Labview interacting with Motion Monitor software. The electromagnetic position sensors were located on the torso at the manubrium, T10, and the sacrum and were held in place using double sided tape. The electromagnetic sensors have a reported resolution of 0.08 cm and 0.1° and an RMS accuracy of 0.76 cm and 0.5°. The beginning and end of the lift cycles were determined based on the height of the sensor located at the manubrium, while the posture during the lift were determined using the T10 and sacral markers.

The position and orientation of these three sensors were exported through the "biofeedback" option within Motion Monitor to be read into the Labview program. The Labview program then performed a number of space translations from the provided quaternion's to Euler angles, rotation sequence of flexion (rotation in the sagittal plane)-lateral bending (rotation in the frontal plane)-axial rotation(rotation in the frontal plane), such that lumbar angle and trunk flexion angle could be calculated. The trunk flexion angle was defined as the angle created between the vectors connecting T10 to the sacrum to the vertical axis (Figure 2). The lumbar angle was defined as the angle created by the intersection of the planes extending through the sensors located at T10 and the sacrum. These definitions are consistent with previous studies (Granata and Sanford, 2000).

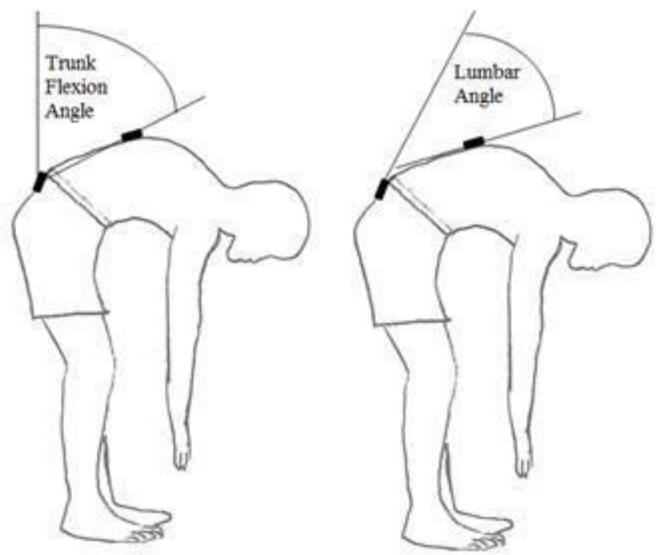

Figure 2. Sensors were located on the spine at T10 and the sacrum. These sensors were used to define the trunk flexion angle, the angle created with the vector connecting T10 to the sacrum and the vector from the sacrum extending in the vertical axis, and the lumbar angle, the angle created by the intersection of the planes extending from the sensors located at T10 and the sacrum.

With the trunk flexion angle and lumbar angles calculated in Labview, a lumbar range of motion envelope was determined for each subject using the method described by Maduri et. al. (Maduri et al., 2008). This was accomplished by having the subject match a target flexion angle and alternate between the maximum and minimum curvatures of the spine to determine the maximum kyphotic and maximum lordotic postures that could be reached (Figure 3). Subjects were asked to hold at the given extreme while the lumbar angle values were recorded three times, which were then averaged for each extreme. These extremes were determined at 0°, 30°, 60°, and 80° trunk flexion angles. The envelope was created by linearly interpolating a maximum and minimum value for all flexion angles between those recorded.

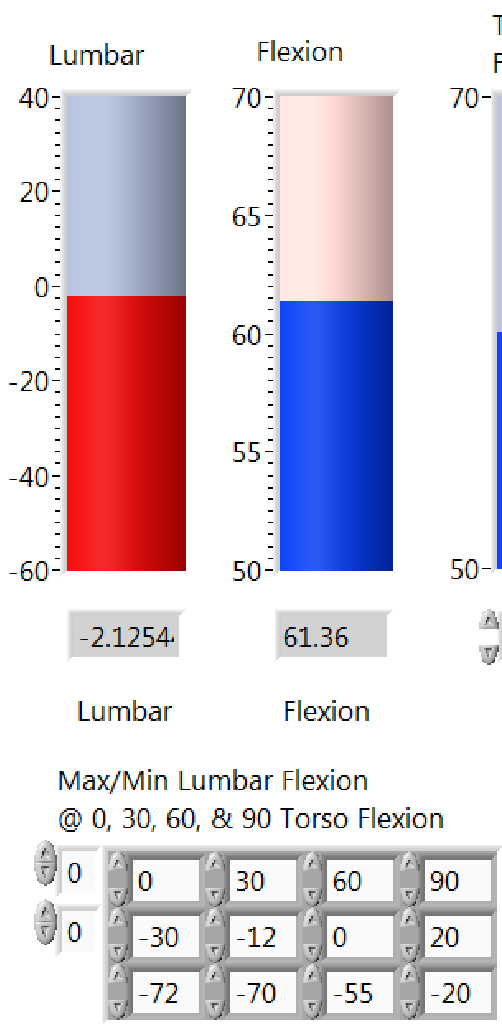

Figure 3. The initial determination of the lumbar range of motion was possible by recording the lumbar angle extremes (left bar) while matching the trunk flexion bar (center) to the trunk flexion target bar (right). The process was repeated for 0°, 30°, 60°, and 80° trunk flexion angles.

The lumbar range of motion envelope was used to normalize the subject's posture during the experimental trials using the equation

$$Normalized\ LA = \frac{LA - LA_{min}}{LA_{max} - LA_{min}} * 100.$$

This allowed for comparison between subjects as well as determining how the posture related to the individual lumbar range of motion limits. An example of the raw data of a single lift cycle and the resulting normalized data are shown in Figure 4.

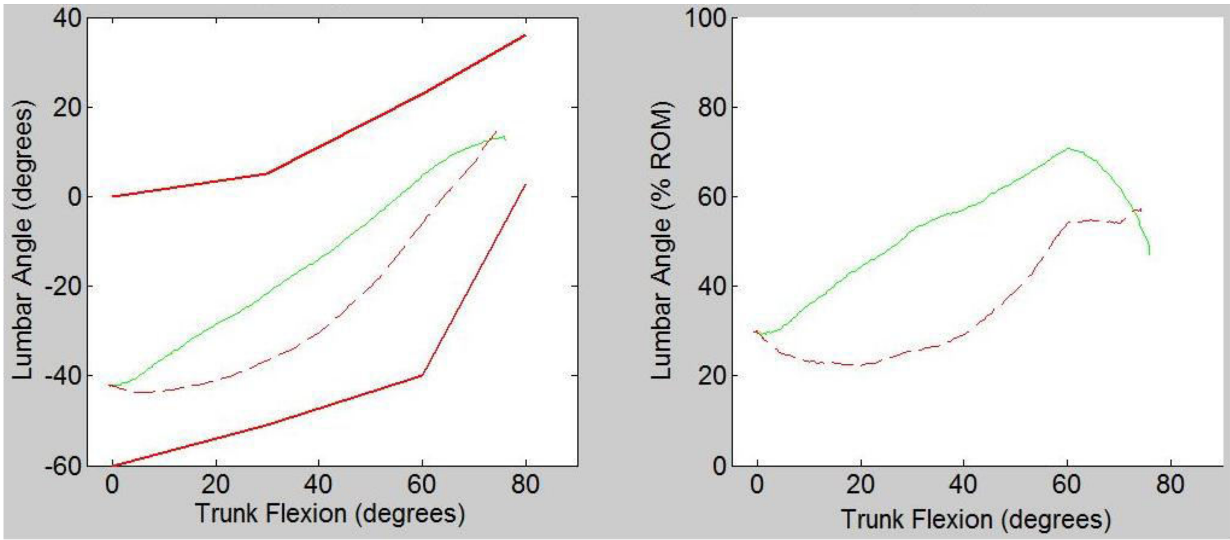

Figure 4. The raw lumbar angles of a single cycle lift are represented with the range of motion envelope surrounding it (left) and is normalized (right) for the analysis.

Subjects performed a straight-legged repetitive lift for four minutes in each of three lifting strategies. The rate of the lift was controlled using a metronome tone sounding at 1Hz with a single cycle lift lasting four seconds for a rate of 15 lifts per minute. The self selected, or initial, lifting strategy was performed without visual feedback and with minimal instructions beyond maintaining straight legs and the metronome.

Following the self-selected strategy, the subject was introduced to the biofeedback program and trained to either a highly kyphotic or a neutral lifting strategy. A visual display was provided to the subject in the form of a graph of the normalized lumbar angle verse flexion angle (Figure 5). The target box ranged from a flexion angle of 70° to 20° for both trained strategies. However, the lumbar range for the highly kyphotic target ranged between 80% and 95% lumbar angle while the range for the neutral strategy was between 42% and 58% lumbar angle. Subjects were instructed to have the cursor pass through the target during the extension phase of the lift, but it did not have to enter on the right side and remain in the target throughout the entire target box. In addition, subjects were told that there was no specific target for the flexion phase of the lift and they were allowed to select the most natural lumbar coordination.

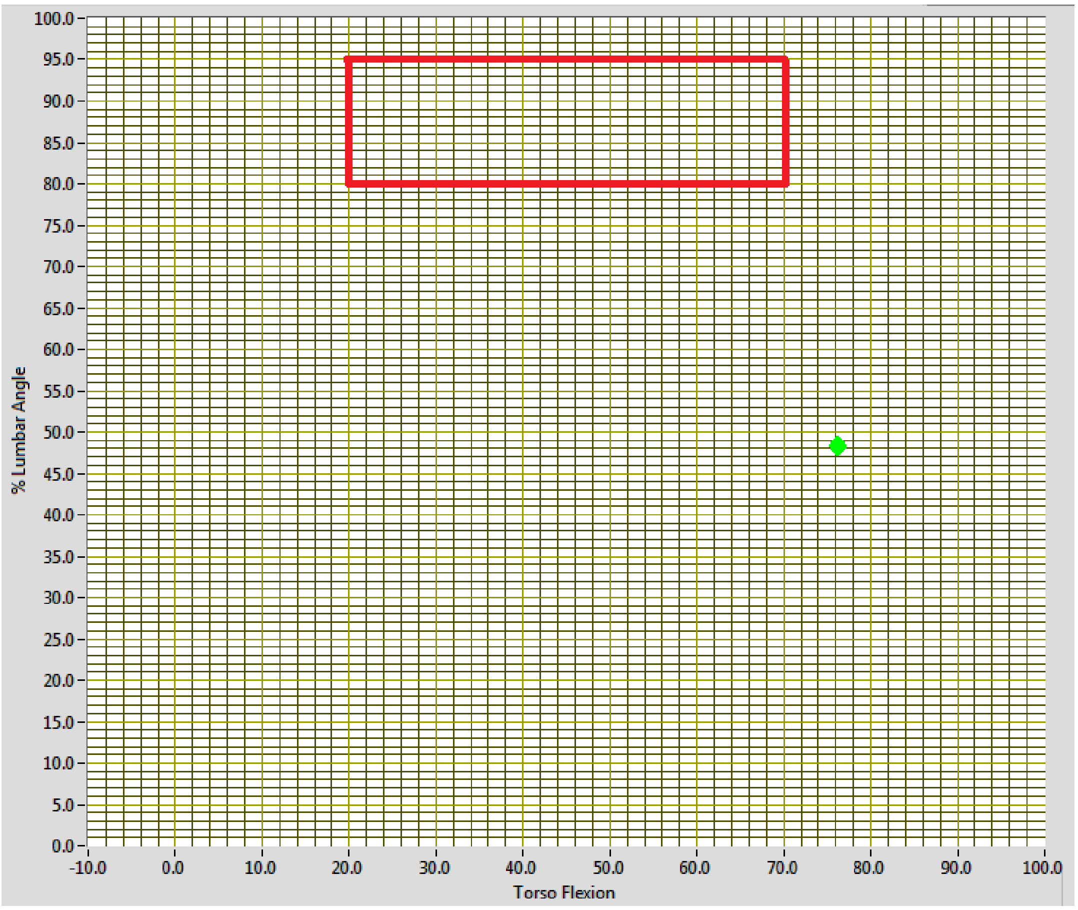

Figure 5. Visual feedback was provided to the subject on the lumbar-pelvic posture. The display is created using torso flexion angle as the x-axis and the normalized lumbar angle as the y-axis. For the trained strategies, a red target box was displayed and the subject had to enter the target box during the extension phase of the lift.

Once the subject could successfully achieve five consecutive lift cycles and felt comfortable with the lifting strategy, a five minute rest period was offered with the trial following the rest period. This routine of training, rest, and trial was repeated for the second trained strategy as well. The order of the trained strategies was randomized to reduce the possible effects of fatigue on a given strategy.

Analysis:

The manubrium sensor was examined to identify the time indices for the division of lift cycles and further division of each lift cycle into the flexion and extension phases of the lift. The minimum vertical height of the manubrium sensor represented the time that the subject reached the bottom of their lift cycle and coincides with the initial time of the extension phase. Conversely, the minimum vertical height of the manubrium sensor identified the time the subject reached the top of their lift and the beginning of the flexion phase of the lift cycle.

The EMG data for the right side erector spinae was examined. The EMG data was bandpass filtered between 20 and 250Hz. Additionally, notch filters were applied to remove noise spikes at 60Hz, 100Hz, and multiples of these frequencies. The data was also demeaned, rectified, and integrated using a 100 point Hanning window. Following the filtering, the data was normalized using the methods described previously for cyclic activities (Cram and Kasman, 1998; Yang and Winter, 1984). These studies normalized EMG data to the average peak value for each cycle using a minimum of four cycles of the cyclic activity. For this study, the average cyclic peak was determined from the self selected lifting strategy and was used in the normalization of the EMG for all lifting strategies. An average EMG curve was created by averaging the normalized EMG data based on the corresponding flexion angle based on the timing. The EMG data was averaged over flexion angles between 10 and 70 degrees for both the flexion and extension phases of the lift.

Due to high mobility of the task, the EMG data was examined to remove trials that recorded predominately noise. There were two criteria for excluding data. The first criteria for exclusion was the loss of a sensor during the trial, identified by the EMG signal dropping to nearly zero for a large portion of the trial. The second criteria for removing a trial was based on the averaged normalized values of the strategies. Any strategy with an average a magnitude larger than the other lifting strategies was removed. Consequently, the removal criteria resulted in the removal of nine subjects from this study from the original twenty-six subjects.

Statistical Analysis

A mixed measures ANOVA with Huynh Feldt correction was performed to examine the area of the difference between the EMG activations for the extension and flexion phases of the lift generated from the normalized EMG activation of the right side ES and the flexion angle. The dependent variable was the difference in the area between the EMG activations for the extension and flexion phases and the independent variables examined were lifting strategy and lifting experience with the repeated measure of time. Variables were considered statistically significant for $p<0.05$.

Results

It was observed that the normalized EMG activation for the extension phase was higher than the activation for the flexion phase during the self selected lifting strategy until the third time period. During the third period of the self selected lifting strategy of the novice group the activation during the flexion phase was higher than the extension phase for high flexion angles (Figure 6). The transition from higher activation in the extension to higher activation in the flexion phase of the lift was more frequent in the trained lifting strategies. In the neutral lifting strategy the experienced group demonstrated this transition multiple times during the third time period (Figure 7). In the highly kyphotic strategy the experienced lifters begin to demonstrate the downward trend at higher flexion angles demonstrated by the novice group (Figure 8). The general curve characterstics for the self selected strategy of the experienced group was closer to the neutral strategy with consistent activations throughout the flexion angles. Additionally the activation during the flexion phase of the trained strategy was higher leading to a smaller area in the EMG activation difference between the extension and flexion phases of the lift for the experienced group.

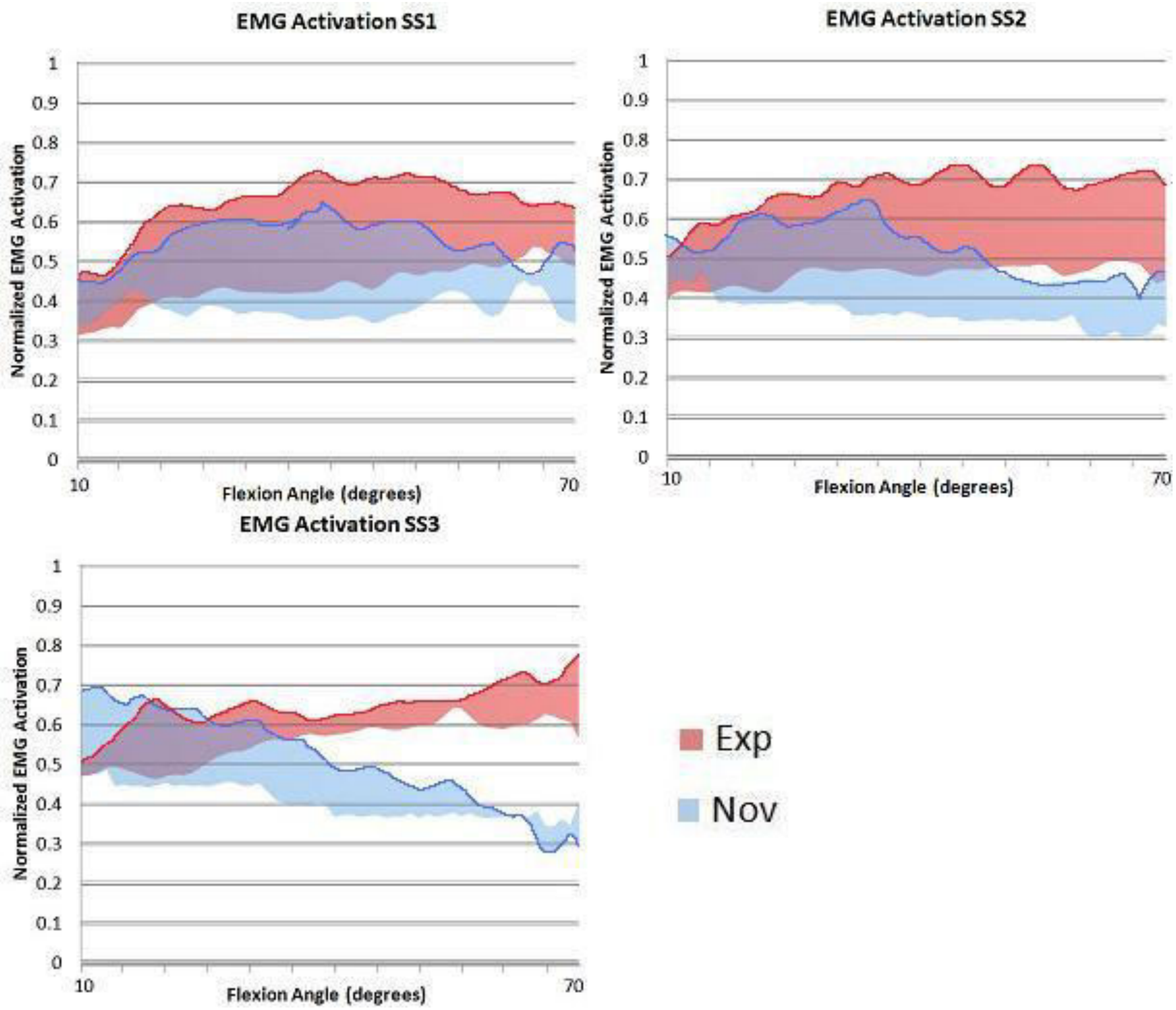

Figure 6. The EMG activations demonstrate the changes observed over time. Over time the novice group has a decreased activation during the flexion phase as EMG activation curve extends downwards at higher flexion angles. Additionally it was observed that the novice group average demonstrates an inflection where the normalized activation is higher in the flexion phase than the corresponding activation for the extension phase in the third time recording. The extension phase sides of the cycle are highlighted.

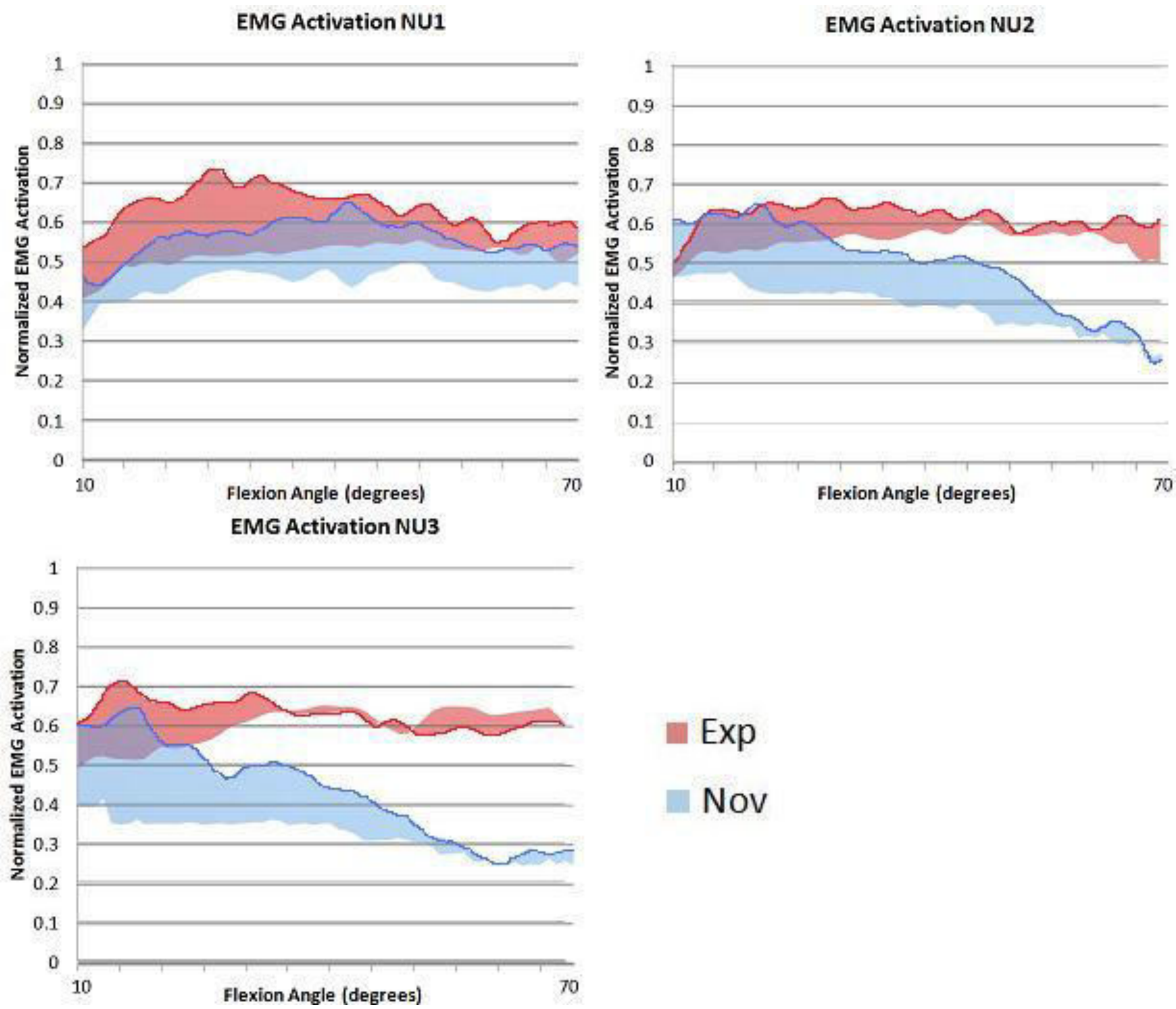

Figure 7. The EMG activations demonstrate the changes observed over time. Over time, the novice group has a downward trend as the activation during the flexion phase decreases with increasing flexion angles. The area within the EMG activation cycle for the neutral lifting strategy appear to be smaller than the areas observed in the self selected strategy.

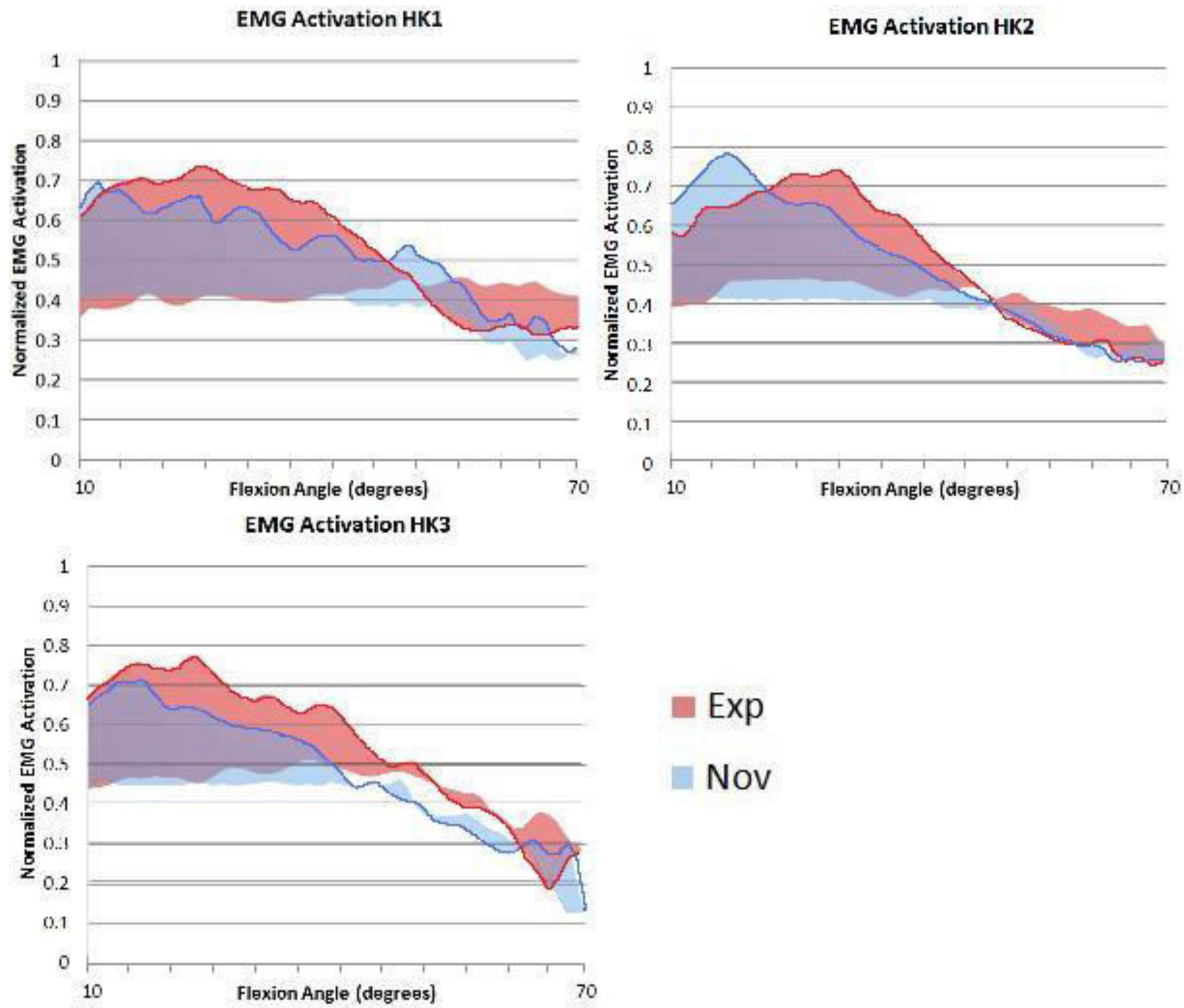

Figure 8. During the highly kyphotic strategy the patterns observed from the experienced lifters change from the other two strategies. They demonstrate a downward trend in activation at higher flexion angles similar to the pattern demonstrated by the novice group.

The examination of the area within the EMG activation cycle curves did not identify statistical differences between the lifting groups ($p = 0.958$). Nor was a difference observed between the lifting strategies ($p = 0.133$). There was however a significant difference observed over time (Table 2).

Table 2. A mixed measures ANOVA was performed to examine the difference in muscle activation in the lifting strategies between the novice and experienced lifters. It was observed that Time was significant ($p<0.05$). There was no significant difference based on lifting experience or lifting strategy.

Measurement	Statistical p-value
Strategy	0.133
Time	< 0.05
Lifter	0.958
Strategy*Time	0.426

Discussion

For this study, it was hypothesized that the highly kyphotic pattern of the self selected strategy of a novice group of lifters would demonstrate lower energy expenditure. The findings of this study do not support the hypothesis. It was believed that the strategy could be incorporating a stretch-shortening coordination in the back musculature allowing for a reduction of muscle activation. This would be tested by creating an average work loop to examine the energy expenditure, where a larger area in the work loop would relate to increased energy expenditure. The typical work loop would be a plot of the muscle force verses the length of the muscle, which poses some challenges for in vivo testing. The idea is to use models to estimate the muscle force and muscle length in the future work.

This study is preliminarily investigating the feasibility of the work loop approach. The muscle force would be modeled from EMG activation so we replaced the force portion of the work loop with the normalized EMG activation. Theoretically, a stronger activation would relate to a stronger force generated. This preliminary study examines the EMG activation curves over flexion angle.A lower EMG activation should theoretically demonstrate a decrease in energy required where the difference in the EMG activation for the two phases of the lift was also examined.

It was hypothesized that novice lifters are selecting a coordination that prioritizes minimizing energy expenditure. It is possible that the implementation of a stretch-shortneing cycle could explain why novice lifters perform a coordination pattern that may increase risk of injury. Our results demonstrate that there is not a significant difference between the lifting strategies based on the difference in the area beneath the EMG activation curves between the phases of the lift cycle. The use of normalized EMG proved difficult as a result of the noise in the measurement, as demonstrated with the large standard deviations for the area summations (Figure 9).

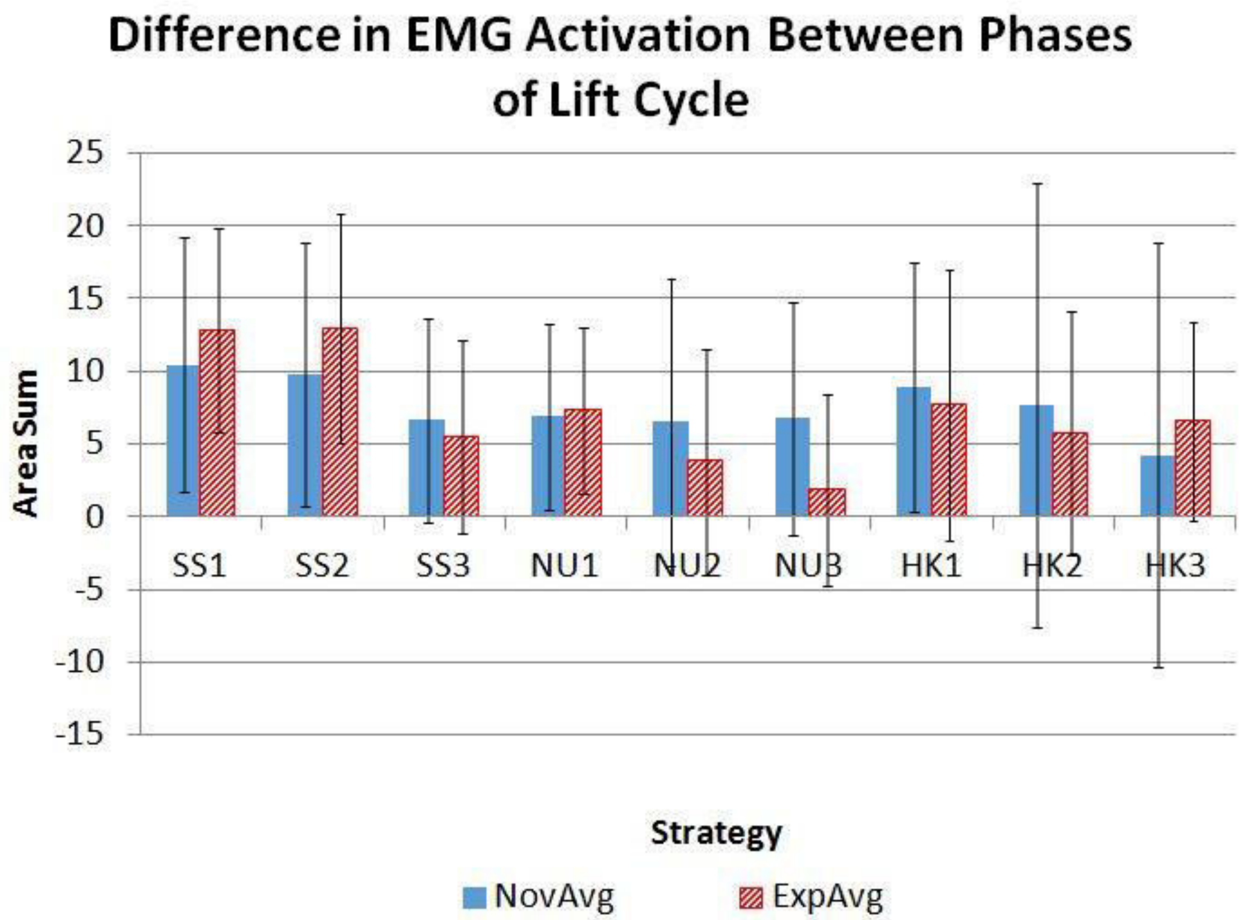

Figure 9. The area of the difference between EMG activation curves for the flexion and extension phases of the lift cycle was calculated between flexion angles of 10 and 70 degrees. The group average for each strategy is shown with the corresponding standard deviations. The standard deviations are very large compared to the measurement so there are no differences observed in this plot.

It is possible that task parameters could have influenced the results. Literature has demonstrated that an appropriate task should be selected for examination. If the task is unfamiliar the novice group could have difficulty in performing the task, but if the task is too simple then the skills developed by the experienced lifters would not come into play (Marras et al., 2006; Parakkat et al., 2007). It is also possible that the energy expenditure was affected by controlling for lift frequency which could have resulted in higher coactivation during the task.

Additionally the metronome could have caused subjects to be more disjointed in their motion as they attempted to continuously adjust their movements to follow the metronome.

In conclusion, this study observed that over time the activation of novice lifters decreased during the extension phase of the lift. Additionally the activation for the flexion phase was observed to increase and at times the flexion phase had higher activations than the extension phase for a given flexion angle. Although the plots demonstrate a decrease in activation at higher flexion angles, there was no significant difference based on the area between the EMG activation of the two phases of the lift cycle. However, the results clearly do not represent the work loop information that is expected with the implementation of the models to simulate muscle force and muscle length.

Future work should expand on the EMG activation curves using models to simulate the muscle force and muscle length. The area within the work loops could then be examined to compare different lifting strategies. The implementation of the models might have issues with one of the limitations of this study, noise from the EMG. The high standard deviations in the EMG may result in too much noise to provide useful information.

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CHAPTER SEVEN: STABLE SEATED SWAY DOES NOT VARY FOLLOWING WHOLE BODY VIBRATION

Introduction

It has been reported that up to 80% of the general population will experience low back pain and low back injury during their lifetime (Kelsey et al., 1984; Pai and Sundaram, 2004). Low back pain and low back injury are serious health concerns affecting up to 80% of the general population (Kelsey et al., 1984; Pai and Sundaram, 2004) and are associated with significant financial costs of work-related disability (Andersson, 1999). Low back pain (LBP) is the leading cause of disability in individuals under 45 years old and accounts for approximately 40% of all compensation claims in the United States (Lis et al., 2007). Add in the fact that a large percentage of compensation claims regarding low back pain are for long durations, and it is understandable that the costs associated with LBP can really add up. Low back disorders are a leading cause of worker disability affecting up to 47% of workers and costing society from $25 to $100 billion annually (Andersson, 1981; Cats-Baril and Frymoyer, 1991). The total annual costs of back pain are estimated to be $23.51 billion annually in the United States (Ricci et al., 2006). Low back motion is a complex task requiring coordination of sensory and motor dynamics and with the potential benefits of reducing the occurrence of LBP in industry, there have been numerous investigations on the topic.

Many investigators have focused on the factors that lead to injury with the majority attempting to identify occupational risk factors (Bernard, 1997). Occupational risk factors commonly thought to be associated with LBP include heavy physical work, a static work posture, repetitive bending, twisting, lifting, whole body vibration, and psychological issues (Alexopoulos et al., 2008; Linton, 2000; Manchikanti, 2000). The National Institute for Occupational Safety and Health have identified whole body vibration as a risk factor for low back disorders (Bernard, 1997; Health, 1981). Exposure to whole body vibration (WBV) in the occupational setting is a common event; more than 7 million workers in the United Sates experience WBV on a daily basis (Wasserman et al., 1997). As WBV has been linked to an increased risk of low back pain, a number of studies have been conducted to understand the etiology of low back pain.

Examination of the resonance frequency of the seated human spine has been reported to be 4-6Hz (Fairley and Griffin, 1989). As a result, this frequency range has been utilized in numerous laboratory studies as this represents the worst case scenario in terms of vibration transmissibility. However the ultimate goal is the identify effects of vibration resulting from those experienced in the occupational setting. Whole body vibration (WBV) exposure has been associated with a higher incidence of low back disorders in workers from a number of occupations including pilots, truck drivers, and heavy equipment operators. It is therefore these vibration exposures that this study will attempt to examine.

In order to examine the effects of vibration, performance based tasks have been created to compare performance prior to vibration exposure to during or following vibration exposure. One such task was a sudden loading task that demonstrated the time to peak muscle activity in the erector spinae and torso flexion following a sudden load perturbation increases during localized vibration compared to a baseline measurement (Arashanapalli and Wilson, 2008). Using the same sudden loading task, 20 minutes of whole body vibration exposure was reported to result in an increase in time to peak activity when comparing the post vibration response time to the response time prior to vibration exposure (Li et al., 2008; Wilder et al., 1988). Additionally, Li's study found a 1.58 fold increase in proprioceptive errors following 20 minutes of vertical vibration when compared to a control group e. The findings of these studies both indicate a loss in neuromotor response that may lead to poor control and higher forces in the low back, which could, in turn, contribute to injury.

The sudden load and proprioceptive assessments by Li et al. can be used to identify differences resulting from a short duration of vibration that individuals may experience in everyday life, particularly in occupational settings. However, the experimental setups used by these authors require a large area, are not easily transportable, and require significant time to set up. They are, therefore, not acceptable to take to industry. Due to portability limitations of the sudden load task, a goal of this study was to create a performance-based task that could assess lumbar, neuromotor dynamics changes in the occupational setting. Criteria for the task were based on discussions with our industrial contacts. The first criterion was that the space necessary for the task needed to be compact as there would be limited space for data collection. The second criterion the task needed to be easily transportable as the contacts were within the construction field and would require the equipment to be transported to different sites. The third criterion required that the setup and removal of the equipment be speedy to prevent the need for early or late access to job sites as well as being quickly removed to minimize any inconvenience to workers at the job site. The fourth criterion was that the task needed to be short as the idea was that subjects would perform the task at the beginning and end of the day, both requiring the subject to extend their work day. This criterion required that the length of the data collection be short as well as any explanation or training necessary for subjects to perform the task. Finally, the task needed to be sensitive enough to identify differences based on the vibration exposure expected in the occupational setting. As such, the goal of this pilot study was to assess this new assessment within the laboratory environment prior to testing in the occupational setting and see if it was able to detect the vibration induced effects that had previously been observed in sudden loading and proprioception experiments.

Although traditionally balance tasks have been used to examine standing postures, there are several studies that use seated sway protocols on a force plate to examine lumbar control of the spine. One study examined the effects of a local paraspinal vibration on the erector spinae on the mean sway speed in both stable and unstable sitting (Soltys, 2011). This author found significantly increased sway speed ($p<0.05$) when vibration was applied directly to the paraspinal musculature compared to a non-vibration condition for both the anterior-posterior and medial-lateral directions during vibration exposure. Choosing the appropriate measurements of sway determine how informative the study results will be. Measures of sway have long been utilized to investigate postural control while standing (Vuillerme et al., 2002; Zatsiorsky and Duarte, 1999, 2000). One reliable measure is the mean sway speed, or the total path length travelled divided by time (Raymakers et al., 2005; Silfies et al., 2003). Standing postural sway studies have been expanded to examine the neuromotor response of the trunk by incorporating seated sway protocols (Cholewicki et al., 2000; Preuss et al., 2005). The theories behind standing and seated sway studies are similar. However, seated sway removes the contribution of the joints of the lower extremities. By removing the lower extremities, any postural control necessary for the trunk to remain upright must be completed by the trunk musculature. In these studies, the subject sat on a platform positioned on a force plate. Some of the platforms are intentionally designed to provide an unstable platform to increase the level of difficulty to maintain balance (Cholewicki et al., 2000; O'Sullivan et al., 2006; Slota et al., 2008). However, Soltys examined both stable and unstable seating conditions and found that stable seated sway speed was affected more than unstable seated sway by vibration (Soltys, 2011). Given these results from the seated sway task for effects of vibration applied directly to the paraspinal musculature and the relative simplicity of stable seated sway as a tool to measure changes in trunk neuromotor control and dynamics, the aims of this study were to use this measure to assess the effects of WBV. The stable seating task appeared promising with local vibration and this study expands on the previous work by examining post vibration effects following whole body vibration instead of during a localized vibration.

As the majority of the subjects time commitment was resulting from the vibration exposure, multiple tasks were created with the idea of identifying the most appropriate measure for use in the occupational setting. A target pursuit-matching task utilizing seated center of pressure biofeedback from the forceplate was included in this study. Pursuit tasks have been used in a variety of settings to examine changes in proprioception (Soltys, 2011). By utilizing the force plate in the same setup as the sway measure for this pursuit-matching task, this addition provides another measurement for analysis without appreciably extending the time demands on the participant.

The purpose of the current study was to design a proprioceptive assessment sensitive enough to identify differences such as those seen previously while also maintaining acceptable time and setup parameters for testing in an occupational setting. Through collaborations with industry, it was determined that the required parameters would require a design to be easily portable, minimal duration in setup and collection, and easily understood instructions for participants. This study would validate the success of the proprioceptive assessment through demonstration in the laboratory. The primary hypothesis for this study is that subjects would have increased mean sway speed during seated sway and increased error in pursuit tracking tasks following exposure to WBV.

Methods

Seven healthy subjects reporting no back pain in the previous year were tested. Five males ranged in age from 24 to 33 with average (SD) for height and weight of 172.7 (5.1) cm and 73.6 (10.1) kg. Two females ranged in age from 23 to 27 years with average height and weight of 170.2 (3.6) inches and 57.3 (0.6) kg. Subjects were recruited by word of mouth from the Lawrence community. All participants gave written informed consent for this study that was approved by the University of Kansas Human Subject's Committee.

Assessment Design

Subjects were seated on a Bertec force plate (Columbus Ohio) and the data from this force plate was acquired at 100Hz and processed using Labview (National Instruments, Austin, TX to obtain the 3D force and moment applied to the force plate. This data was used to calculate the center of pressure on the force plate. The subjects were seated such that their legs were allowed to freely dangle.

Four trunk motion tasks (seated sway, lateral linear pursuit tracking, anterior-posterior linear pursuit tracking, and circular pursuit track) were assessed using this setup. Following a baseline measurement of task performance for the four tasks, subjects were exposed to 20 minutes of whole body vibration. Immediately following the vibration exposure, the subjects were retested on the task performance of the four tasks. On a separate day, each subject completed a control condition where subjects were assessed for the four tasks and then remained stationary in a seated position without back support for 20 minutes before a second assessment of the four tasks was performed. This resulted in four different task performance assessments: 1) pre-control, 2) post-control, 3) pre-vibration, and 4) post-vibration. Subjects performed the study over two days, with the order of the vibration and control randomized.

Vibration Characteristics

Vibration exposures in an occupational setting are made of a combination of frequencies, magnitudes, durations, and direction (Griffin, 1990). The vibrations can be measured using a tri-axial accelerometer mounted to the solid seat. They can then be assessed over a representative period of time to determine the frequencies present and the magnitudes of acceleration vibrations for the three axes. A common limitation of WBV studies has been the representation of vibration, often reducing the exposure to a single axis vibration. In this study, a more realistic profile of vibration exposure using data from a dump truck seat was used. Still limiting the vibration to a single axis, a vibration profile was created using experimental data collected from three 30 minute collections on three separate dump trucks during normal operations (Figure 1).

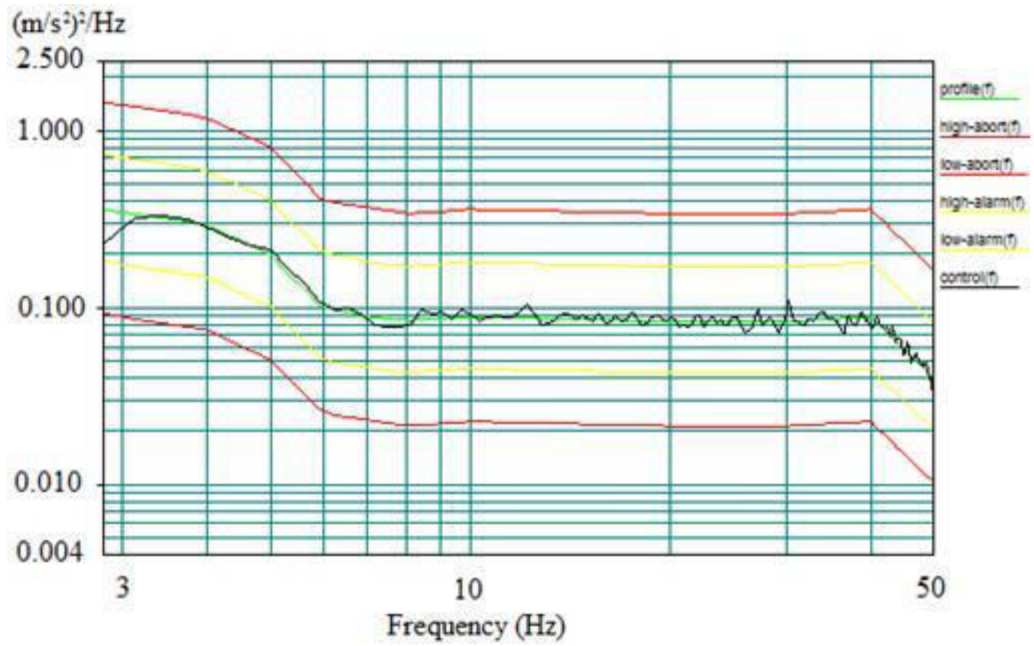

Figure 1. A random vibration profile was created from the average of three thirty minute measurements of normal operation of a dump truck.

Seated Sway

The assessment trials included four separate tasks with an order of: 1) stable seated sway with eyes closed, 2) a pursuit task with a linear pattern in the medial-lateral motion, 3) a pursuit task with a linear pattern in the anterior-posterior motion, and 4) a pursuit task with a a circular pattern (Figure 2). Each assessment trial collected all four tasks in series. The order was constant with 30 seconds of stationary seated sway with eyes closed before beginning the pursuit task patterns.

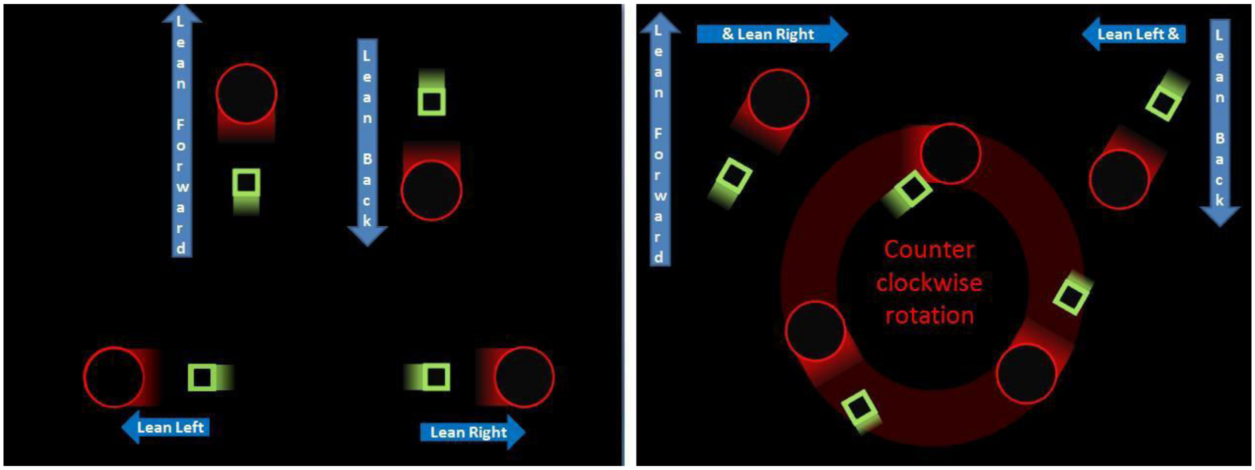

Figure 2. The pursuit task was created using a red circle target and biofeedback of actual position with a green square. The target pursuit task followed three different patterns. The two patterns shown on the left side involved linear motion in either the anterior-posterior directions or the medial-lateral directions. On the right, the more complex pattern involving manipulation of both the ML and AP planes demonstrates how the target moved around in a circle with three separate time frames imposed on the single figure.

Target Pursuit Task

For the pursuit tasks, a biofeedback display was created using Labview programming to provide the pursuit-tracking task. Using the center of pressure measured with the force plate, the neuromotor control of the lumbar motion was assessed. The target marker followed predefined patterns of motion, which were visible to the subject throughout the experiment. The subjects sat on a force plate facing the monitor and were asked to adjust their trunk posture to move their center of pressure such that their instantaneous marker followed the target cursor pattern. The subject was allowed to practice the motions until they felt comfortable with the task before the collection began. Subjects were able to move their instantaneous marker by leaning in the desired direction (anterior flexion corresponds upward movement of the cursor, left lateral bending corresponds left movement of the cursor, posterior extension corresponds downward movement of the cursor, and right lateral bending corresponds right movement of the cursor).

To defined the bounds of the biofeedback of the center of pressure, an assessment of range of center of pressure motion was collected at the beginning of each day. This was accomplished by having the subject flex to an extreme position and recording their maximum trunk flexion center of pressure. This was performed in the anterior, posterior, and both lateral directions to determine the limits appropriate for individual subjects. The pursuit task was then limited to 75% of the subject's range of motion and center of pressure was normalized for comparison to other subjects.

Each individual pursuit task pattern lasted for 50 seconds and included 10 iterations. The target visible throughout the trial and the first 5 cycles of the task was with visual feedback of their instantaneous marker position followed by 5 cycles in the absence of the instantaneous visual feedback. The first and last cycle was removed from the analysis to reduce transition effects between the different pursuit tasks or feedback conditions.

Analysis:

The mean sway speed (MSS) of the center of pressure was examined for the stationary seated condition. The MSS examined the middle 20 seconds, removing the first and last 5 seconds of the seated condition. MSS was examined overall as well as individually for the anterior-posterior and lateral motion of the center of pressure. A repeated measures ANOVA was performed on the MSS for four vibration conditions including pre-vibration, post-vibration, pre-control, and post-control. Differences were considered to be significant at $p<0.05$.

The linear tasks were examined by identifying the individual cycles in each direction. The cycles for each iteration and visual feedback condition were reduced from five cycles to the middle three cycles in each direction to remove transition effects. Once the cycles were identified, the slope was calculated using the end points of the cycle. The calculated slope as well as the peak to peak COP motion were compared to the target values and the errors of those two measurements were examined in a repeated measures ANOVA for four vibration conditions including pre-vibration, post-vibration, pre-control, and post-control. Additionally, the absolute value of the errors of the measurements was also assessed using a repeated measures ANOVA.

The circle task data was converted between Cartesian coordinates to polar coordinates, radius and theta. Each cycle of the circle task was identified based on the timing. The error between the target and actual was calculated for both the radius and angle theta. The average error values of each quadrant and the absolute value of the error values of each quadrant were examined using a repeated measures ANOVA for four vibration conditions including pre-vibration, post-vibration, pre-control, and post-control. The first cycle was removed from both visual feedback conditions resulting in four iterations in the analysis. Differences were considered statistically different for $p \leq 0.05$.

Results

No effects of vibration were observed in seated sway for the stable seated task. The area travelled by the center of pressure appeared consistent between the vibration conditions when examining the individual subjects (Figure 3) as well as the average group mean sway speed (Figure 4). There was a significant difference ($p < 0.05$) in the mean sway speed between the sagittal and coronal planes (Table 1).

Table 1. A repeated measures ANOVA was performed on the AP and ML center of pressure mean sway speed. Mean sway speed was only found to be significantly different between the sway directions (AP and ML).

Measurement	MSS p-value
Test Order	0.953
Direction (AP vs ML)	<0.05
Condition (control-vibration)	0.298
Time (pre-post)	0.819
Condition x Time	0.488

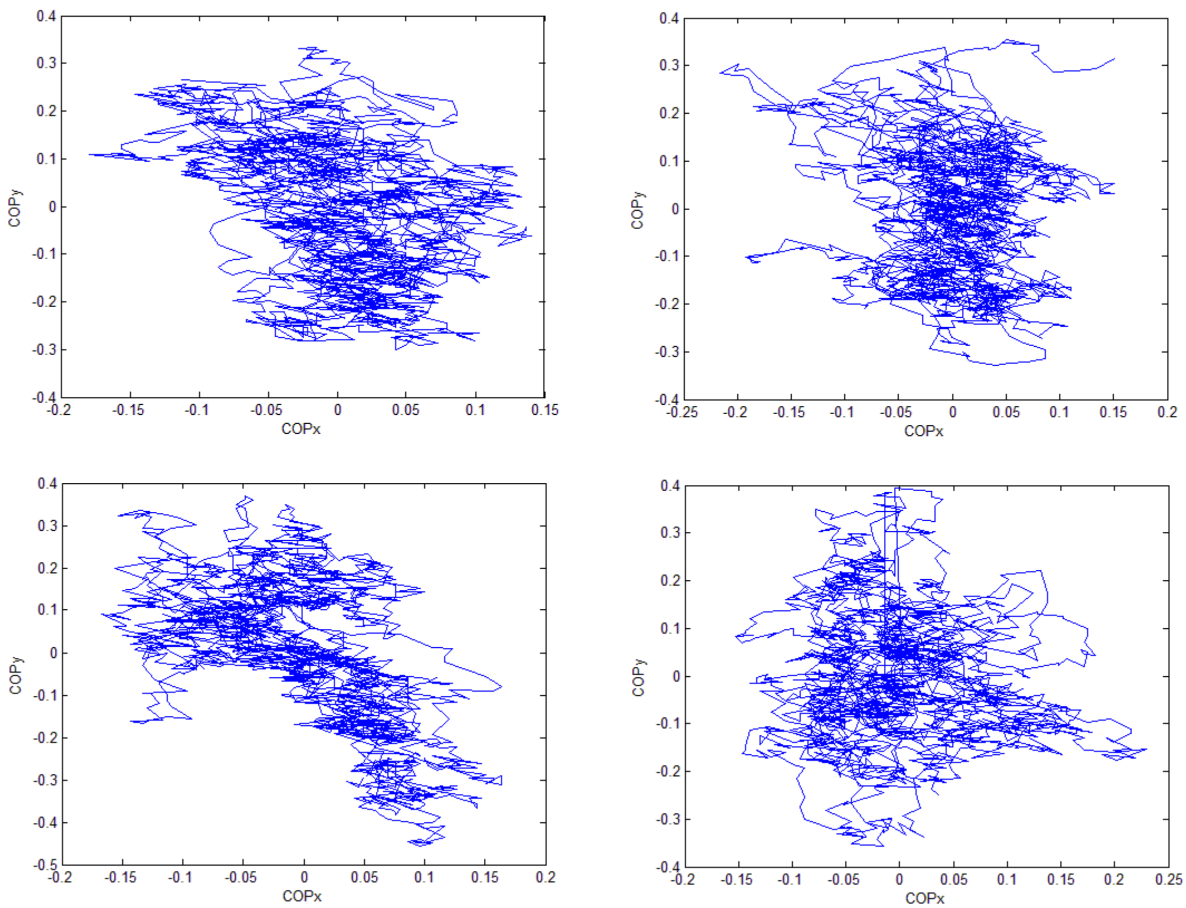

Figure 3. The area travelled of the raw center of pressure data is consistent through the four vibration conditions (pre-vibration - top left, post-vibration - top right, pre-control - bottom left, and post-control - bottom right).

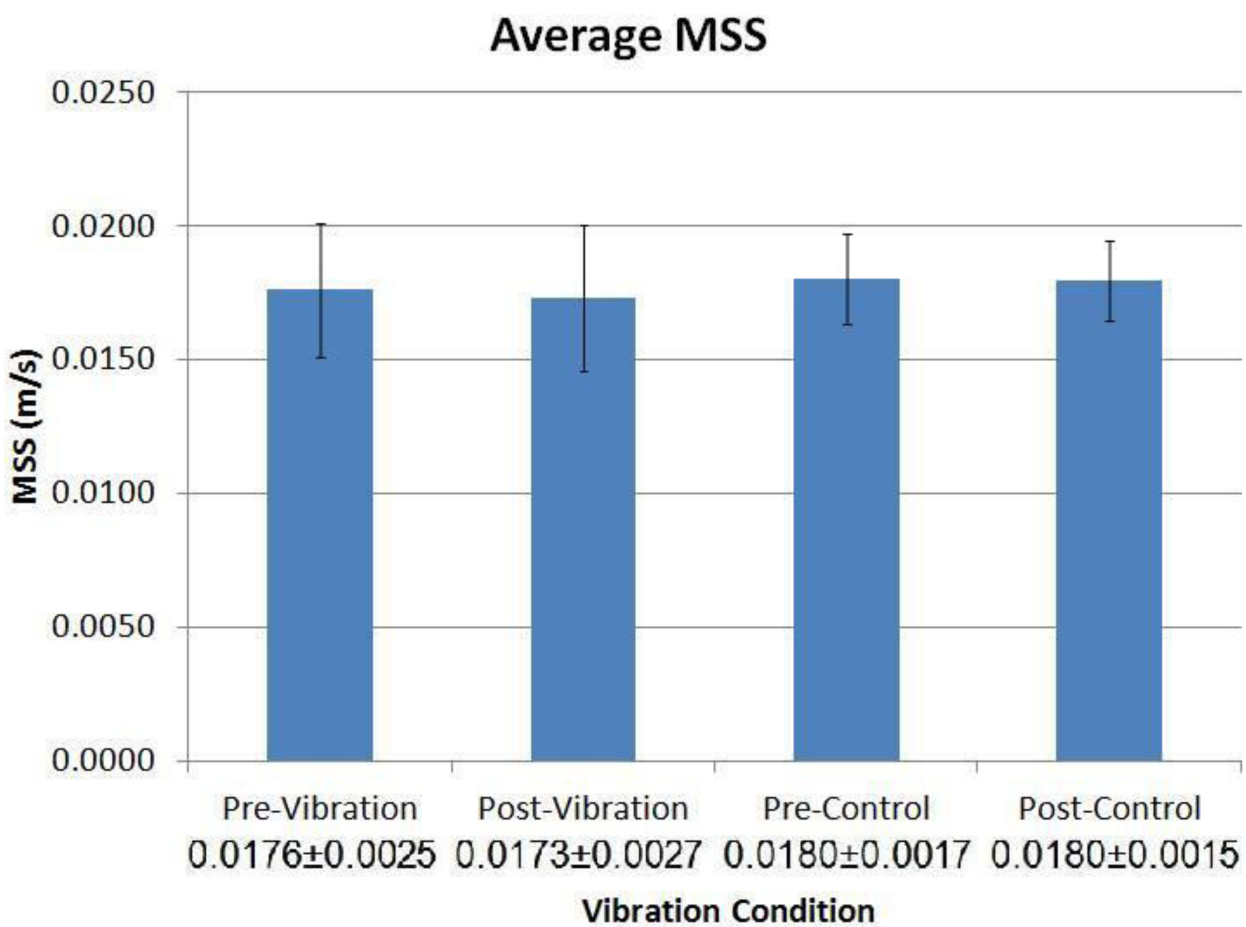

Figure 4. There was no difference in the total mean sway speed for the different vibration conditions.

Examination of the linear task involved sectioning the data into the two feedback conditions. The data is plotted with the target and the transitions of directions are marked (Figure 5). The error in peak to peak values were determined and the slope was calculated and compared with the target slope to determine the error in slope. Neither measure identified a difference in the peak-to-peak error due to vibration ($p=0.275$), time ($p=0.144$) or the interaction between vibration and time ($p=0.837$)(Table 2A). Similarly, there was no significant differences in the absolute value of the peak-to-peak error, although both time ($p=0.058$) and direction ($p=0.084$) demonstrated some trends suggesting possibly a learning effect and a handedness effect that was not significant (Table 2B). Similarly, ANOVAs of the slope error and absolute value of the slope error did not demonstrate significance or any demonstrable trends other than a slight but not significant difference in absolute error with direction ($p=0.105$).

Table 2. ANOVAs in the error of the radius and theta measures in the circular pursuit tasks also did not show any statistically significant patterns except that error in theta differed between the quadrants of the circular motion.

A. An ANOVA of the radius error

Measurement	p-value
Test Order	0.88
Condition (control-vibration)	0.759
Time (pre-post)	0.836
Quadrant	0.168
Iteration	0.173
Condition x Time	0.244

B. An ANOVA of the theta error

Measurement	p-value
Test Order	0.145
Condition (control-vibration)	0.962
Time (pre-post)	<0.05
Quadrant	0.013
Iteration	0.386
Condition x Time	0.111

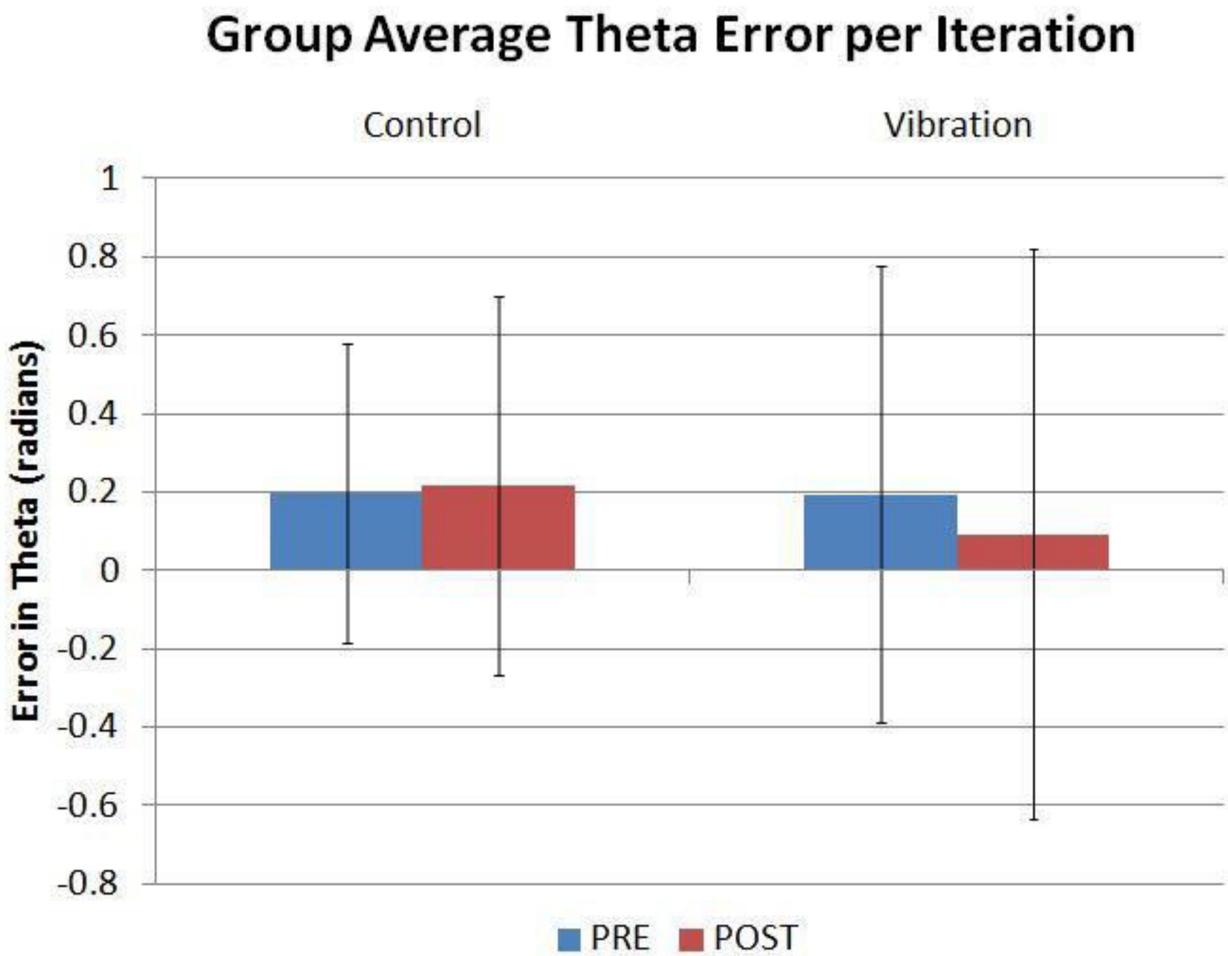

Figure 5. The error in theta is similar for the pre and post control conditions as well as the pre vibration condition, while the post vibration is roughly half of the others. However, a significant difference is not observed as the standard deviation of the error is so large compared to the average value.

The circular pattern was examined using the polar coordinate system. A sample of the error from the target for the radius and angle theta of the circular path is plotted below (Figure 6). The error in the radius was directional as the error was generally negative for all quadrants. The error in theta was not directional as sometimes the error was positive and other times it was negative. Both error measurements had large deviations between iterations as well was between subjects. The results of the ANOVA identified that the vibration condition (vibration vs control) was not significantly different for the measurement theta or the radius measurement (Table 2). The error in theta was found to be significantly different between the quadrants ($p<0.05$).

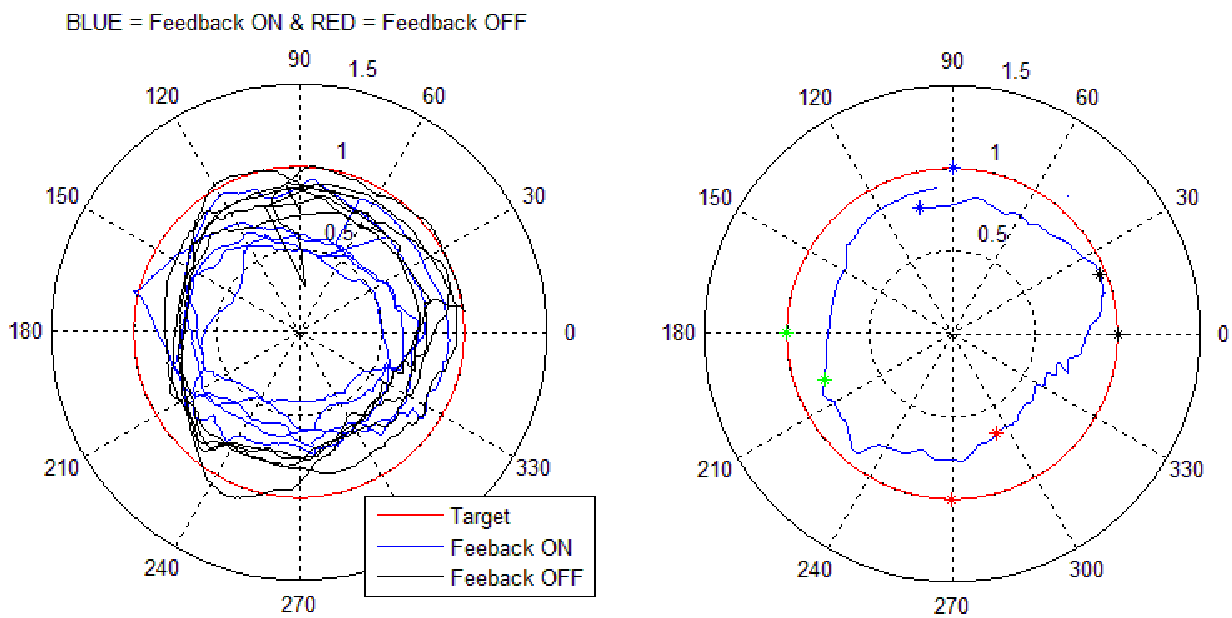

Figure 6. The circular task was segmented into cycles where the polar coordinates (radius and theta) were examined. The left figure shows the overall patterns observed in the circle pursuit task. Each cycle was further segmented to examine if there were any effects local to a quadrant (right). The timing for the beginning of each quadrant is marked with an asterisk.

Discussion

The proprioceptive task created achieved some of the desired criteria including being portable with minimal time required to set up and train individuals to the task. However, tasks were lacking one critical criterion; they were not sensitive to differences between pre and post vibration conditions. Without meeting this specific criterion, it is apparent that the tasks need further development.

The circle task proved to be the best candidate for further examination. The results identified that there was a difference between the control and vibration test with the measurement theta (Table 2). In the circle task, theta is related to the timing of completing the task and includes a measure on the velocity sense that is possibly a contributing factor for error within the proprioceptive system. However, further development is still necessary as the iteration and quadrants were identified as significant. This could be reduced through reordering an alternating pattern between feedback and assessment. By removing the stable seated sway and linear tasks, there would be more time allowed for the circle task. In so doing it would be possible to alternate between training and assessment conditions while still removing transitional periods.

An interesting observation for the circle task was the directionality of the error in the radius. The radius was always smaller than the target as subjects would minimize the deviation from stable when matching the target circle from the biofeedback program. Although some of this is a result of the target covering an area and not simply a point at the target value, the directionality observed could identify the control strategy of maintaining stability through the task. The error in theta had no directionality, as the velocity would adjust to correct the error to the target sometimes leading and sometimes lagging the target.

It is possible that the number of adjustments from previous work were too much in one step. The vibration effects detected in the sudden loading task were apparent 20 minutes following whole body vibration, but the vibration from that study examined a sinusoidal 5hz vertical vibration (Li et al., 2008). That study selected 5hz vibration as it is reported to be a resonance frequency of the human spine (Kitazaki and Griffin, 1998). As a resonance of the human spine, the effects resulting from the vibration would have the greatest effect on the proprioceptive system. However, this study is interested in examining a vibration profile that resembles a measured occupational vibration more closely. It was believed that if the effects were seen following 20 minutes of quiet sitting, as the study reported that the adjustment of the vibration profile to the dump truck would still result in observing effects of vibration immediately following the vibration.

When considering options for a portable task a seated sway study observed differences between a localized vibration condition as compared to without vibration(Soltys, 2006). That study examined an unstable and stable seat with localized vibration. In that study, the effects of the localized vibration were observed in both stable and unstable seating. Although the unstable seating had a greater effect on the task, the stable seating was selected for the current study to minimize the training for subjects. However, the localized vibration exposure was different from the current study that was attempting to examine a more relevant occupational vibration.

The current study could have made incremental adjustments to improve the probability of achieving success at designing a task to meet the desired criteria. The adjustment of both the measurement task as well as the vibration could have adjusted too many parameters at once. It would have been possible to perform fewer alterations from the previous studies to assure that the effects were still observed. Performing the sudden loading with the alternate vibration profile would have confirmed the observance of the effects with the more relevant occupational vibration profile. Similarly, if the seated sway task was performed with a 5hz whole body vibration it may have become apparent that the unstable seat would be required.

The target-pursuit tasks were included in this study as the additional time requirement for the subject was minimal and increased the possibility of identifying a task sensitive to the effects of vibration. Previously a target-pursuit task identified that there was a significant effect on a joystick task resulting from localized vibration on the forearm(Soltys, 2011). It was hypothesized that a similar effect may be observed with the musculature of the spine. Therefore the target-pursuit task was examined using the linear patterns in the sagittal and coronal planes. Additionally a circle pattern was included to include a more complex pattern.

Although it would have been possible to perform experiments incrementally, it would have required more subjects and time. The differences observed in the previous work appeared to be great and therefore believed that differences would be observed using the current task design. However, the results of the current step have identified that the current task requires further development.

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CHAPTER EIGHT: SUMMARY

Summary of Project

The primary goal of this project was to improve understanding of factors related to occupational back pain. The two factors examined were repetitive lifting and whole body vibration. Both factors are prevalent in the occupational setting and this research began with an investigation into the effects of vibration that was eventually redirected as another source of funding presented the possibility of investigating repetitive lifting.

The first and second studies reported in this dissertation examined the kinematics of repetitive lifting. The first study observed differences in lumbar-pelvic coordination preference between novice and experienced lifters. Novice lifters selected a highly kyphotic lifting strategy approaching their lumbar range of motion (ROM) limits while the experienced lifters selected a strategy remaining near the middle of their range of motion. This highly kyphotic strategy was hypothesized to be an attempt to increase mechanical efficiency of the cyclic lift task by implementing a stretch-shortening cycle within the back musculature. This highly kyphotic pattern could potentially increase risk of injury and therefore lifters may become conditioned away from this pattern with increased experience. The second study examined the ability to train a new lumbar-pelvic coordination strategy and found that both groups could be trained to perform a pattern more closely resembling the other group.

The hypothesis of implementing an energy saving strategy was examined in two separate approaches. The first approach, study five, utilized a metabolic cart to examine the oxygen consumption during the lifting strategies. There were no significant differences in oxygen consumption between the different lifting strategies. However, there was a significant difference over time. This was believed to be a result of ramping up to the plateau region of oxygen consumption and extending beyond the plateau when subjects began fatiguing.

The second way energy was examined, study six, was by investigating muscle activation curves relating the normalized EMG signal verses flexion angle. The muscle activation approach agreed with the metabolic cart results in that there were no significant differences observed between the different lifting strategies. These studies appear to refute the theory that novice lifters are selecting a highly kyphotic strategy to reduce the energy required, although both studies had some challenges that should be investigated further. In particular, the trained strategies, while having similar lumbar pelvic coordination patterns to the highly kyphotic and neutral strategy, the timing and EMG patterns were not necessarily the same, particularly over the duration of the assessment period. As such, subjects may not be as successfully using any energetic efficiencies while also trying to maintain a trained pattern.

Finally, the seventh and last study was an attempt to design a measurement task that could be used to expand vibration research from laboratory to the occupational setting. The task was designed to be easily portable with minimum time required for set up, training subjects, data collection, and tear down all while using a minimal amount of space. The choice of using a force plate and center of pressure sway and pursuit tasks in a seated posture accomplished all these things, but failed to observe useful differences when comparing the measurements following twenty minutes of whole body vibration to those collected prior to the vibration exposure. Without demonstrating differences resulting from the vibration, it was determined that the measurement task needs further development before it is ready to take to the occupational setting.

Conclusions and Recommendations

This work has demonstrated that novice lifters select a lifting posture that approaches the limits of their static lumbar range of motion, or performing a highly kyphotic strategy. This strategy differs from experienced lifters that maintain near the middle of their static lumbar ROM. The reason novice lifters select such a posture is unknown, but the strategy is believed to increase the risk of injury. It was hypothesized that the novice lifters were prioritizing energy consumption over the injury risk, but the results of this work failed to demonstrate this to be true. Examination of the energy expenditure was completed two ways, using metabolic conversion and EMG activation. Neither demonstrated a difference in between the trained lifting strategies.

It was observed that it is possible to alter the lumbar-pelvic coordination strategy with visual biofeedback. The novice lifters succeeded in performing a lifting strategy resembling the self selected pattern of experienced lifters, however over time their success quickly decreased. The experienced lifters also were able to adjust to a different lifting strategy and consistently maintained their success rate.

There were some interesting observations in the EMG activation. Although the trained lifting strategies resembled patterns selected by one group or the other, the respective group had different EMG activations between the trained and self selected strategies. The kinematics of the two strategies, trained and self selected, were very similar but why were the activations different? It is recommended that this data be further examined.

Additionally the adjustment of lifting strategy in the presence of biofeedback is good, but the goal of creating a training method to reduce injury risk would need to have sustained effects on the lifting strategy. It is therefore recommended that training methods be further explored.

The duration and frequency of training should be examined to better understand the requirements of a training regimen to reduce risk on injury.

Limitations and Future Work

There are a few limitations resulting from this project. Regarding the lifting studies, the measure for controlling the various lifting strategies required the determination of the individual subject's lumbar ROM. This process utilized a static posture where the subjects had to reach the limits and hold the position momentarily. This method is believed to have resulted in a smaller lumbar range of motion as the subject would remain in a posture that could be held without uncomfortable sensation. The dynamic nature of the task demonstrated that the ROM extended beyond the measured static posture as the normalized lumbar angles reached beyond 100% during the collection. While it is possible the ROM changes during the lifting trials, when the ROM of a small subset of subjects was examined following the task, there was effectively no change in the ROM. Another limitation included the biofeedback program. The introduction to the visual biofeedback program following the self selected lifting strategy altered the sensory systems involved in a subject's control feedback. This could have led to patterns that are different than those that might occur without the additional distraction of biofeedback. Finally, the definition of lifters for this work has been related to individuals with experience lifting weights, however, there are several categorizations for lifting experience in the literature including months to years in a manual materials handling occupation. The results in these studies may not be directly comparable to studies with different definitions of experience.

Future work should examine parameters that could contribute to a training program that could alter lifting posture in the absence of continued feedback. This study demonstrated that the biofeedback could alter the lifting strategy, but no observations were made in the absence of feedback. It would be necessary to determine the appropriate duration of training as well as frequency of training necessary to have sustained alterations to lifting behavior.

Future work should also address the design of a task to measure differences resulting from vibration exposure in the occupational setting. Studies in the laboratory have observed differences from twenty minutes of whole body vibration remaining more than twenty minutes after the vibration exposure. However, this attempt to address limitations of the previous measurement task has demonstrated that further development is necessary before the task is ready to take to an industry setting. Perhaps simplifying the task to include the individual parts would prevent possible stretching resulting from the additional tasks that might be reducing the duration of possible effects. Additionally as the feedback condition was observed to be nearly significant during the linear task, it would might be better to incorporate an alternating protocol between the feedback conditions instead of a single block protocol.

In conclusion, this research has demonstrated that, unlike novice lifters, those with experience in lifting activities select a lumbar-pelvic coordination that is more neutral to their range of motion. While it is likely these experienced lifters choose such a strategy to avoid moving to the elastic region of spine motion and potential injury, the reason why novice lifters choose a more highly kyphotic strategy was not determined. It was speculated that there might be an energetic advantage but this was not supported in these studies. The research did find that subjects could be trained to follow a different lumbar-pelvic coordination strategy. Future research should continue this investigation by researching how to successfully implement the training methods developed here to help those with low back pain and those in manual materials handling occupations avoid future injury.

Appendix

A1:Repetitive Lift Study

Consent Form Repetitive Lifting Study

RESEARCH CONSENT FORM Energetics of Lifting Strategies Protocol # 13133

You are being asked to join a research study. You are being asked to take part in this study because you are a healthy volunteer without back pain and can easily complete the low exertion exercise desired. Your participation in this research study is voluntary and is not required. The main purpose of the study is to create new knowledge for the benefit of future patients and society in general. Research studies may or may not benefit the people who participate.

Research is voluntary, and you may change your mind at any time. There will be no penalty to you if you decide not to participate, or if you start the study and decide to stop early. Either way, you can still get medical care and services at the University of Kansas Medical Center (KUMC).

This consent form explains what you have to do if you are in the study. It also describes the possible risks and benefits. Please read the form carefully and ask as many questions as you need to before deciding about this research.

You can ask questions now or anytime during the study. The researchers will tell you if they receive any new information that might cause you to change your mind about participating.

This research study will take place at the University of Kansas Medical Center (KUMC) with Dr. Sara Wilson, Dr. Neena Sharma, or Timothy Craig as the researcher. About 60 people will be in the study at KUMC.

BACKGROUND

Low back pain (LBP) is common in the working population. LBP is associated with significant workers' compensation claims and medical costs. The National Institute for Occupational Safety and Health has identified an association between such LBP and related low back disorders and a number of working conditions, including heavy physical work, lifting and forceful movements, awkward bending and twisting postures. In particular, repetitive lifting, flexed (forward bent) postures, and lifting heavy loads have been identified as risk factors of LBP.

It is possible that the risk of injury due to repetitive lifting and flexed postures could be reduced if the lifting technique were altered. Individuals with lifting experience (numerous repetitions of lifting through *a sport, work,* etc.*) have the same rotational forces applied to the trunk as non-experienced lifters, but they bend their lower back less during a lifting task. In a preliminary study in our laboratory, inexperienced (novice) lifters were found to show bending in the lower back that reached the limits of the subjects' range of motion of the joints in the lower back. It is therefore worth investigating whether training good lifting techniques to avoid extreme bending of the lower back during lifting results in less risk for injury. It is also worth investigating why inexperienced lifters might select such a risky technique during lifting.*

PURPOSE

By doing this study, researchers hope to compare any differences in selected lifting techniques between novice and experienced lifters. The researchers believe that energy expenditure will vary between the groups. Researchers believe that the strategies used by the experienced group will use more energy, but these strategies are less likely to result in injury. This information could then be used to create training programs to prevent back injuries.

PROCEDURES

If you are eligible and decide to participate in this study, your participation will last approximately 2.5 hours over a single visit. Your participation will involve completing this consent form and an exclusionary questionnaire. The exclusionary questionnaire will remove volunteers that may be at increased risk for injury should they participate in the study. Then you will be fitted with a number of sensors including EMG and electromagnetic positions sensors. This will require you to change into suitable attire (loose shirt with open back and pants/shorts that do not fit tightly at the waist) which may be provided by the researcher if necessary. Loose clothing will allow the sensors to be taped to your skin at the desired locations. These locations include along the spine and over muscles of the abdomen and back. These data collection systems will collect muscle activation and the location and orientation of bony spine segments. Additionally, a VO2 system will be used to perform an analysis of the gas composition exhaled from breathing. This is accomplished by wearing a special mask that covers your mouth and nose. You will be asked to complete a single lift of maximal effort to determine the appropriate weight to be used during the study, which will be less than 30% of your maximal effort. Additionally we will measure the maximal effort of your muscle contraction you are stationary. In order to contract the desired muscle groups, you will be asked to do a motion similar to performing a sit up and a back extension.

You will complete a lifting task where you will lift a weight from the floor to your waist, taking 2 seconds for the movement. You will pause for 2 seconds before you lower the weight to the floor. After pausing for 2 seconds with the weight at the floor height, you will repeat this lifting task continuously while data will be collected. You will be given about 10 minutes to rest before continuing. You will then be trained in a lifting strategy using a visual display created from the sensors positioned along your spine. This display will be a movable height bar that you will attempt to match to a set target height bar. Once you are comfortable with the lifting strategy you will complete about 5 minutes of the lifting task with this strategy followed by about 10 minutes of rest. You will repeat this cycle of lifting task, rest, and training until your self-selected lifting strategy and all three trained lifting strategies are completed. The order that you will complete the lifting strategies will be randomly determined using an Excel program. After completing the lifting tasks, your sensors will be removed, and final paperwork will be completed.

RISKS

There is minimal risk during the experiment, but you are being asked to perform brief maximum exertions a few times at the beginning of the experiment. Performing maximum exertions may result in tiring your muscles. Additionally you will be performing a repeated lifting task that may result in muscle soreness depending on your physical fitness level. You will be supervised during the study procedures to minimize potential risk of injury while participating in this study.

You might be embarrassed by some of the questions the researchers ask you. You are free not to answer any questions. These questions are designed to make the researcher aware of possible concerns with completion of the required physical exertion.

There may be other risks of the study that are not yet known.

NEW FINDINGS STATEMENT

You will be told about anything new that might change your decision to be in this study. You may be asked to sign a new consent form if this occurs.

BENEFITS

You will not directly benefit from this study.

Researchers hope that the information from this research study may be useful in better understanding factors that may contribute to low back injuries. With better understanding, training programs may be created to decrease back injuries in the future.

ALTERNATIVES

Participation in this study is voluntary. Deciding not to participate will have no effect on the care or services you receive at the University of Kansas Medical Center.

COSTS

There is no cost for being in the study.

Appendix

PAYMENT TO SUBJECTS

You will be reimbursed $25 for your time participating in this experiment. The researchers will submit payment information on the first business day of the month, and you will receive a check once payments are processed through KU Center for Research.

The KU Center for Research will be given your name, address, social security number, visa information (if applicable) and the title of this study to allow them to write checks for your study payments. Study payments are taxable income. A Form 1099 will be sent to you and to the Internal Revenue Service if your payments are $600 or more in a calendar year.

IN THE EVENT OF INJURY

We anticipate no side effects or bodily harm, but it is always possible. If you have a serious side effect and medical assistance is necessary call 911 or your local emergency department. For other problems related to this study, you should immediately contact Dr. Sara Wilson at 785-864-2103.

If you have a bodily injury as a result of participating in this study, treatment will be provided for you at the usual charge. Treatment may include first aid, emergency care and follow-up care, as needed. Claims will be submitted to your health insurance policy, your government program, or other third party, but you will be billed for the costs that are not covered by the insurance. You do not give up any legal rights by signing this form.

INSTITUTIONAL DISCLAIMER STATEMENT

If you think you have been harmed as a result of participating in research at the University of Kansas Medical Center (KUMC), you should contact the Director, Human Research Protection Program, Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160. Under certain conditions, Kansas state law or the Kansas Tort Claims Act may allow for payment to persons who are injured in research at KUMC.

CONFIDENTIALITY AND PRIVACY AUTHORIZATION

The researchers will protect your information, as required by law. Absolute confidentiality cannot be guaranteed because persons outside the study team may need to look at your study records. The researchers may publish the results of the study. If they do, they will only discuss group results. Your name will not be used in any publication or presentation about the study.

Appendix

Your health information is protected by a federal privacy law called HIPAA. By signing this consent form, you are giving permission for KUMC to use and share your health information. If you decide not to sign the form, you cannot be in the study.

The researchers will only use and share information that is needed for the study. To do the study, they will collect health information from the study inclusion questionnaire. You may be identified by participant number. Your health information will be used at KU Medical Center by Dr. Neena Sharma and members of the research team, thee KUMC Human Subjects Committee and other committees and offices that review and monitor research studies.

Dr. Sharma and her team will share information about you with collaborators Dr. Sara Wilson and Timothy Craig on the KU-Lawrence campus, KU Center for Research Lawrence, and U.S. agencies that oversee human research, if a regulatory review takes place. Some of the persons or groups that receive your study information may not be required to comply with HIPAA privacy laws. Your information may lose its federal protection if those persons or groups disclose it.

Your permission to use and share your health information remains in effect until the study is complete and the results are analyzed. After that time, researchers will remove personal information from study records.

QUESTIONS

Before you sign this form, Dr. Sara Wilson or other members of the study team should answer all your questions. You can talk to the researchers if you have any more questions, suggestions, concerns or complaints after signing this form. If you have any questions about your rights as a research subject, or if you want to talk with someone who is not involved in the study, you may call the Human Subjects Committee at (913) 588-1240. You may also write the Human Subjects Committee at Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160.

SUBJECT RIGHTS AND WITHDRAWAL FROM THE STUDY

You may stop being in the study at any time. Your decision to stop will not prevent you from getting treatment or services at KUMC. The entire study may be discontinued for any reason without your consent by the investigator conducting the study.

You have the right to cancel your permission for researchers to use your health information. If you want to cancel your permission, please write to Dr. Sara Wilson. The mailing address is Dr. Sara Wilson, Mechanical Engineering, 3013 Learned Hall
1532 W. 15th St., University of Kansas, Lawrence, KS 66045. If you cancel permission to use your health information, you will be withdrawn from the study. The research team will stop

collecting any additional information about you. The research team may use and share information that was gathered before they received your cancellation.

CONSENT

Dr. Sara Wilson or the research team has given you information about this research study. They have explained what will be done and how long it will take. They explained any inconvenience, discomfort or risks that may be experienced during this study.

By signing this form, you say that you freely and voluntarily consent to participate in this research study. You have read the information and had your questions answered.
You will be given a signed copy of the consent form to keep for your records.

____
Print Participant's Name

____ _____________
Signature of Participant Time Date

____
Print Name of Person Obtaining Consent

_____________________________________ _____________
Signature of Person Obtaining Consent Date

Appendix

Exclusionary Questionnaire

Subject Number: ____
Age: ____
Height: ____
Weight: ____

Do you have any history of cardiovascular (heart) disease?

Have you ever had any of the following (circle any that you have experienced)?

Prolapsed Heart Valve
Heart Murmur
Myocardial Infarction (heart attack)
Angiography
Chest Pain
Hypertension (high blood pressure)
Shortness of Breath on Exertion
Pulmonary (lung) Disease
Dizziness on Light Exertion
Claudication (pain in arms and legs during light exertion)
Diabetes
Fainting
Seizures

Are you on any current medications? If yes, what?

Have you ever had pain in your low back for more than one week?

Have you had any instances of low back pain within the last year? If yes, describe.

Do you currently have any musculoskeletal injuries (sprains, broken bones, sore muscles…)? If yes, describe.

How long has it been since you have eaten your last meal?

The equipment will be shown and discussed how it will be connected during the study. You will be asked: Will you feel comfortable enough to participate in the experiment?

Appendix

Recruitment Flyer

Opportunity to participate in a biomechanics research study.

The Human Motion Control Research Lab (Dept. of Mechanical Engineering, KU) is conducting a study assessing light weight lifting strategies. We are currently seeking participants. The experiment will be at KU Medical Center, take ~2.5 hours and subjects will be compensated for their time.

If you have questions or would like to participate please contact Alice Riley at a645r571@ku.edu or call 785-864-3913.

Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu	Biomechanics Study a645r571@ku.edu

Appendix

A2: Sway Study

Consent Form

THE EFFECTS OF OCCUPATIONAL WHOLE-BODY VIBRATION ON POSTURAL CONTROL TASKS

INTRODUCTION

The Department of Mechanical Engineering at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time without penalty. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

We are interested in evaluating the ability to sense posture and velocity of the human spine, specifically in the lumbar region. We speculate that after exposure to vibrations such as in a vehicle, this ability is altered for a short time. By understanding these chances, we hope to be able to make recommendations that can be used to prevent low back injury in construction and other vehicle drivers.

PROCEDURES

If you choose to participate, we will first give you a health questionnaire to make sure you do not have any musculoskeletal or general health conditions that would make this study difficult for you.

We may choose to use electrogoniometer, electromyographic, and/or electromagnetic markers, to record your movements. These devices are commonly used in biomechanics research and all involve attaching sensors to your skin that detect motion and muscle activity.

You will be asked to sit on a platform that measures how your weight shifts in space over time. We will ask you to perform various tasks in front of a computer monitor. You will use your body similar to a joystick to control a specific curser on the screen. You will have **three** tasks. In one task you will sit quietly with your arms folded across your chest and breathing normally. In another task you will try to control a cursor by tilting your trunk and using that cursor to follow a prescribed motion. Lastly, you will try to replicate the movements of the target cursor with your trunk while your cursor is invisible. The tasks will be presented in multiple blocks of 20 seconds each. These tasks will be performed prior to receiving vibration and following 20 minutes of vibration. The vibration will be created by a shaker table vibrating the platform as you sit on it. The vibration you experience will be comparable to what you would feel while riding in a car on a bumpy road.

Appendix

Your participation is strictly voluntary and you can stop at anytime. We assure that your name will not be associated in any way with the research findings. This protocol will take approximately 1 hour to complete.

RISKS

Truckers and similar workers who are exposed to vibrations all day in their trucks are known to experience higher rates of back injuries (about 2 or 3 times other workers). We believe that these increased risks are due to how the vibration alters back motion making lifting and other manual handling tasks less controlled. Following this experiment we will request you to limit strenuous activity for 20 minutes after the vibration to minimize these risks. Some people have allergies to adhesives such as in band-aids or in the tape we are using to attach the markers. In rare cases, some subjects may experience dizziness or motion sickness after extended vibration. If you feel dizzy or motion sick, please inform the investigator so he/she can stop the vibration.

If you would like additional information concerning this research before or after it is complete, please feel free to contact Dr. Sara Wilson by phone (785-864-2103) or mail (3138, Learned Hall, sewilson@ku.edu). If you have any concerns or questions about your rights as a research participant you may contact the University of Kansas' Human Subjects Committee – Lawrence (HSC-L) at (785) 864-7429, Youngberg Hall or by email to David Hann at dhann@ku.edu.

BENEFITS

With this research we hope to better understand how the vibration affects the muscular and nervous system of the body and how a person changes how they move after vibration will tell us something about why these workers get injured more often. There is, however, no direct benefit for the subject of this study.

PAYMENT TO PARTICIPANTS

Subjects will receive compensation of $10 per hour (rounded up to the nearest half hour) for participation in the study. In order to receive payment we will need your social security number and visa status. This information may be shared with IRS if amounts of payment for all studies at KU exceed $600.

INFORMATION TO BE COLLECTED

To perform this study, researchers will collect information about you. This information will be obtained from a questionnaire that will assess if you have health problems that might make the activity previously described inadvisable.   Also, information will be collected from the study activities that are listed in the Procedures section of this consent form. This includes information about your age, height, and your weight.

Your name will not be associated in any way with the information collected about you or with the research findings from this study. The researcher will use a subject number instead of names.

Appendix

Some persons or groups that receive your information may not be required to comply with the Health Insurance Portability and Accountability Act's privacy regulations, and your information may lose this federal protection if those persons or groups disclose it.

The researchers will not share information about you with anyone not specified above unless required by law or unless you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

INSTITUTIONAL DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose information collected about you, in writing, at any time, by sending your written request to: Dr. Sara Wilson, Mechanical Engineering, University of Kansas, Lawrence, KS 66045. If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study and the use and disclosure of information about me for the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email dhann@ku.edu.

Appendix

I agree to take part in this study as a research participant. I further agree to the uses and disclosures of my information as described above. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_________________________________ ____________________ Type/Print

Participant's Name Date

____ _____________________

Social Security Number Visa Status

____

Participant's Signature

Researcher Contact Information

Sara E. Wilson

Principal Investigator

Mechanical Engineering

3013 Learned Hall, University of Kansas

Lawrence, KS 66045. Phone: (785) 864-2103

Appendix

Recruitment Flyer

Opportunity to participate in a biomechanics research study.

The Human Motion Control Research Lab (Dept. of Mechanical Engineering, KU) is conducting a study assessing light weight lifting strategies. We are currently seeking participants. The experiment will take 2-3 hours and subjects will be compensated for their time ($30).

If you have questions or would like to participate please contact Tim Craig at pluto@ku.edu, or call 785-864-3913, or stop by room 1111 in Learned Hall for more details.

Biomechanics Study	Call: 864-3913	Email: pluto@ku.edu
Biomechanics Study	Call: 864-3913	Email: pluto@ku.edu
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Biomechanics Study	Call: 864-3913	Email: pluto@ku.edu
Biomechanics Study	Call: 864-3913	Email: pluto@ku.edu

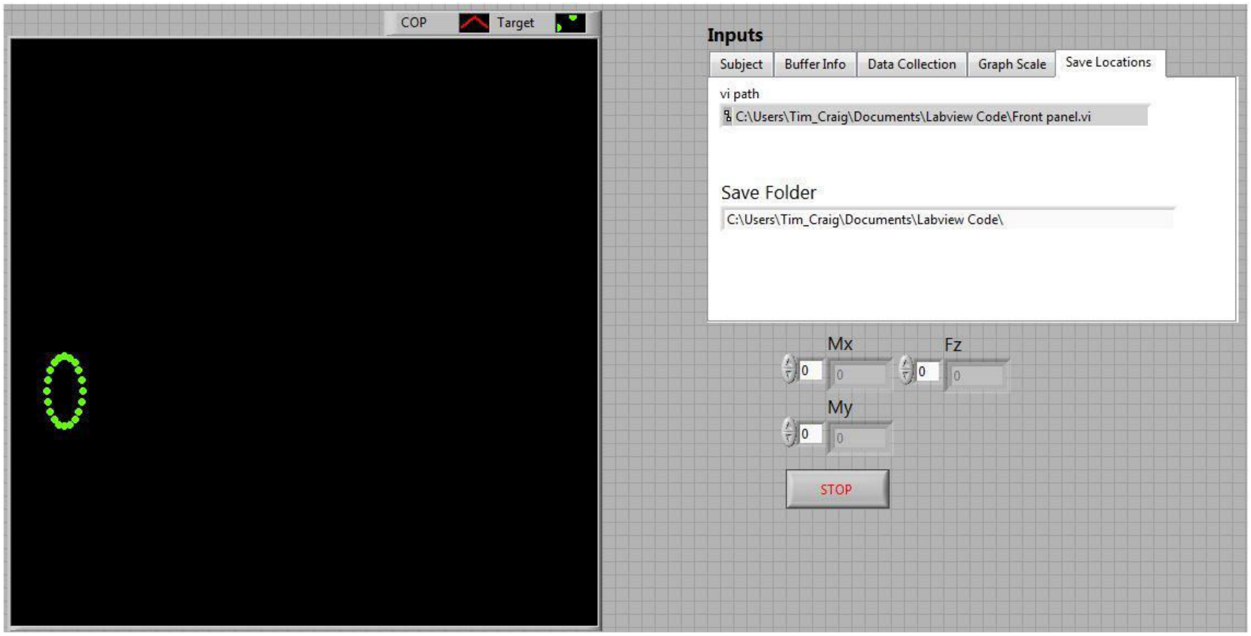
Appendix

A3: Labview Programs

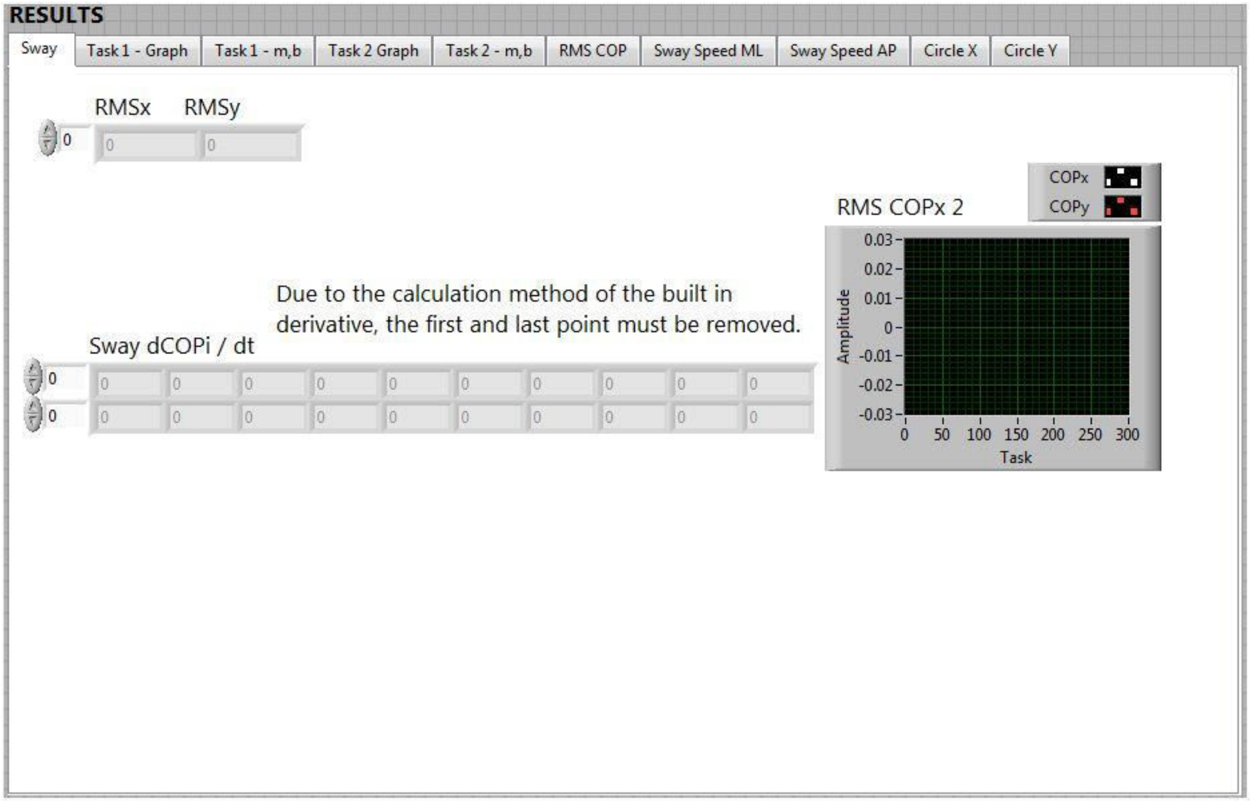
Repetitive Lifting Study

Sway Study

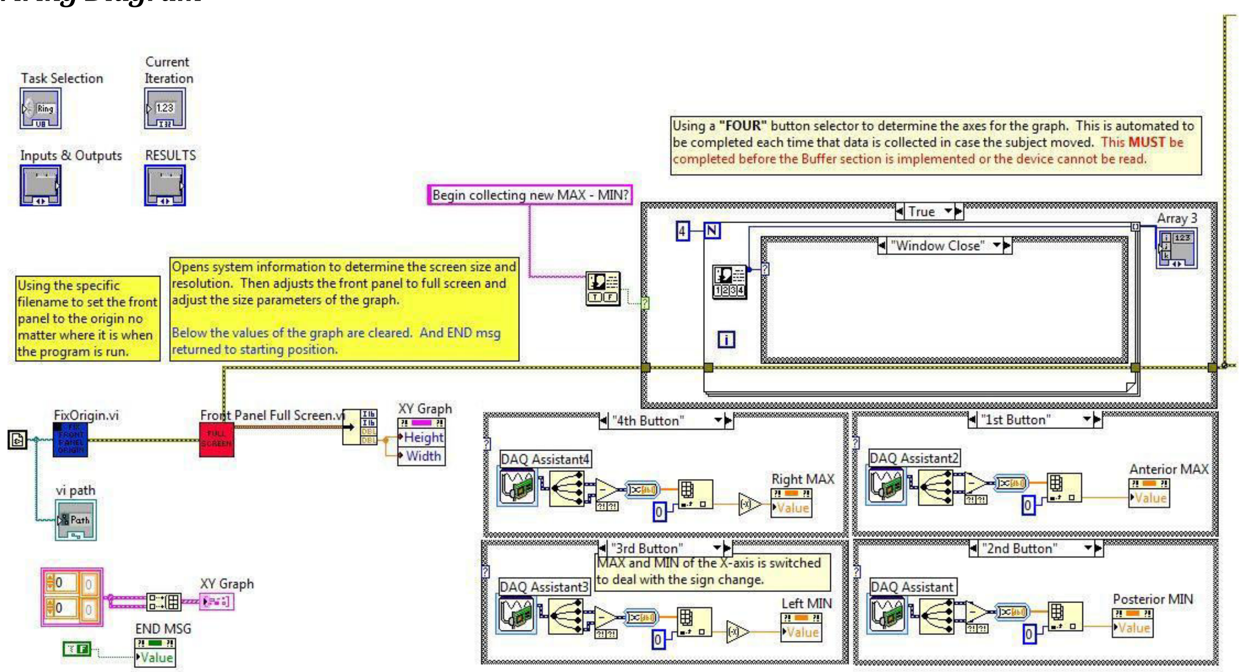
Front Panel



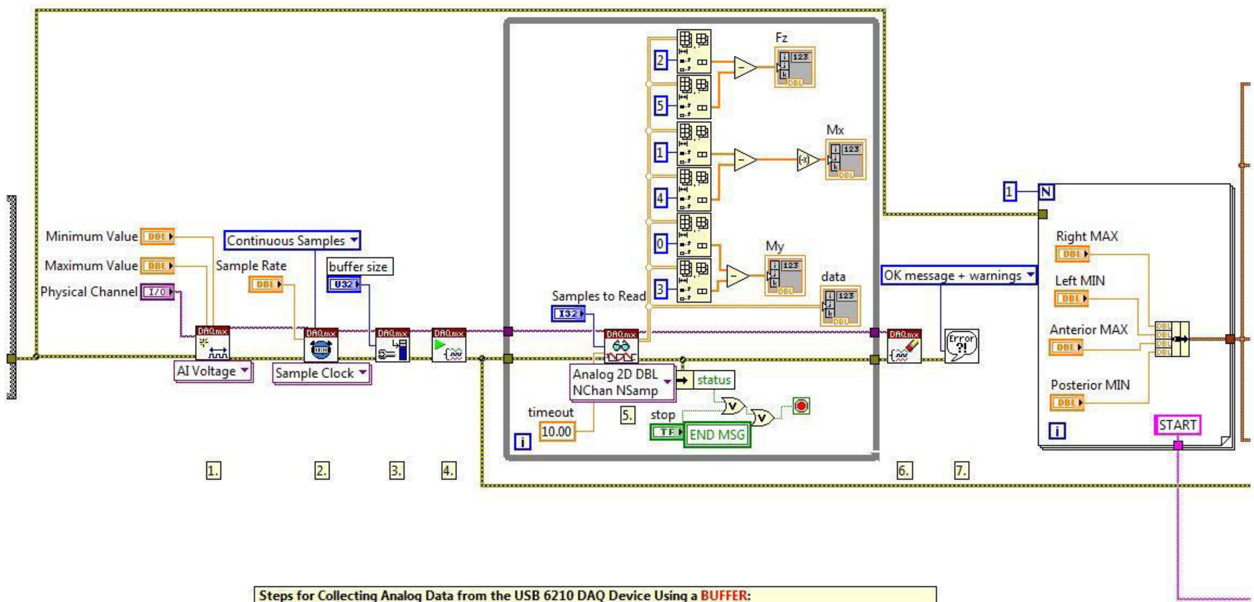
Appendix



Wiring Diagram



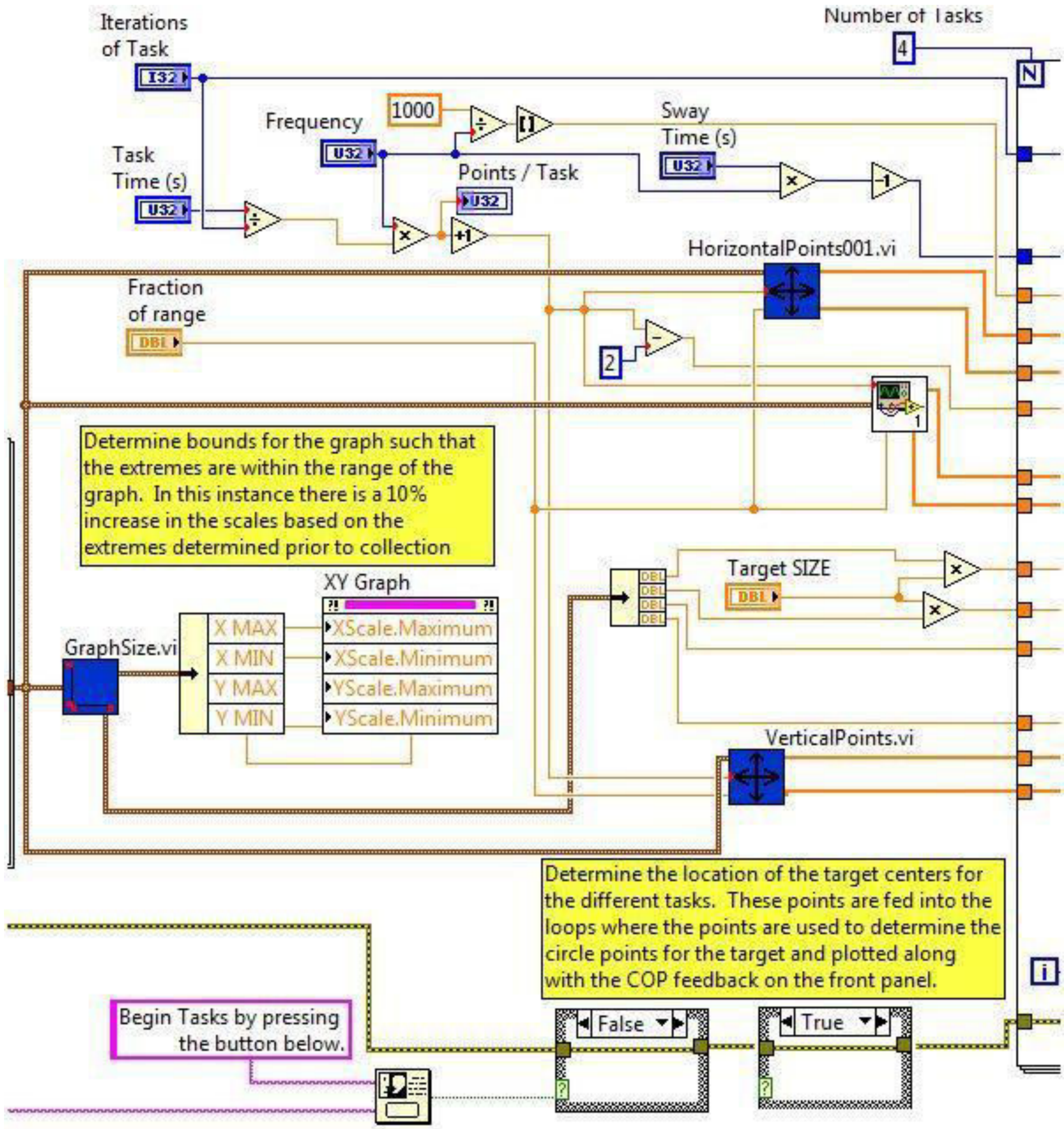
Appendix



Steps for Collecting Analog Data from the USB 6210 DAQ Device Using a BUFFER:
1. Create an analog input voltage channel.
2. Set the rate for the sample clock. Additionally, define the sample mode to be continuous.
3. Set the Input Buffer size.
4. Call the Start VI to start the acquisition.
5. Read the waveform data in a loop until the user hits the stop button or an error occurs.
6. Call the Clear Task VI to clear the Task.
7. Use the popup dialog box to display an error if any.

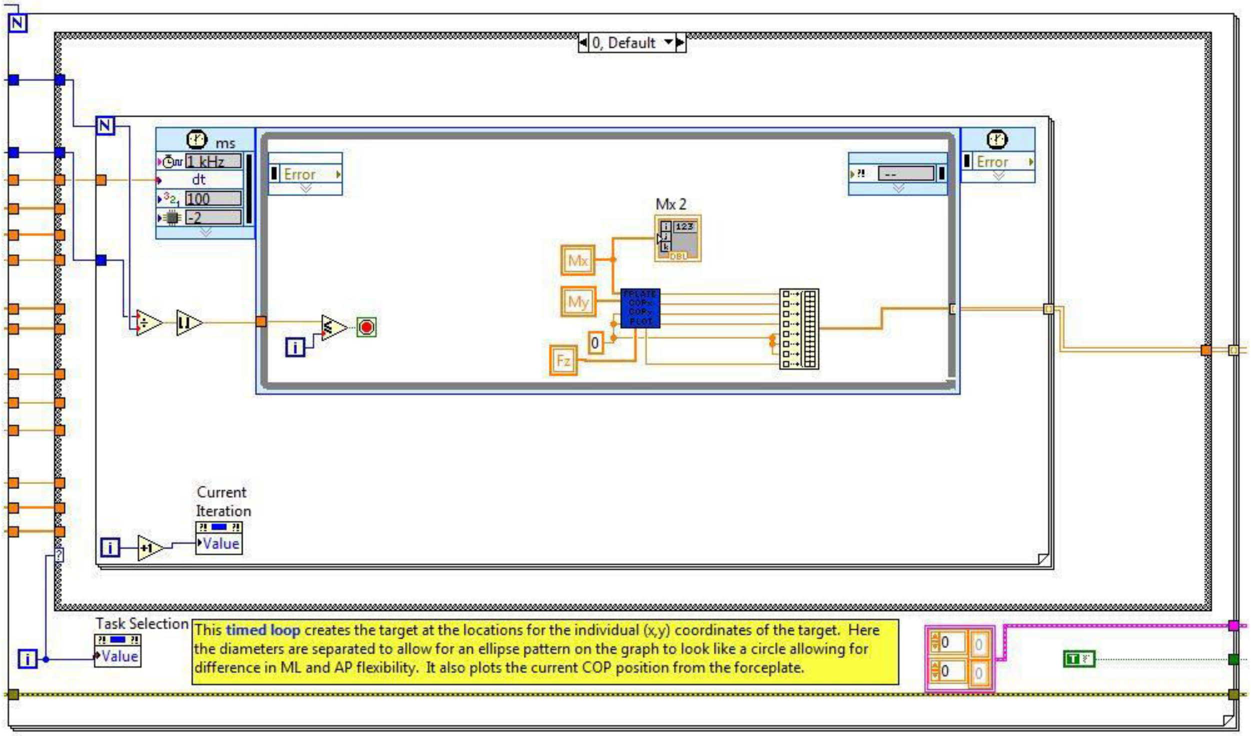
NOTE: Use stop button or the device will not close & possibly lead to memory issues and Labview CRASHING!

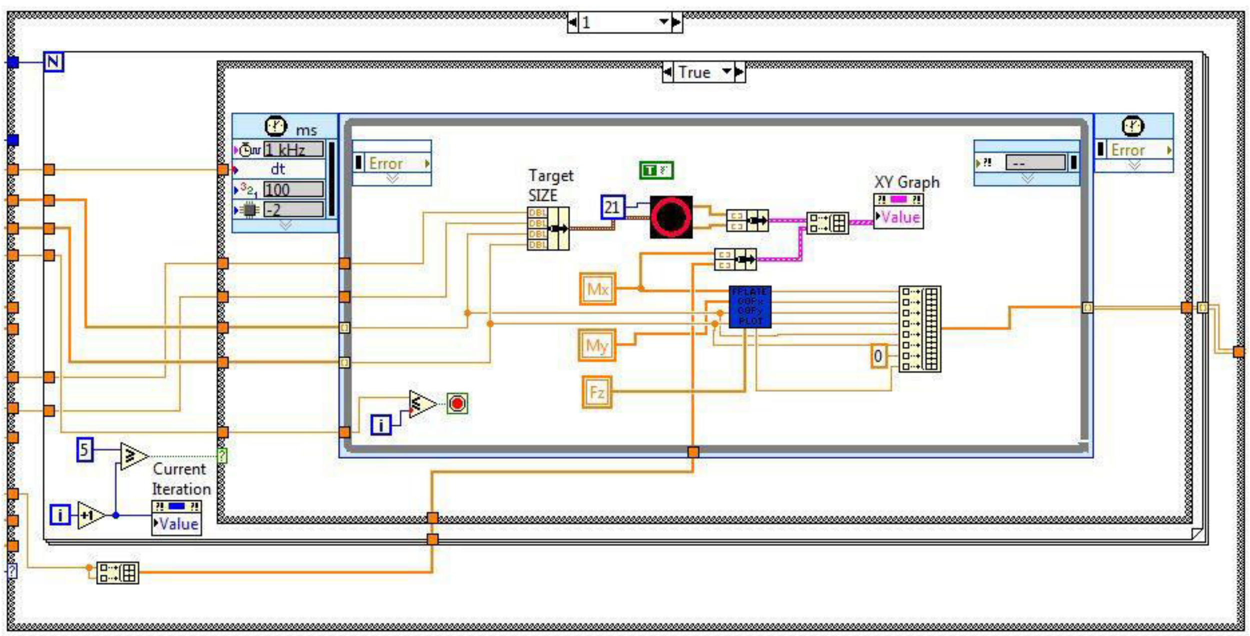
Appendix



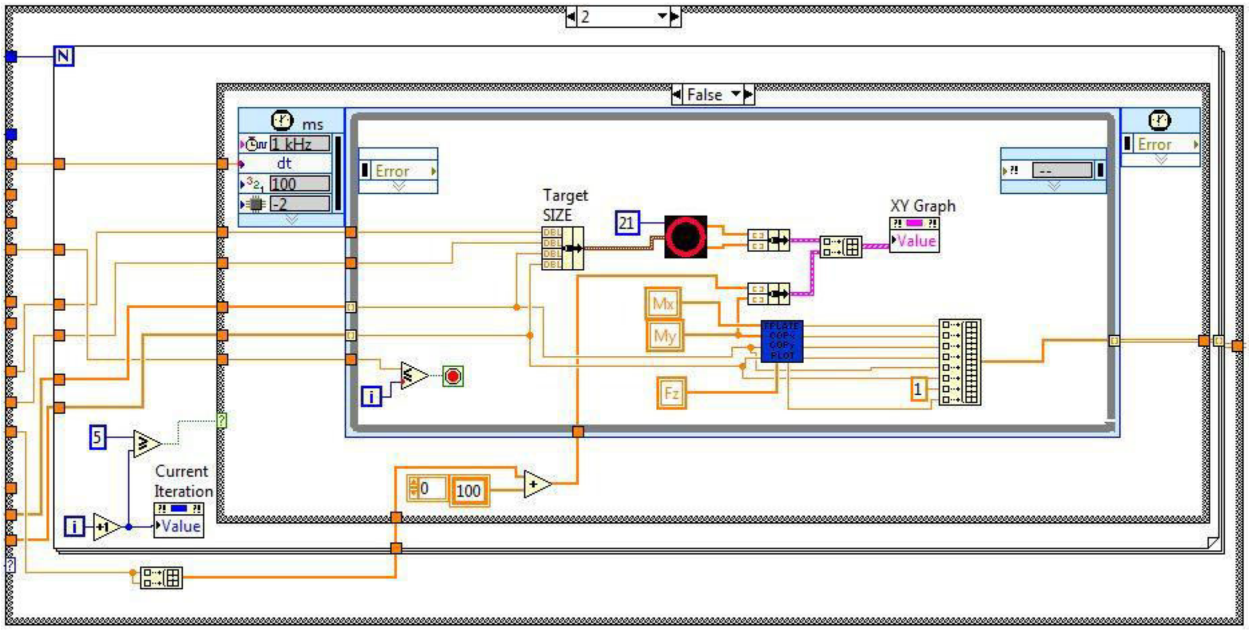
Iterations of Task
Number of Tasks
Frequency
1000
Sway Time (s)
Task Time (s)
Points / Task
HorizontalPoints001.vi
Fraction of range
Determine bounds for the graph such that the extremes are within the range of the graph. In this instance there is a 10% increase in the scales based on the extremes determined prior to collection
XY Graph
Target SIZE
GraphSize.vi
X MAX
X MIN
Y MAX
Y MIN
XScale.Maximum
XScale.Minimum
YScale.Maximum
YScale.Minimum
VerticalPoints.vi
Determine the location of the target centers for the different tasks. These points are fed into the loops where the points are used to determine the circle points for the target and plotted along with the COP feedback on the front panel.
Begin Tasks by pressing the button below.
False
True

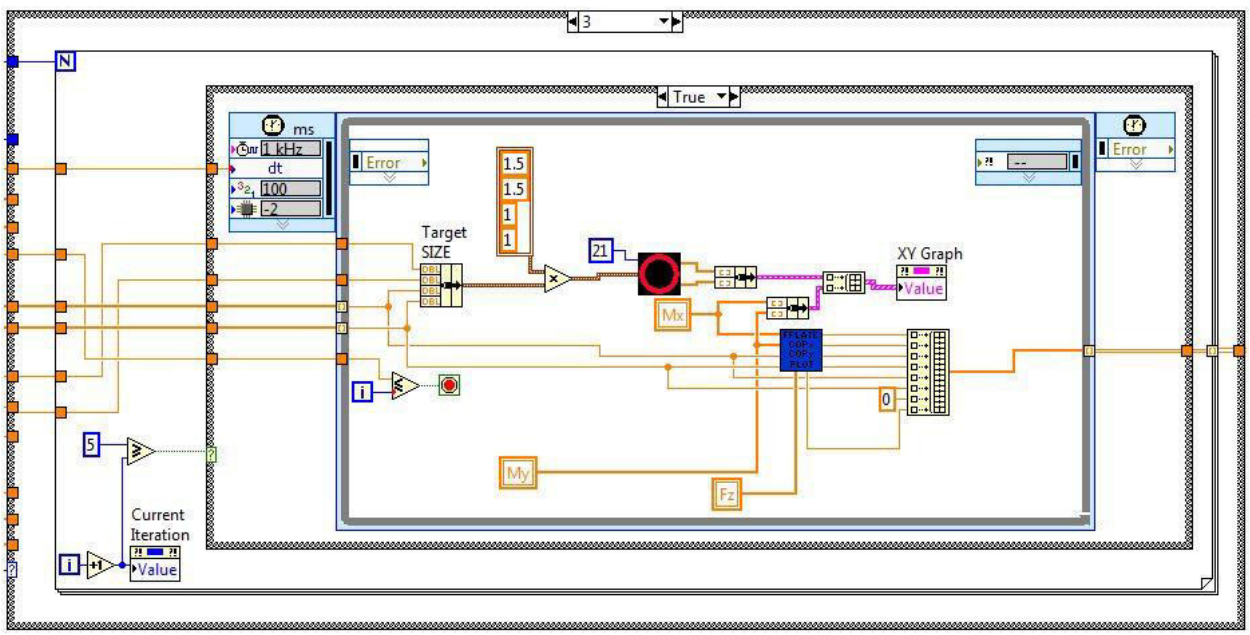
Appendix


0, Default
ms
1 kHz
dt
100
-2
Error
Mx 2
Mx
My
Fz
0
Current
Iteration
Value
Task Selection
Value
This timed loop creates the target at the locations for the individual (x,y) coordinates of the target. Here the diameters are separated to allow for an ellipse pattern on the graph to look like a circle allowing for difference in ML and AP flexibility. It also plots the current COP position from the forceplate.

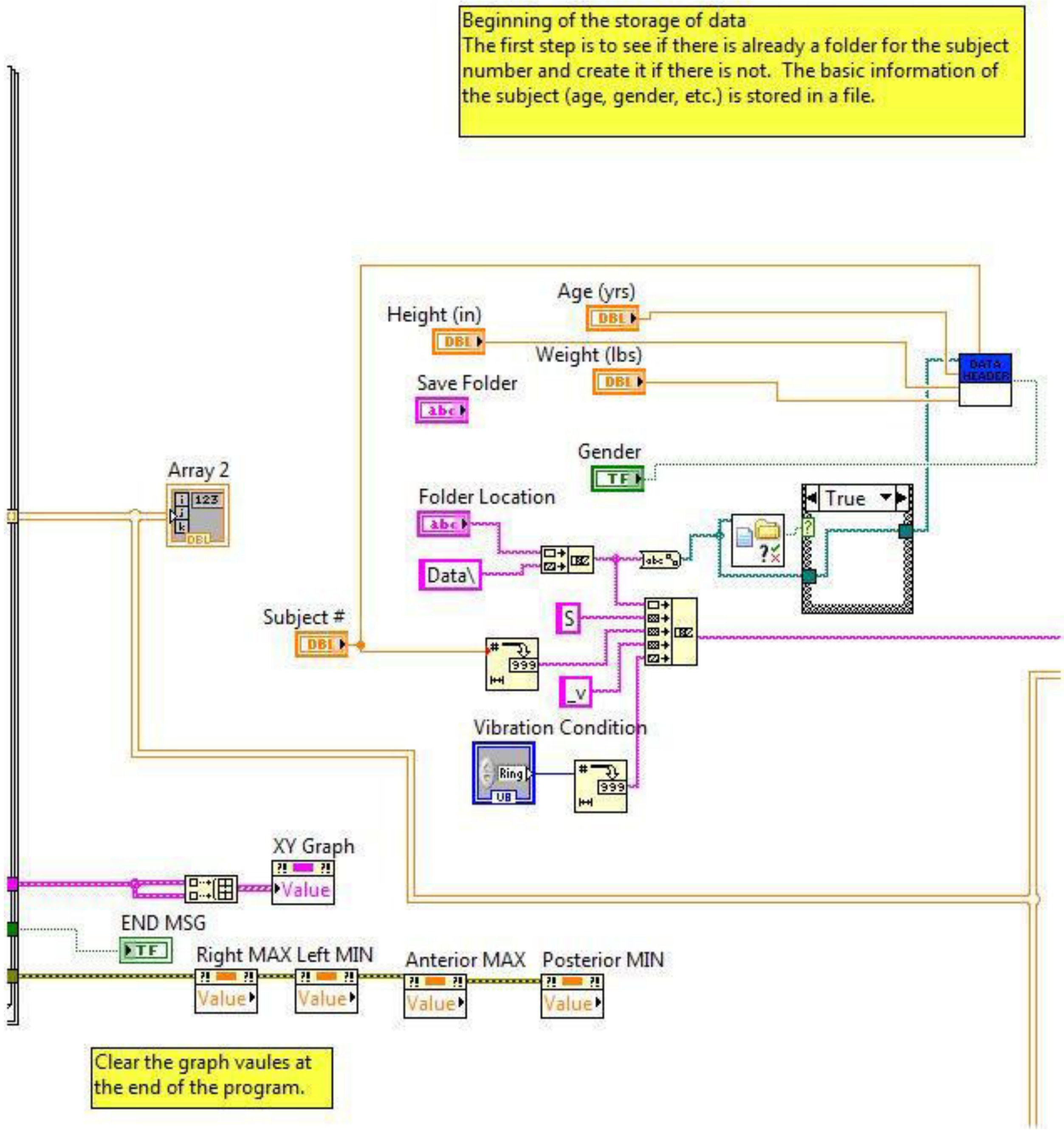

1
True
ms
1 kHz
dt
100
-2
Error
Target
SIZE
21
XY Graph
Value
Mx
My
Fz
0
5
Current
Iteration
Value

Appendix


2
N
False
ms
1 kHz
dt
100
-2
Error
Target
SIZE
21
XY Graph
Value
Mx
My
Fz
1
5
Current
Iteration
Value
0
100


3
N
True
ms
1 kHz
dt
100
-2
Error
1.5
1.5
1
1
Target
SIZE
21
XY Graph
Value
Mx
My
Fz
0
5
Current
Iteration
Value

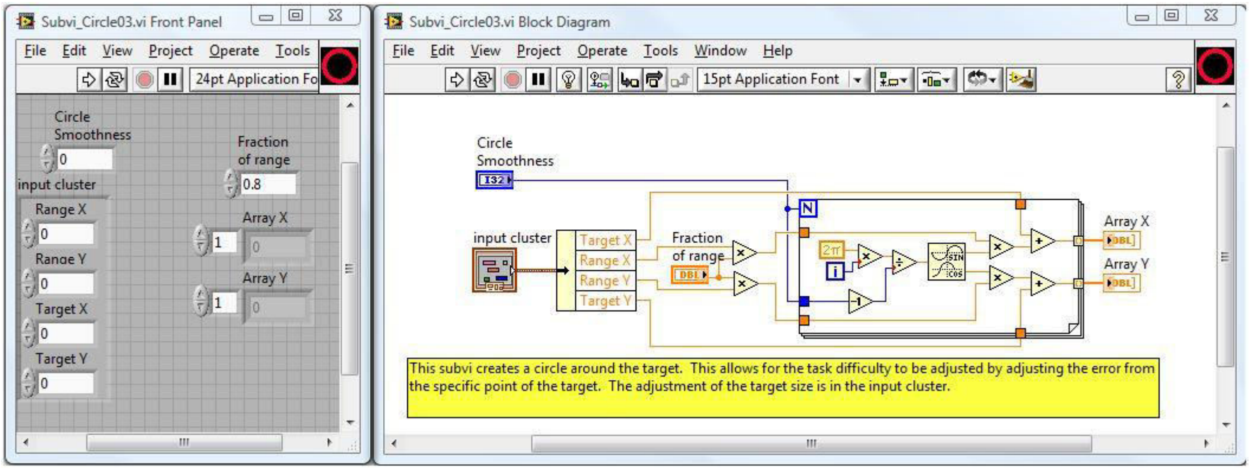
Appendix

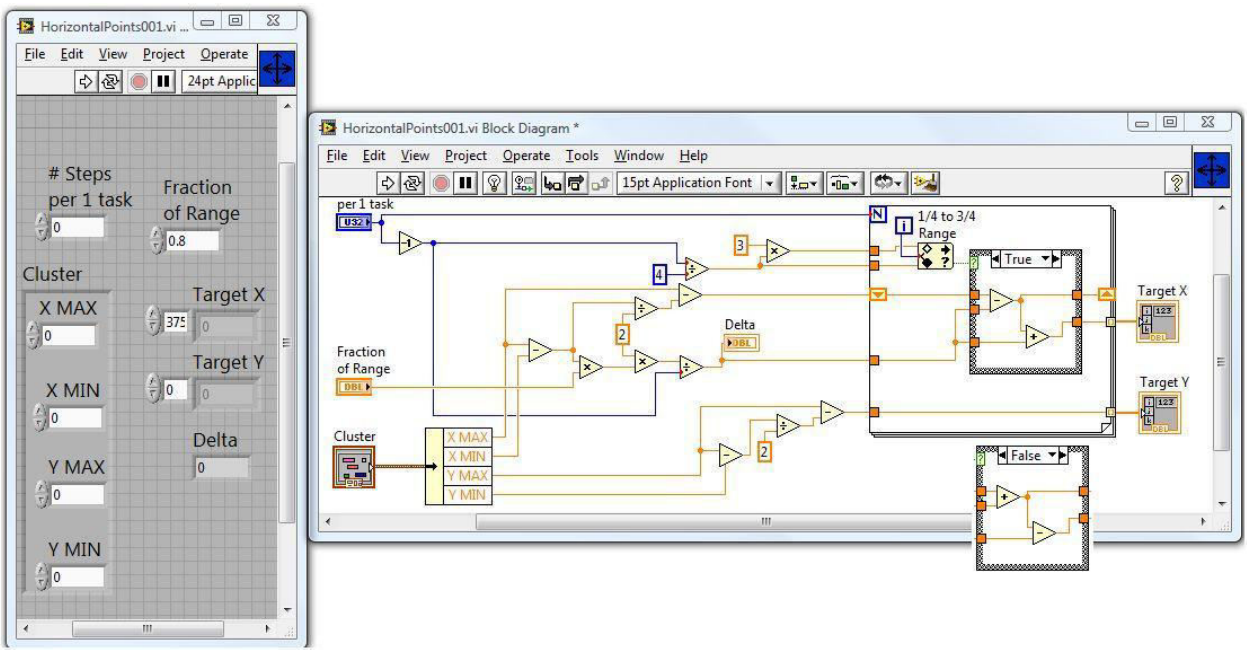


Beginning of the storage of data
The first step is to see if there is already a folder for the subject number and create it if there is not. The basic information of the subject (age, gender, etc.) is stored in a file.
Age (yrs)
Height (in)
Weight (lbs)
Save Folder
Gender
Array 2
Folder Location
True
Data\
S
Subject #
_v
Vibration Condition
Ring
XY Graph
Value
END MSG
Right MAX
Left MIN
Anterior MAX
Posterior MIN
Value
Value
Value
Value
Clear the graph vaules at the end of the program.

Appendix

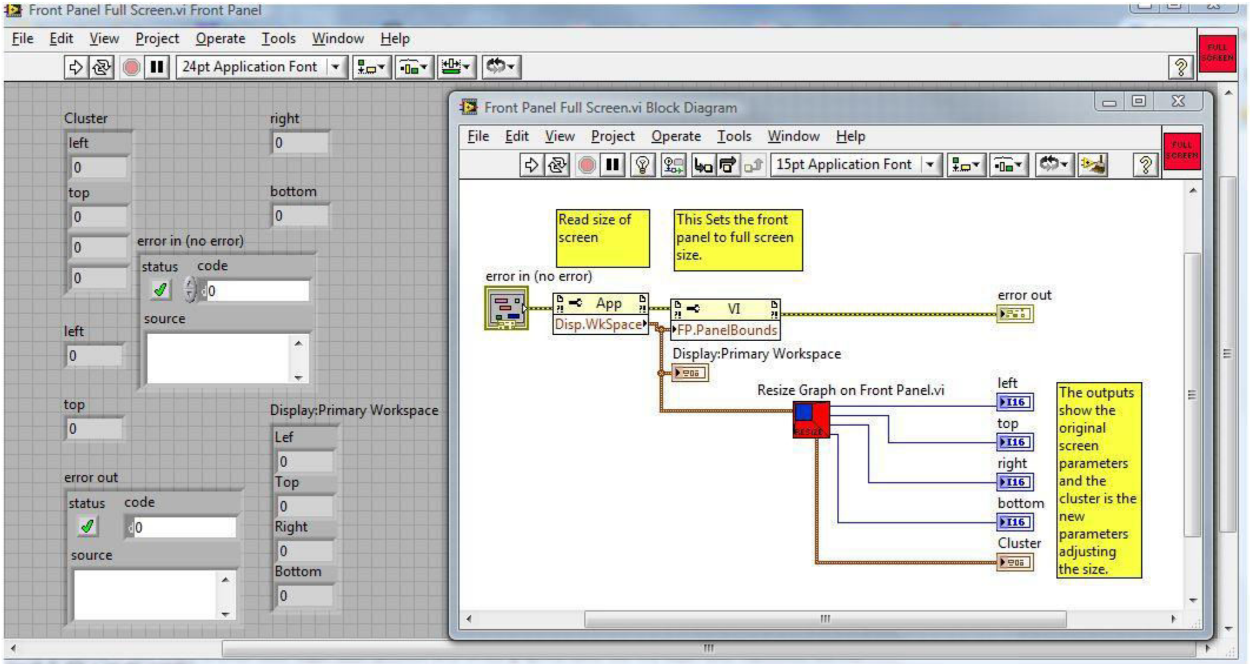
Target Creation Subroutines

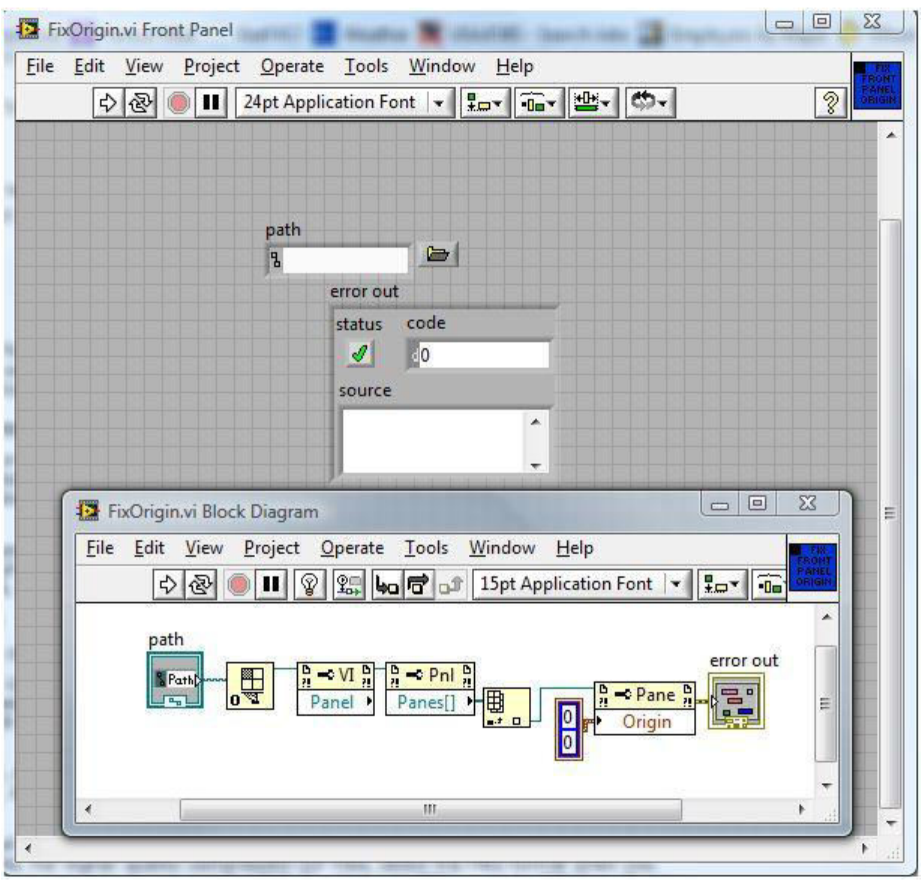




Appendix

Graph Full Screen





Appendix

Range of Motion Limits for Graph