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Spine Lifting Biomechanics Between Varying Occupational Activity Levels And Recreational Physical Activity Levels

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SPINE LIFTING BIOMECHANICS BETWEEN VARYING OCCUPATIONAL ACTIVITY LEVELS AND RECREATIONAL PHYSICAL ACTIVITY LEVELS

A Thesis
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The University of Mississippi

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ABSTRACT

Background: Moderate to vigorous physical activity as the optimum movement patterns for health have continued to be the dominant focus of health and fitness research. Yet, emerging evidence of deleterious, adverse health effects of prolonged inactivity, independent of regular physical activity, presents a new element to establishing the ideal model of movement patterns for health. The musculoskeletal trunk of the body becomes unbalanced as a result of prolonged inactivity, and a biomechanical analysis can help to identify high-risk loading behavior associated with these unbalances. Moreover, poor spine biomechanics can indicate a need for adjustment to present recommendations for optimum movement patterns. Some research of spine biomechanics associated with sedentary occupation or lifestyle exists. However, up to the author's knowledge, no research exists on sedentary lifestyle independent of recreational physical fitness in respect to spine biomechanics.

Purpose: The purpose of this study was to identify biomechanical patterns and significant differences in lifting biomechanics among individuals who are occupationally inactive and active, as well as recreationally active and inactive.

Methods: Participants were divided into four groups using the Cambridge EPIC (European Prospective Investigation into Cancer and Nutrition)-Norfolk Physical Activity Questionnaire (EPAQ2): inactive, moderately inactive, moderately active, and active. A total of 23 participants completed the protocol. Spine kinematics of lifting was collected through VICON motion capture system. Additionally, ground reaction forces (GRF) and ground reaction moments

(GRM) were collected by forceplate. Kinematic dependent variables were calculated from joint angle curves of trunk segments; included was maximum angular displacement of the middle trunk and lower trunk. Kinetic dependent variables were calculated from the GRF and GRM data, including maximum anterior excursion, maximum anterior velocity, and sway area of the center of pressure (COP) trajectories. Difference of each dependent variable between groups was detected by 1-way ANOVA. When difference existed, post-hoc pair-wise comparisons were conducted and Bonferroni correction was applied to minimize family-wise errors. The significance level was set at $\alpha = 0.05$.

Hypothesis: Participants who maintain an inactive lifestyle, regardless of recreational physical activity, will exhibit significantly different lifting biomechanics when compared to the lifting biomechanics of an active population performing the same lifting tasks.

Results: Results indicated a statistically significant difference in flexion range of motion for the inactive group compared to all other groups ($p=0.014$). The inactive group had a significantly lower degree of flexion range of motion. Joint kinematic data indicated little difference between groups for the reaching phase and lift up phase of straight leg lifts. For bent leg lifts, the active population had significantly greater middle trunk flexion displacement during the reaching phase ($p=0.005$) and lifting phase ($p=0.023$) of bent leg lifts. No other significant differences existed between the other groups. Analysis of force platform data produced no significant differences between groups. Percent flexion range of motion was significantly different for the active population during the bent leg reaching phase and lifting phase compared with all other groups.

The active population used a much larger degree of their total flexion range of motion to reach and lift up the box from the ground.

Discussion: The current study aimed to investigate the effect of a largely inactive lifestyle, independent of regular participation in planned physical exercise, on spine kinematics, center of pressure, and range of motion. Results show evidence of a tendency for greater range of motion and greater flexion displacement of the active sample. Although not statistically significant, the inactive sample findings unexpectedly indicated a tendency for increased flexion displacement compared with the moderately active and moderately inactive groups. The moderately inactive group did not have any significant differences when compare to the moderately active group, which did not support the original hypothesis. However, the inactive group had poorer range of motion compared with all other groups, which supports the initial predictions. In summary, the inactive group presented some evidence of poor biomechanics. The active group showed signs of increased range of motion and flexibility. Finally, the moderately active and moderately inactive groups were very similar among all calculated variables. These findings support previous evidence of regular activity improving range of motion and flexibility. Occupational inactivity coupled with regular recreational activity appears to reduce the risk of developing poor lifting biomechanics.

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CHAPTER I: INTRODUCTION

BACKGROUND

The living and working environment in 21st century industrialized nations typically requires little physical movement over long durations of time. Changes in transportation, communication and entertainment have also increased the amount of time people spend sedentary. With a reduced demand for movement; the health implications of a less active lifestyle have gained attention and become the focus of an increasing body of research (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). Over the past 60 years, research into movement patterns to support physical health have emphasized moderate-to-vigorous physical activity -- particularly the frequency, intensity and duration of physical exercise an individual participates in. Only recently have researchers begun to investigate the importance of movement patterns outside of an individual is not participating in moderate-to-vigorous exercise (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). For instance, if an individual's occupation, travel, recreational and household activity is sedentary aside from a single workout, it is not currently known if the regular participation in a small amount of physical exercise is sufficient to offset the negative physical health effects from the other 23 hours a day spent relatively inactive.

Traditionally, sedentary referred to an individual who failed to meet the public health guidelines for physical activity. Rather in this new context, sedentary refers to an individual who is characterized by time spent engaged in sedentary behaviors, without regard to physical activity level (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). This new designation is supported by increasing evidence suggesting time sedentary and increased risk of morbidity is independent of an individual's level of physical activity (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). The definition now recognizes that it is possible for an individual to accumulate significant levels of both time sedentary and physical activity and remain a risk factor for overall health.

The existing research implicating sedentary lifestyle as an independent source of adverse health effects supports the need for further inquiry from various disciplines. The social, environmental and biological pathways which lead to sedentary behavior are different than physical activity (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). Additionally, the health effects associated with physical activity are a result of different biological mechanisms to that of sedentary activity (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). This notion is supported by recent evidence linking time spent inactive as an independent risk factor for detrimental and deleterious health effects spanning from metabolic dysfunction to cardiovascular, neurological, mental dysfunction and premature mortality (Tremblay, et al. 2010; Ekelund, et al. 2015; Owen, et al. 2010). Although sedentary lifestyle contributes to a higher risk of obesity, the association with premature all-cause mortality is generally higher based on activity level rather than body mass index (BMI) (Ekelund et al. 2015).

Independent of BMI, although visually less obvious, the body undergoes many structural changes as a result of a long term sedentary lifestyle. Reduced bone density and muscle strength are two important biomechanical changes caused by prolonged sedentary duration, and these musculoskeletal changes directly impact metabolic dysfunction (Ekelund, et al. 2015). A multidisciplinary approach to understanding the unique biological pathways of prolonged inactivity can form a better comprehensive understanding, which will then assist in treatment of the various, intertwining disorders.

Sedentary individuals experience varying degrees of reduction in bone density (Cann, e al., 1983; Globus, et al. 1984, Kim, et al. 2003; LeBlanc, et al. 2000). This phenomena has been well documented in both animals and humans (Cann, e al., 1983; Globus, et al. 1984, Kim, et al. 2003; LeBlanc, et al. 2000). Individuals post spinal cord injury exhibit significant bone density loss as well as those who are required long term bed rest. Zerwekh, et al., reported 1-4% reduction in bone mineral density in the lumbar spine of healthy men and women following 12 weeks of bed rest. The relationship between sedentary lifestyle and reduction in bone mass is likely mediated by changes that occur between the balance between bone deposition and resorption (Zarwekh, et al. 1998). The functional demand which is placed on the body causes this type of adaption and in turn results in changes in muscle structure as well.

Mammal skeletal muscles adapt to accommodate demand. Persistent changes in activity will alter cellular structure, volume and function of muscle fibers; demonstrating the plastic nature of skeletal muscle under different situations (Adams, Burton, & Bogduk, 2006; Nordin & Frankel, 2012). Situations can range from disuse owing to immobilization or high resistance exercises (Adams, Burton, & Bogduk, 2006; Nordin & Frankel, 2012). Efficient skeletal muscle functioning is permitted under the demands of these various situations.

As structural changes occur within the muscle and bone of the body, a muscle imbalance often occurs (Adams, Burton, & Bogduk, 2006; Nordin & Frankel, 2012). A muscular imbalance is defined as one side of opposing muscles become stronger than the other (Adams, Burton, & Bogduk, 2006; Nordin & Frankel, 2012). This is especially common in individuals who lead a sedentary lifestyle and over time can contribute to poor posture along with an increased risk for lower back pain (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Sitting involves a significant degree of spine flexion (Adams, Burton, & Bogduk, 2006). Although seated postures conserve energy and allow for workers to focus on a task, when held for a prolonged period the seated posture, especially in bad alignment, generates unexpected excessive loading; mainly on the lumbar spine region (Adams, Burton, & Bogduk, 2006; Owen, et al. 2010). The strain and compression of tissues through the lower back and buttocks could potentially be a source of pain for an individual (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Movement, flexion and extension, of the lumbar spine is regulated by a network of active and passive components which fashion a complex neuromuscular system (Nordin & Frankel, 2012). A neuromuscular imbalance of these tissues during load sharing can result in pain and disability (Nordin & Frankel, 2012).

Various muscles interact to produce hip flexion, this action being the motion of the thigh and trunk towards each other (Nordin & Frankel, 2012). The most paramount of these muscles is the iliopsoas, composed of both the iliacus and the psoas (Nordin & Frankel, 2012). When the hip is kept in a constant, flexed position, such as a seated position, these hip flexor muscles will shorten and shrink (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Shortened hip flexors will not allow for the hip to fully extend, or straighten (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Day after day, sitting for long periods, the lumbar region can become bowed by the shortened muscles (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

In the case that the primary hip flexors are at a disadvantage, the concomitant muscles compensate to support hip flexion (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). When in a seated position daily for long durations, in addition to the hip flexors tightening, the glutes weaken and hamstring muscle group becomes the primary hip extensor (Adams, Burton,

& Bogduk, 2006; White & Panjabi, 1990). The weakness in the gluteus maximus forces the hamstrings to compensate; they must perform more work than their design allows for (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). This synergistic dominance significantly increases risk of injury, such as low back pain (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

Along with increased muscle effort, the seated positon of the body causes the pelvis to rotate backward, reduces lumbar lordosis and trunk-thigh angle which increases vertebrae disc pressure (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). The ischial tuberosity bears upper body weight rather than it distributing along the arch of the spine (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). When erect, the intervertebral discs expand and contract encouraging uptake of fresh blood and nutrients; unlike when an individual is seated for an extended duration (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Furthermore, with the unevenly squished discs from the arched spine, a sedentary individual is at an increased risk for lumbar disc herniation (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

From structural changes alone, the risk for a variety of potential injuries to the lower back is considerably high. Although lower back pain is commonly observed in individuals which live a sedentary lifestyle, the exact cause of injury remains controversial. Existing literature clearly points to prolonged sitting as a major contributor to lower back pain, however conclusive evidence is lacking.

Although regular physical activity does not sufficiently counteract the metabolic and cardiovascular damage inflicted by a constant sedentary lifestyle, it may negate some of the adverse effects observed muscularly and structurally (Owen, et al. 2010). Back pain is more common among individuals who lack regular physical activity (Owen, et al. 2010). Physical activity is considered a strong preventative measure of lower back pain (Owen, et al. 2010). Several studies have recognized low-impact aerobic exercise as beneficial for maintaining the health and strength of intervertebral discs (Jensen, 1980; Yung, et al. 2005). Lower back pain management and prevention of a recurring injury is often managed through physical exercise (Owen, et al. 2010). Endurance of the body's core, or trunk, is required to maintain good spine health (White & Panjabi, 1990).

Some research of spine biomechanics associated with sedentary occupation or lifestyle exists. However, to the author's knowledge, no research exists on sedentary lifestyle independent of recreational physical fitness in respect to lumbar spine biomechanics. There is evidence which supports the preventative effects regular exercise has against lower back pain, however the deleterious effects to the muscle and structure within the body as a result of remaining sedentary for the majority of the day may not be reversed with regular exercise (Heneweer, 2009). The widely referred to guidelines for physical activity by the American Heart Association (AHA) recommends a total of 150 hours of exercise over 5 days per week in addition to 2 days which incorporate strength and conditioning as well (American Heart Association, 2015). Does meeting the AHA guidelines for physical activity, in a population which is otherwise sedentary, maintain the heath of the core, in particular the lumbar spine? The guidelines are not necessarily in question as much as the continued focus of a physical fitness regimen, in general, as the dominant health related aspect to human movement. By identifying biomechanical differences in sedentary individuals compared to active individuals this does not necessarily merit a revision in physical fitness guidelines but the necessity for recommended guidelines to limit inactivity.

PURPOSE OF THE STUDY

The purpose of the study is to identify biomechanical patterns and significant differences in lifting biomechanics among four groups of individuals; those who meet the criteria for an occupationally active lifestyle or occupationally inactive lifestyle, and further classified based on whether those in each group are recreationally active.

PREMISE OF THE STUDY

Normal spine biomechanics is required to maintain a healthy spine. Muscle weakness, ligament stress or strain, bone density loss or damage to the intervertebral disc are common sources of abnormal changes in biomechanics (Nordin & Frankel, 2012). These biomechanical changes are a major factor in the development of lower back pain (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). One method to evaluate significant risk of injury to the lower back in individuals which live a sedentary lifestyle, independent of physical activity, consists of a biomechanical analysis of the spine. Justification for application of biomechanical principles to a clinical situation lies within a basic understanding of normal spine biomechanics and their role in the health of the spine.

The segmental design of the vertebral column offers shock absorption, adequate motion, protection of the spinal cord and transfer of weight forces and bending moments (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Because the spine is curved it has increased resistance to compressive forces (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). A seated position involves backward tilting of the pelvis and straightening of the lumbar lordosis (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Together, these increase the moment arm of the trunk weight relative to the lumbar spine (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

A spinal segment consists of a vertebral body and an intervertebral disc (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). The vertebral body has a greater elastic modulus than the disc, since it is a stiffer material (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). The disc hydrostatically allows distribution of resultant forces (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Here, strain can be produced much more easily (Adams, Burton, & Bogduk, 2006). If a disc is degenerated, under the same compressive load the disc will not absorb the stress and transfer it appropriately (Adams, Burton, & Bogduk, 2006). Injuries to the spine are most likely a result of stresses in the form of bending and torsion (Adams, Burton, & Bogduk, 2006).

Bending in forward flexion, extension or lateral flexion results in compressive stress on the concave side of the bend, and tensile stress on the other, convex side (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). The side of the intervertebral disc which must withstand the tension stretches the annulus and the compressive side bulges (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

Therefore, the critical factor in the onset of lower back pain is less what action the individual performed, but the posture or position the individual was in at the time of the activity. For an individual who spends their days engaged in prolonged sitting, with the lumbar lordosis straightened, the structural changes, muscle weakness, synergistic dominance and resultant imbalances will often result in poor posture (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). Poor posture will alter their lifting biomechanics and present another facet of risk (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

Measuring and analyzing lumbar spine biomechanics in regards to risk of injury is one of the best approaches through observation of an individual’s lifting motion and form. Nachemson and colleagues extensively researched in vivo inter-disc pressures, in particular in the lumbar region. In one study, results indicated that leaning forward 20 degrees increased the load on the spine by 30% and when lifting a 20 Kg object while at 20 degrees forward flexion the load increased 100% with a 40% increase in tensile stress on the convex, or posterior, aspect of the annulus (Nachemson, 1960). In a different study, Nachemson reported differences in externally applied loads to normal, otherwise healthy intervertebral discs and moderately degenerated discs. Pressure in a normal disc was documented as one half of the externally applied load while the moderately degenerated disc pressure was equal to the full external load (Nachemson, 1960).

Furthermore, prolonged flexion in combination with lifting is associated with increased risk of lower back disorders (Beach, et al. 2005; Toosizadeh & Nussbaum, 2013). Intervertebral discs between spine segments deform during trunk flexion and trunk stiffness is reduced (Beach, et al. 2005; Toosizadeh & Nussbaum, 2013). For the spine to maintain equilibrium, a reduction in passive tissue stiffness forces compensatory muscle activation, sequentially increasing loads on supplementary soft tissues and intervertebral joints (Beach, et al. 2005; Toosizadeh & Nussbaum, 2013). Also, forces or inter-disc pressure develop during lifting tasks from the comparatively small moment arms of supporting spinal muscles (Beach, et al. 2005; Toosizadeh & Nussbaum, 2013). By the very nature of spine biomechanics, small changes in passive stiffness, like instances of flexion exposure, results in key changes in loading during ensuing lifting tasks (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990).

Research on complex spine loading in regards to lifting style (bent knee or straight knee), loading with and without weight, speed of movement, and obesity have provided valuable data on high-risk spine loading. The consensus for ideal lifting style is to lift with bent knees and to maintain spine alignment (Adams, Burton, & Bogduk, 2006; White & Panjabi, 1990). However, straight knee lifting style can still yield valuable insight to musculoskeletal abnormalities and compensatory strategies (Anderson & Chaffin, 1986). The mass of the object lifted significantly impacts spine loading. The heavier and bulkier the object the greater impact on spine loading. The impact of motion speed when lifting varied throughout the literature and results are often reported as not significant (Ning & Nussbaum, 2015). However, compressive cumulative loading is commonly described during slow speed lifts while compressive peak loading is described during faster speed lifts (Dolan, et al., 1994; Greenland, et al., 2013; Toosizadeh & Nussbaum, 2013). Body mass index (BMI) and spine lading when lifting remains a controversial subject. Some research has reported significant increases in loading as BMI increases, however, in studies which loading has been adjusted specific to the individuals BMI, there is no significant difference in loading between different BMI's (Xu Xu & Simon, 2007). Although spine loading is impacted by variations in motion speed and BMI, variations in the weight of the object lifted and lifting style produces the greatest spine loading. These variables should be controlled for properly to avoid significantly influencing results.

In conclusion, the structural changes occurring with the muscle and bone of a sedentary individual and the cascading effects these changes have on posture and biomechanics of the core creates a significant risk of injury. According to previous research, lifting an object from the ground takes neuromuscular coordination and a healthy core to perform this properly. One of the best approaches to quantitatively compare lumbar spine biomechanics among populations is analysis of lifting an object from the ground in both a bent knee and straight knee position. Providing insight into the risk an individual poses for lower back strain or injury and essentially identifying a trend in spine biomechanics of those differing in lifestyle independent of physical activity level.

HYPOTHESIS

Participants who maintain an occupationally inactive lifestyle, regardless of recreational activity, will exhibit significantly different lifting biomechanics when compared to the lifting biomechanics of an active population performing the same lifting tasks. Specifically, the inactive and moderately inactive participants compared to the active participants will exhibit:

1. Less maximum joint angular displacements in all directions during trunk functional tasks.
2. Less anterior excursion of center of pressure trajectories (COP) during lifting tasks.
3. Slower anterior linear velocity of the COP during lifting tasks.

SIGNIFICANCE

Currently, there is no consensus that sedentary lifestyle is a major contributor to lower back pain. Although research has identified a distinct trend, further research is required. It remains unclear the benefits regular exercise has on maintaining the health of the core and preventing lower back disorders, with particular regard to those who otherwise maintain a sedentary lifestyle.

A biomechanical analysis of the lumbar spine can expose risk for damage among individuals with populations separated by more than just time spent sedentary but also whether they meet the daily recommended guidelines for physical activity, according to, the most commonly referred, American Heart Association.

These findings may assist in the design of more appropriate treatment options and require less guess work for clinicians. Furthermore, independently analyzing lifestyle and regular recreational physical activity can highlight whether or not meeting the guidelines for physical activity can reduce that risk. Moreover, exposing the need for changes in time spent sitting, not necessarily physical fitness regimen.

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CHAPTER II: LITERATURE REVIEW

The current American Heart Association model of recommendations for public health stresses moderate to vigorous aerobic exercise 5 days a week with resistance training at least twice a week. These recommendations are thoroughly supported by more than 60 years of scientific research validating the claim that following these guidelines for exercise provides a broad range of beneficial effects. However, sedentary lifestyle has continuously risen over the years. Technological advances in transportation, entertainment and communication require little movement. Inactivity has developed into an independent facet of health which cannot be addressed by meeting the recommended physical activity guidelines. Possibly the greatest barrier in advancement of public health is the widespread inability to develop alternative modes of thinking.

Moderate to vigorous physical activity as the optimum movement patterns for health have continued to be the dominant focus of research. Yet, emerging evidence of deleterious, adverse health effects of sedentary behavior, independent of physical activity, presents a new element to establishing the ideal model of movement patterns for health (Owen, et al. 2012; Pate, et al. 2008; Pratt, et al. 2014). An improved return on investment in regards to enhancing quality of life through movement patters demands addressing prolonged inactivity, regardless of meeting recommended physical activity guidelines. The 60 years of research supporting an appropriate physical fitness regimen is not necessarily in question. The need for recommended guidelines for inactivity is. Deconditioning of the lumbar spine as a result of long term sitting often leads to lower back pain. Moreover, several studies have identified high prevalence of lower back pain in office workers. So, lower back pain is considered a common indicator of muscular and structural deficiencies as caused by a mostly sedentary lifestyle. A better understanding of lumbar biomechanics can provide insight to the degree of damage and risk associated with inactivity as well as suggestions for adjustments to movement patters when inactive.

A BRIEF HISTORY OF ENERGY EXPENDITURE AND DEFINING INACTIVE LIFESTYLE

Energy balance is a central selective force observed throughout evolutionary history. Humans evolved to possess rather high levels of energy expenditure, when compared with the requirements of non-human primates (Leonard & Robertson, 1992; Leonard & Robertson, 1994; Leonard & Robertson, 1997). At a time when early Homo rapidly evolved in brain size, concomitantly, the need for a more diverse and higher quality diet developed (Leonard & Robertson, 1992; Leonard & Robertson, 1994; Leonard & Robertson, 1997). Thus, more land needed to be covered to collect diverse foods. Much of human evolution occurred as hunter-gatherers; the larger foraging ranges increased energy expenditure (Leonard & Robertson, 1992; Leonard & Robertson, 1994; Leonard & Robertson, 1997). Only very recently, has advances in technology and agriculture altered the energy balance in humans. In industrialized nations the vast majority of occupations requires employees to remain seated at a desk for the entirety of working hours. An estimated 75% of work in industrialized countries is performed while seated; a staggering statistic that warrants the extensive scientific investigations on a variety of physiological systems and biological pathways associated with prolonged inactivity. (Lis, et al. 2007; Pynt, Mackay & Higgs, 2008). A lifestyle which requires no movement, for an animal which has for hundreds of thousands of years remained erect and mobile for the entirety of their days, has proven detrimental to the body. Today, individuals who meet the recommended physical activity guidelines can still lead an almost entirely sedentary lifestyle. It is questionable whether meeting the recommended guidelines for physical activity is enough to combat the many adverse health effects caused as a result of sedentary lifestyle.

Despite a vast amount of scientific inquiry, there is no consensus definition for sedentary behavior or method of measuring and analyzing it. In order to avoid an exhaustive list of all possible sedentary behaviors, researchers refer to a series of global measures representative of what will ideally capture what is considered sedentary.

Separation of sedentary activities and physical activities can be determined by energy expenditure. Although there are bound to be discrepancies among varying individuals, much of the literature has designated specific activities based on the Metabolic Equivalent of Task (MET); a physiological measure used to quantify energy expenditure (Owen, et al. 2012, Tremblay, et al. 2010, Pate, et al. 2008). One MET is the equivalent of 3.5 mL oxygen consumption per kilogram of bodyweight, O2·kg−1·min−1 (Owen, et al. 2012, Tremblay, et al. 2010, Pate, et al. 2008). A behavior that is considered sedentary is defined by an energy cost of 1.5 MET's or less (Owen, et al. 2012, Tremblay, et al. 2010, Pate, et al. 2008). When an individual is sitting or lying down, the energy cost falls under the measure of sedentary behavior. Prolonged sitting at work, playing video games or watching television and commuting to work are considered low energy expenditure activities. Classifying an activity as moderate to vigorous requires an energy expenditure of 3 to 8 METs. Walking, running, riding a bicycle or swimming would fall under this classification (Owen, et al. 2012).

Defining a sedentary activity is fairly straightforward however defining a sedentary lifestyle is slightly more complex. Sedentary behaviors are sporadic and vary throughout a given day, making it difficult to isolate, or define, a sedentary lifestyle. One approach to defining a sedentary lifestyle is similar to that of the method categorizing physical activity under the acronym of FITT (Tremblay, et al. 2010). Since sedentary activities do not vary in intensity, the acronym SITT can be used to describe the sedentary behavior frequency (number of periods of a particular duration), interruptions, time (duration) and type of activity (Tremblay, et al. 2010). By referring to this acronym, a researcher or clinician can have a better idea as to whether an individual lives a sedentary lifestyle.

Researchers and clinicians mostly rely on self-report measures of health behaviors. This approach works well for volitional physical activities which are easily recalled however less so for sedentary activities which vary throughout the day. At present, direct measurement of free-living movement is a growing field lacking a consensus methodology which accurately quantifies sedentary activity. Therefore, a well-constructed, thoroughly studied questionnaire, specific to identifying sedentary behaviors and physical activity independently, is currently the most common form of measurement. In this manner, subjects are not required to where any activity measurement device, which can be forgotten or even impact their choices in activities. They are not required to return for a later visit which often hinders an individual from participating in a study.

LACK OF EXERCISE AND TOO MUCH SITTING AS INDEPENDENT HEALTH RISK FACTORS

Human movement is a complex behavior which varies from person to person and is impacted by numerous elements. For example, the physical and social environment a person lives in, health issues and personal motivation influences tendency to participate in sedentary or physical activity. Just as the social and environmental pathways leading to an individual engaging in sedentary activity versus physical activity may be different; so might the biological pathways of the health effects associated with these behaviors.

Envisioning sedentary behavior as a separate health factor from inadequate physical activity is necessary for several reasons. As stated, the physiological responses to sedentary lifestyle differ from the responses of an individual to physical activity (Katzmarzyk, et al. 2010; Finni, et al. 2014). Responses and adaptions to exercise is not necessarily opposite to the adaptions caused by sedentary behaviors (Katzymarzyk, et al. 2010; Finni, et al. 2014). Adaptions differ between and within physiological systems, for example, musculoskeletal versus cardiovascular (Katzymarzyk, et al. 2010; Finni, et al. 2014). Understanding movement and non-movement behaviors that occur throughout a given day are key because of their unique impact on biological processes (Katzymarzyk, et al. 2010; Finni, et al. 2014). Furthermore, the unique nature of sedentary behavior requires unique measurement. Surveillance and assessment of sedentary behavior cannot be executed using the same metrics and indicators used when analyzing physical activity.

In order to isolate the physiological nature of too much sitting, an understanding of the adverse health effects unique to this behavior must be understood. A 2009 study published by Katzmarzyk, et al, collected 12 years of data about daily activity and sedentary time over 17,000 individuals. Over this time period death rates were reported highest in persons who spent the majority of time sedentary, regardless of whether or not recommended physical activity guidelines were met (Katznarzyk, et al. 2009). Intriguingly, mortality rates were not dissimilar between sedentary exercisers and sedentary non-exercisers (Katznarzyk, et al. 2009). A similar study on an even larger scale collected data from more than 330,000 subjects from 1992 to 2000 as part of the European Prospective Investigation of Cancer and Nutrition (EPIC) at Cambridge University. Dr. Ulf Ekelund, and colleague's, analyzed occupational inactivity, recreational physical exercise, and obesity independent of each other. The reported mortality rates based on inactivity alone were twice as high as mortality rates based on obesity (Ekelund, et al. 2015). Mortality rates declined with increases in regular physical activity and all around active lifestyle (Ekelund, et al. 2015). Just slight activity compared with none was found to significantly improve health, however, it is still a poor comparison to that of an active population (Ekelund, et al. 2015). Ekelund's findings determined mortality rates were highest among those who sat for the majority of their day, regardless of obesity or a regular physical fitness regimen.

In 2015, a Canadian study analyzed sedentary time and the association between disease incidences independent of physical activity. After statistical adjustment for physical activity, time spent sedentary was independently associated with greater risk for all-cause mortality and cancer incidence (Biswas, et al. 2015). An upward trend in deleterious outcome effects generally decreased in magnitude the higher the level of physical activity (Biswas, et al. 2015). Between the years of 1999 and 2000 the Australian Diabetes, Obesity and Lifestyle study collected data from over 11,000 subjects. Initial findings indicated that time spent sedentary was related to high blood glucose an triglycerides as well as other cardiovascular risk factors (Barr, et al. 2007). Most notably, uninterrupted sitting time resulted in significantly worse cardiovascular and metabolic health compared with sedentary time which was broken up (Barr, et al. 2007). These results were consistent even after accounting for participation in regular physical fitness (Barr, et al. 2007). Despite regular exercise and regardless of abdominal adiposity, time spent sitting is at the root of metabolic dysfunction, numerous cardiovascular risk factors and all-cause mortality.

Although these studies focused on cardiovascular health, metabolic health and mortality rates, they are included in this review because of the unique nature of which adverse health effects are linked. All systems intertwine and each can provide insight to another. Furthermore, these studies all evaluated health with sedentary behaviors and physical activity as independent health factors. Based on their results it is clear that each of these health factors have different biological pathways impacting overall health status. Since cardiovascular health, metabolic health and mortality rates are only slightly affected by regular exercise, are there still significant structural abnormalities impacting biomechanical function? It is likely that an individual is still suffering from structural abnormalities and dysfunction leading to a higher risk of injury despite meeting the AHA recommended guidelines for physical activity. A biomechanical analysis of the spine, specifically the lumbar spine because of its association with prolonged sitting and sedentary behaviors, can strengthen the need for guidelines addressing inactivity as well as further support these previous studies from a different approach.

STRUCTURAL AND PHYSIOLOGICAL CHANGES IN INACTIVE HUMANS

An important characteristic of skeletal muscle in animals is accommodation according to demand. Efficient functioning for different situations means muscle fiber and connective tissue cells respond and adapt based on changes in muscle activity (Milani, et al. 2008; Haddad, et al. 2003; Goldspink, 1998). Persistent changes and modifications in load of a muscle forces the cells which compose muscle connective tissue to react by proliferation while muscle fibers respond with alteration in cellular structure and volume (Milani, et al. 2008; Haddad, et al. 2003; Goldspink, 1998). However, the plastic nature of muscle will adapt to a lack of functional demand as well (Milani, et al. 2008; Haddad, et al. 2003; Goldspink, 1998). For example, unloaded inactivity when sitting deconditions the skeletal muscle in the lower extremity.

In addition to muscular adaptions to immobility, changes in bone mineral density are well-documented. Humans returning from a long-term orbit experience dramatic reductions in bone mass and individuals post spinal-cord injury also face significant declines (Cann & Adachi, 1983; Globus, et al. 1984). Zerwekh and colleagues investigated bone mineral density of the lumbar spine, femoral neck and greater trochanter of healthy males before and after just 12 weeks of bedrest. Results stated a reduction of 1-4% in bone mineral density (Zerwekh, et al. 1998). Changes in bone density are swift. An individual who has held a desk job for many years is likely at risk for significant declines in bone density.

Furthermore, sedentary lifestyle and bone mass reduction is related to changes in the balance of bone resorption and bone deposition. Kim, et al, identified changes in biomarkers associated with bone resorption following bedrest, however, bone formation biomarkers were mostly unaffected by immobility. This sudden increase in bone resorption without the accompanying changes in bone formation leads to impactful uncoupling which then swiftly leads to loss in bone mineral content (Kim, et al. 2003). Zwart, el at, investigated biomarkers following extended bedrest as well, but with the added variable of a vigorous exercise regimen. Findings indicated that although subjects retained bone mineral density, changes in biomarkers were not impacted; thus failing to prevent harmful alterations in bone metabolism as a result of extended immobilization (Zwart, et al. 2007). Similar findings have been documented by Yung, et al., and LeBlanc, et al. Therefore, physical activity alone most likely cannot prevent changes in bone metabolism caused from too much sedentary time.

As structural changes occur within the muscle and bone of the body, a muscle imbalance can develop. A muscular imbalance being one side of opposing muscles becoming stronger than the other. This is especially common in individuals who lead a sedentary lifestyle and over time can contribute to poor posture along with an increased risk for lower back pain (Nordin & Frankel, 2012). Sitting involves a significant degree of spine flexion. Although seated postures conserve energy and allow for workers to focus on a task, when held for a prolonged period the non-neutral posture generates high-risk loading (Nordin & Frankel, 2012). The strain and compression of tissues through the lower back and buttocks could potentially be a source of pain for an individual (Nordin & Frankel, 2012). Movement, flexion and extension, of the lumbar spine is regulated by a network of active and passive components which fashion a complex neuromuscular system (Nordin & Frankel, 2012). A neuromuscular imbalance of these tissues during load sharing can also result in pain or disability (Nordin & Frankel, 2012).

Structural changes that occur within the body of a sedentary individual may also result in reduced elasticity and loss of spinal flexibility (Yapark, 2014). The decreased flexibility may be a contributor to increased risk of injury due to an inability to utilize full range of motion (Yapark, 2014). Flexibility is a physical attribute resulting from the interrelationship between tendons, muscle and ligaments (Graciosa, et al. 2013; Yapark, 2014). This physiological condition is necessary to achieve voluntary movements, within morphological limits, pain-free and without restrictions (Graciosa, et al. 2013; Yapark, 2014). Deficits in flexibility as a result of muscle imbalance or other structural changes attributed to sedentary lifestyle, limits range of motion and could result in a variety of negative consequences (Graciosa, et al. 2013; Yapark, 2014). A lack of flexibility is the root of many musculoskeletal injuries. Blood flow is less efficient in tight, bound muscles (Nordin & Frankel, 2012). Pain and inflammation are a more common occurrence when attempting to maintain full range of motion (Nordin & Frankel, 2012).

Various muscles interact to produce hip flexion, this action being the motion of the thigh and trunk towards each other. When standing, the hip flexors act when stepping up on a stool or up a flight of stairs (Nordin & Frankel, 2012). When lying flat on the back this group can lift the leg towards the trunk or the trunk towards the leg into a sit-up (Nordin & Frankel, 2012). The most paramount of these muscles is the iliopsoas, composed of both the iliacus and the psoas (Nordin & Frankel, 2012). The psoas, lying deep to the abdomen traveling within the abdominal cavity, originates on the sides of the lumbar vertebrae (Nordin & Frankel, 2012). As the psoas tightens, the lumbar spine is pulled forward (Nordin & Frankel, 2012). The iliacus originates within the inner bowl of the pelvis (Nordin & Frankel, 2012). Both insert to the proximal shaft of the femur (Nordin & Frankel, 2012). In the case where the hip is kept in a constant, flexed position, such as a seated position, these hip flexor muscles will shorten and shrink (Nordin &

Frankel, 2012). Shortened hip flexors will not allow for the hip to fully extend, or straighten (Nordin & Frankel, 2012). Day after day, sitting for long periods, the lumbar region can become bowed by the shortened muscles (Adams, Burton & Bogduk, 2006; White & Panjabi, 1990).

In the case that the primary hip flexors are at a disadvantage, the concomitant muscles compensate to support hip flexion (Nordin & Frankel, 2012). When in a seated position daily for long durations, in addition to the hip flexors tightening, the glutes weaken and hamstring muscle group becomes the primary hip extensor (Nordin & Frankel, 2012). This synergistic dominance significantly increases risk of injury (Nordin & Frankel, 2012). The reason for increased chance of injury in this case is in the case that the gluteus maximus cannot extend the hip and the hamstrings, which are much weaker, the hamstrings are then forced to compensate and perform much more work than they are designed for (Nordin & Frankel, 2012).

SEDENTARY LIFESTYLE, LOWER BACK PAIN, AND A BIOMECHANICAL UNDERSTANDING

Lower back pain (LBP) is commonly experienced in individuals between the ages of 30 and 60 (Hoy, et al. 2014). Senescence is undoubtedly one contributor to injury but sedentary lifestyle with too little exercise also forms a high-risk foundation for injury (Heneweer, et al. 2009; Hoy, et al. 2014). According to recent statistics, the majority of people, approximately 70-85%, will suffer from some form of LBP at one point in their life (Liddle, Baxter & Gracey, 2004; Hoy, et al. 2014). LBP is the most common cause of job related disability and missed work (Hoy, et al. 2014). Despite diseases being treated individually, most are not independent of each other. An understanding of diseases or conditions and the underlying mechanisms involved requires a comprehensive understanding of the various components involved in its pathogenesis. For example, an understanding of the bone and muscle changes contributes to a better understanding of biomechanical function, an understanding of biomechanical function can help to better predict, treat and manage musculoskeletal dysfunction and injury.

The vertebral column is composed of a series of segments. Each segment is comprised of an anterior and posterior motion unit (White & Panjabi, 1990). The anterior segment consists of a vertebral body and intervertebral disc (White & Panjabi, 1990). The posterior segment is formed by the vertebral arches, transverse and spinous processes and inferior and superior articular facets (White & Panjabi, 1990). The posterior segment is protective of neural structures and directs flexion and extension motion. This segmental design allows for shock absorption, adequate range of motion and the transfer of bending moments and weight forces (White & Panjabi, 1990). The vertebral body is a stiffer material and has a greater elastic modulus compared to the intervertebral disc (White & Panjabi, 1990). The vertebral body is cylinder of cancellous bone with trabeculae, surrounded by a thin layer of cortical bone (White & Panjabi, 1990). The trabeculae acts like a strut and resists bowing from compressive forces. It is the intervertebral disc which must distribute resultant forces (White & Panjabi, 1990).

Strain can be more easily produced in the intervertebral disc. A healthy, otherwise normal disc withstands compressive forces by stretching the inner annulus fibers (White & Panjabi, 1990). The outer layers endure tensile stress with no transference (White & Panjabi, 1990). When the spine is loaded, the disc acts as a cushion between vertebral bodies (White & Panjabi, 1990). The nucleus pulposus hydrostatically distributes pressure from the load and concurrently stores energy (White & Panjabi, 1990). Similar to a sponge, the disc deforms by fluid content being squeezed out of the disc, the disc thinning, and then absorbed back following unloading (White & Panjabi, 1990). Disc pressure indicates a response to rotational and shearing loads (White & Panjabi, 1990).

The curved spinal column increases resistance to compressive forces. The seated positon of the body causes the pelvis to rotate backward, reduces lumbar lordosis and trunk-thigh angle (White & Panjabi, 1990). Together, these increase the moment arm of the trunk weight in reference to the lumbar spine, which increases vertebrae disc pressure (White & Panjabi, 1990). The ischial tuberosity bears upper body weight rather than it distributing along the arch of the spine (White & Panjabi, 1990). When erect and moving around intervertebral discs expand and contract soaking up fresh blood and nutrients (citation, White & Panjabi, 1990). Unlike when an individual is seated for an extended duration and the discs are unevenly squished and collagen begins to harden around supporting ligaments and tendons. Despite a lack of conclusive evidence, individuals who lead a sedentary lifestyle are ordinarily accepted as having a substantial risk for the development of low back pain and an increased risk for a herniated lumbar disc (Mörl & Bradl, 2013; O'Sullivan, McCarthy, et al. 2012; O'Sullivan, O'Sullivan, et al. 2012).

Outside of working hours, sedentary behavior during leisure hours can further damage the health of the spine. Furniture designers commonly engineer home and leisure seating for kyphosed, relaxed postures. Although kyphosed sitting posture may be more comfortable this does not necessarily equate with spine health (Pynt, et al. 2008). Kyphosed sitting posture can be especially harmful because in this position the intervertebral can slowly degenerate in the absence of pain (Pynt, et al. 2008). The relationship between various seated postures and spine health have been the focus of many epidemiological and experimental studies. Kyphosed seated postures are reported as much more harmful when compared with lordosed posture (Pynt, et al. 2008). Furthermore, recreational sitting behavior can lead to a different form and location of soft tissue damage which can be carried over into the following workday and create an added layer to risk of pain or injury.

Ironically, physical activity can be considered both a wasted opportunity for long term maintenance of spine health as well as concomitantly the cause of initial back pain onset (Heneweer, et al. 2009). Onset of lower back pain is often a result of an individual participating in a new activity which the body and core is not adequately adapted for (Heneweer, et al. 2009). Individuals who do not make physical activity a daily habit are more likely to suffer a spine injury when participating in a new activity and in the event that an individual overreaches beyond the parameters of their current ability (Heneweer, et al. 2009). Since the body is accustomed to sedentary behaviors, the muscles and bone have adapted to the demand placed on them and are, therefore, efficient for those demands and not the demands of the new strenuous task (Adams, Burton & Bogduk, 2006; Heneweer, et al. 2009). Consequentially, back pain in the form of a spams, sprain or strain can simultaneously compound the musculoskeletal system and nervous system (Adams, Burton & Bogduk, 2006). Depending on the loading and position, the spine may be overly compressed and cause the intervertebral disc to bulge or rupture (Adams, Burton & Bogduk, 2006). A bulging or ruptured disc places pressure on the nerves within the spinal column and results in signals transmitting to the brain resulting in back pain (Adams, Burton & Bogduk, 2006).

BIOMECHANICAL EVAULATION FO THE LUMBAR SPINE

To maintain a healthy spine an individual must have normal spine biomechanics. Abnormal spine biomechanics can be catalogued in multiple ways, often dependent on an individual’s range of motion. Abnormal biomechanics can be classified by vertebrae motion which is hypomobile, decreased range of motion, hypermobile, increased range of motion, or by a severe loss in stability (White & Panjabi, 1990).

Mechanically, when the vertebral column is exposed to prolonged loadings all components exhibit time-dependent behavior (Toosizadeh & Nussbaum, 2013). The systematic rearrangement of collagen fibers force ligaments and passive components of muscles to act as viscoelastic materials (Adams, Burton & Bogduk, 2006; Toosizadeh & Nussbaum, 2013). Lower back pain onset and injury commonly occurs when an individual is performing a lifting task or a combination of lifting and prolonged trunk flexion (Adams, Burton & Bogduk, 2006; Toosizadeh & Nussbaum, 2013). During lifting, load geometry, body posture and inertial (dynamic) factors significantly impact vertebral loads (Adams, Burton & Bogduk, 2006; Toosizadeh & Nussbaum, 2013). Trunk angle throughout the lift can determine disc compressive and shear forces as well as strength of spinal segments (Toosizadeh & Nussbaum, 2013).

During trunk flexion the passive tissues exposed undergo viscoelastic deformation and subsequently reduce trunk stiffness (Adams, Burton & Bogduk, 2006). The resulting stiffness effects range of motion and normal spine biomechanics (Adams, Burton & Bogduk, 2006). To maintain equilibrium, the reduction in trunk stiffness requires an increase in muscle activation of the para-spinal muscles, which then substantially increases load within the intervertebral joints and other supporting soft tissues (Adams, Burton & Bogduk, 2006; Toosizadeh & Nussbaum, 2013). These small changes in passive stiffness of the trunk can result in meaningful changes in spine loading, in the form of compression and shear forces, when lifting (Toosizadeh & Nussbaum, 2013). Beach and colleagues investigated the effects of prolonged sitting on passive flexion stiffness of the lumbar spine. They reported that the lumbar spine in men exposed to prolonged sitting became significantly stiffer after only one hour of sitting (Beach, 2005). In women there were inconsistent responses to seated exposures (Beach, 2005). Findings indicate that the passive structures, consisting of intervertebral discs and posterior ligaments, are levied at lower lumbar flexion angles (Beach, 2005). Therefore, following prolonged sitting these structures are subjected to much higher stresses given the seated position lumbar angle (Beach, 2005). When attempting to perform tasks which require a normal range of motion in the spine, for example lifting tasks, this stiffness greatly impacts load distribution.

In addition to increased spine loads from duration of a lift and trunk flexion exposure, the speed in which an individual is lifting can affect loading. Peak biomechanical loading and speed of lifting tasks have been the focus of several studies (Greenland, et al., 2013; Toosizadeh & Nussbaum, 2013). Greenland, et al., investigated slow, medium (natural) and fast lifting speeds and the associated peak and cumulative loading. Results indicated slow lifting speed was preferable to fast lifting speed (Greenland, et al. 2013). Based on the analysis, peak loading was 18% lower when lifting slower, confirming results from similar studies (Greenland, et al. 2013). Although the medium speed peak loading was higher than the slow speed, the cumulative loading values were less, suggesting the medium, natural, speed to be the optimum lifting speed (Greenland, et al. 2013).

Lastly, cadaveric studies have demonstrated that simultaneous compression and bending is the most threatening condition to injure the intervertebral discs and ligaments (Adams, Burton & Bogduk, 2006; Dolan, et al. 1994). Disc compression, in particular, is widely considered responsible for disc herniation and nerve root irritation (Dolan, et al. 1994). Nachemson and colleagues extensively researched in vivo inter-disc pressures, in particular in the lumbar region. Results stated that leaning forward 20 degrees increased the load on the spine by 30%; and when lifting a 20 Kg object, while at 20 degrees forward flexion, the load increased 100% with a 40% increase in tensile stress on the convex, or posterior, aspect of the annulus (Jenson, 1980). Nachemson also studied the differences in externally applied loads to, otherwise, healthy intervertebral discs and moderately degenerated discs. Pressure in a normal disc was documented as one half of the externally applied load while the moderately degenerated disc had pressure equal to the full external load (Jenson, 1980). Nachemon's research provided insight to the significance angle of a lift is to intra-discal loading as well as the health of the disc in managing a load.

Extensive research exists on lumbar spine biomechanics in regards to lifting form, loading with and without weight, prolonged flexion exposure and subsequent loading, obesity, and lower back pain. However, to date no research has explored lumbar spine biomechanics in regards to time spent sedentary independent of physical activity level. Below, Table 2.1 is a summary of several studies which are similar in design with focus on a healthy population, whereas Table 2.2 is similar in design with participants both healthy and suffering from lower back pain or a lower back disorder.

Table 2.1 Lumbar Lifting Biomechancis

Reference	Purpose of Study	Partici-pants	Lift Technique	Weight (Kg or lb.)	Findings
Anderson & Chaffin, 1986	Biomechanical evaluation of five lifting techniques	1 male	5 lifting techniques; differing between (1) foot placement, (2) knee orientation (3) back orientation	-	Keep load close to the body, straddle stance for bulky items, keep back aligned throughout lift.
De Looze, et al., 1993	Comparison of mechanical loading of the musculoskeletal system when lifting and lowering	8	Two techniques- (1) lift with knees and (2) lift with back	-	When lowering forces are distributed over smaller cross-sectional area of active muscle, which may imply higher risk of injury
Dolan, et al., 1994	Bending and compressive stresses acting on the lumbar spine during lifting activities	21 male 18 female	Knee angle	-	Complex spinal loading during lifting tasks depends as much on the speed of movement, and the size and position of the object lifted, as on its mass.
Gatton, et al., 1999	Kinematics during flexion of the lumbar spine	7 male 7 female	Unconstrained flexion transition from upright standing to seated	5 Kg or No weight	No single movement sequence exhibited by same pop.
Greenland, et al., 2013	Lifting speed and cumulative biomechanical loading of symmetrical lifting task	10	Floor-to-shoulder, floor-to-waist, and waist-to-shoulder lift at three different speeds (slow, medium, and fast)	Light load (2.25 kg) and heavy load (9 kg)	Based on peak values, BCF highest for fast speeds, but BCF cumulative loading highest for slow speeds, with largest difference between fast and slow lifts.

Ning & Nussbaum, 2015	The effect of motion speed on lumbar passive moment output was investigated	12	In standing position flex back while keeps legs straight at 3 different speeds, slow, normal and pseudo-static	-	The effect of motion speed was not significant on lumbar passive moments
Toosizadeh & Nussbaum, 2014	Analysis of prolonged flexion and lifting from a sagittally symmetric model was developed containing six sagittally-deformable lumbar motion segments	Model	Varied flexion exposures followed by simulated lifting tasks at varied spinal loads	180 N load on model	Peak spine load, peak axial stiffness and absorbed energy increased with flexion exposure and increased spine loads; changes were magnified by increasing flexion duration and angle
Xu Xu & Simon, 2007	Effects of obesity on lifting performance	12	Uninstructed with varying symmetry	Varied loads	No significant differences between people of different BMI
Yaprak, 2014	Spine ROM comparison among active and sedentary females	45 active females 54 sedentary females	Spine range of motion analysis	-	Positive effect on the health of the spine from a physically active lifestyle

Table 2.2 Lower Back Pain Population Lifting Biomechanics

Reference	Purpose of Study	Partic-ipants	Lift Technique	Weight (Kg or lb.)	Findings
Lariviere, et al., 2001	Uninstructed lifting techniques between chronic lower back pain patients and healthy control subjects	15 LBP 18 Healthy	Freestyle lift of object directly in front and ≈ 90 ° to the right of the participant	12 kg box	No significant difference in lifting technique between samples however EMG analysis of para-spinal muscles differed
Marras, et al., 1993	Determine what trunk loading factors, or combination of factors, was associated with occupationally related LBP via 3-D biomechanical analysis	111 high risk LBP 124 low-risk LBP	Uninstructed	Varied dependent on occupation	By collectively varying lifting frequency; load moment; trunk lateral velocity; trunk twisting velocity; and trunk sagittal angle during a lift LBP risk decreases by almost 11 times.
Shum, et al., 2005	Low back pain effect on kinematics of lumbar spine and hip during sit to stand and stand to sit	60 LBP 20 Healthy	Sit to stand, stand to sit	-	Spine mobility significantly limited in low back pain population, various compensation strategies
Vogt, et al, 2001	Influences of Nonspecific Low Back Pain on 3-D Lumbar Spine Kinematics in Locomotion	34 with LBP 22 without LBP	Walking on treadmill	-	Phasic patterns and angular spinal displacements of patients with LBP were within normal limits, yet, showed less than optimum gait patterns, higher degrees of stride-to-stride variability.

The summarized tables support a difference between loaded and unloaded lifting as well as a difference in lifting following prolonged flexion. Furthermore, maybe less surprising but still important, the differences in subjects suffering from lower back pain or a lower back disorder in loading and range of motion compared with a healthy population. These studies support the idea that a biomechanical analysis of the lumbar spine between populations of varying physical activity and time spent inactive will provide insight to musculoskeletal abnormalities and possibly a higher risk for injury. Based on the alarming evidence of health effects specific to prolonged inactivity there is a glaring need for broader research to bridge an interdisciplinary approach to form a solution to the problem. Analysis of the lumbar spine when performing a lifting task at a medium, natural, speed, can assist in identifying potential health-risks to the spine as a result of sedentary lifestyle and existing structural deficiencies.

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CHAPTER III: MATERIALS AND METHODS

RESEARCH DESIGN

Quasi-experimental design. This study was experimental, sample of convenience, with non-random assignment of participants to participant group dependent on occupational activity level and recreational physical activity level (Table 3.2).

PARTICIPANTS

Participant recruitment consisted of flyer advertisement, word of mouth, and as extra credit opportunities, see Appendix B for recruitment flyer. A total of 26 participants were recruited to participate in the study; all of whom successfully completed the study protocol. Of the twenty-sex, three were excluded from analysis. One met exclusionary criteria for weight, one was excluded due to marker placement failure, and one was excluded due to force platform data collection failure. Gender distribution was fairly even, with ten males and thirteen females. The average age of males was 24 years old and the average age of females was 25 years old (Table 3.1).

Participants fell between the ages of 18 and 60 years old. They were otherwise heathy, with no known current illnesses, injuries or medical conditions which could have impacted movement or endangered the participant's well-being. Participants did not display or self-report any physical pain or discomfort that could have potentially influenced movement or safety of the individual. The participants were capable of picking up a 5 lbs. object off the ground without dropping to one knee or using other external supports. All participants who met the criteria for occupationally inactive or occupationally active maintained this lifestyle for a minimum of at least 6 months.

Participants who did not meet the inclusionary criteria were excluded from the study. Additionally, had any participant displayed or self-reported any of the following, they were also excluded from further investigation. Had the participant had a previous lower extremity, back, neck or head injuries which required medical treatment or any previous issues with balance that has not been resolved. If they were experiencing dizziness, nausea or experiencing any undiagnosed medical conditions. If the participant suffered from chronic neuromuscular or musculoskeletal injuries, diseases, and/or illnesses which may impact performance and safety, they were excluded. The following extreme anthropometric measurements were excluded: 1) height < 130 cm, 2) weight > 250 kg, 3) under normal weight (BMI < 18.5), 4) waist circumference (WC) < 40 cm, 4) WC > 160 cm, or 5) BMI > 25 and WC < 60 cm (Ekelund et al., 2015).

Upon a clear appreciation and understanding of the facts, implications, and consequences of the study, consenting participants provided consent by signing the informed consent form (Appendix C). The consent form was approved by the Institutional Review Board at the University of Mississippi.

Table 3.1 Participant Demographics. Mean age, height, waist circumference, and mass between male and female participants.

Variable	Males (10)		Females (13)	
	Mean	SD	Mean	SD
Age (years)	24.0	4.0	25.0	8.3
Height (cm)	181.6	14.0	162.0	7.7
Waist Circumference (cm)	85.1	7.9	74.9	5.7
Mass (kg)	83.3	13.3	64.5	7.4

PARTICIPANT CLASSIFICATION

Participants were divided into four groups in the study by the Cambridge EPIC (European Prospective Investigation into Cancer and Nutrition)-Norfolk Physical Activity Questionnaire, EPAQ2. The EPAQ2 is a self-completed questionnaire that assesses past-year physical activity behaviors in occupational and recreational domains. Based on the data collected with EPAQ2, participants were classified first based on whether their occupational activity level. Occupational activity level consisted of two groups: an active occupation group and an inactive occupation group. Inactive occupation is dependent on greater than 80% of the workday spent inactive. Active occupation consists of participants who fall under the 80% of the workday spent inactive. Following occupational activity level classification, participants were further classified based on whether their recreational physical activity met the American Heart Association recommended guidelines for physical activity (Table 3.3).

Table 3.2. Classification Criteria. Classification criteria of participants firstly categorized by American Heart Association guidelines for physical activity and further classified by occupational activity level.

Occupational Activity Level	American Heart Association Recommended Physical Activity	Group Name
Yes	Yes	Active
	No	Moderately Active
No	Yes	Moderately Inactive
	No	Inactive

Table 3.3. American Heart Association Guidelines. American Heart Association recommended guidelines for physical activity for adult population.

AHA Recommendation	
For Overall Cardiovascular Health:	At least 30 minutes of moderate-intensity aerobic activity at least 5 days per week for a total of 150 OR At least 25 minutes of vigorous aerobic activity at least 3 days per week for a total of 75 minutes; or a combination of moderate- and vigorous-intensity aerobic activity AND Moderate- to high-intensity muscle-strengthening activity at least 2 days per week for additional health benefits.
For Lowering Blood Pressure and Cholesterol:	An average 40 minutes of moderate- to vigorous-intensity aerobic activity 3 or 4 times per week

PROTOCOL

Data Collection was performed at the University of Mississippi Applied Biomechanics laboratory. The procedure of the study was as follows:

1. Participant visits the laboratory.
2. Explained the study to the potential participant and obtain signature for Consent form.
3. Participant fills the EPAQ2 and the health questionnaire.
4. Anthropometric measurements are taken and recorded. Body weight (kg) and height (cm) will be taken according to standardized procedures without shoes. Other measurements consist of leg length, knee, and ankle width of both legs, waist circumference, shoulder width (distance between acromian process), elbow and wrist width of both arms.
5. Upon review of EPAQ2 and healthy questionnaire answers and the anthropometric data, should the participant meet any of the exclusionary criteria, they will not be asked to participate in the study. Those who meet the inclusionary criteria will continue to prep for marker placement.
6. Participant exchanges proper clothes and 50 reflective markers will be placed on the participant. Marker Placement consists of palpation of bony landmarks and placement of the marker on the specific bony landmark, see Appendix A for marker placements.
7. Once markers are placed, the participant will warm up and stretch includes following motions:
    a. Bend at the hip, maintain a flat back, no weight

    b. Trunk rotations
    c. Dead-lift, no weight
    d. Limited stretching, simply stand and reach down to the toes
8. Participants will be directed to stand on a force platform following functional range of motion (ROM) tasks, and movements and ground reaction forces (GRF) and moments (GRM) will be recorded by a motion capture system. Five good trials will be collected for each task.
    a. Anterior-posterior flexion and extension
    b. Left and right flexion/bending
    c. Left and right axial rotation
9. Immediately following warm-up and ROM tasks, the participant will perform two lifting tasks: stand lifting (the hands touch an object with minimum knee flexion then lift) and squat lifting (have significant knee flexion before the hands touch the object then lift).
10. In order to identify 'natural lifting style' for each participant, the order of the two lifting tasks are:
    a. A 5 lbs square box with dimensions X-X is set in front of participant on the ground and 5 cm away from the force platform.
    b. First ask participant performs a lifting task without any instruction to identify the 'natural lifting'.
    c. Then, the participant will perform their 'natural lifting' and 5 good trials will be recorded.
    d. Next, the participant will perform the other lifting task and 5 good trials will be recorded.

    e. If the natural lifting is stand lifting, then the 2nd lifting task is squat lifting, and vice versa.
    f. A good trial is define as pick up the object in front of them without lifting either foot off from the force plate.

11. Following the lifting tasks the markers are removed and data collection is complete.

EXPERIMENT SETUP

Experimental setup for a motion measurement test is illustrated in Figure 3.1. All motion, video, and analog data will be synchronized by VICON motion capture system.

Motion Capture System

An eight visible-red light cameras motion capture system (Vicon Motion Systems, Ltd; Oxford, UK) will be used to record trajectories of the reflected markers in three dimensional space. Vicon Nexus software (v.1.8.5) will be used to record the spatial locations of the reflective markers affixed to the participant at 120 Hz. In addition, a digital-video camera will be used to capture a front view of the performances of the test tasks for later qualitative purposes as needed.

Marker Set

As listed in Table A1 (Appendix A), a total of 50 reflective markers 14 mm diameter), including 30 lower extremity markers (Lu & O'Connor, 1999; Lu, O'Connor, Taylor, & Walker, 1998) and 20 trunk markers will be placed on the participant. Criteria of those marker locations are followed the suggestion of Cappozzo (Cappozzo, Catani, Della Croce, & Leardini, 1995) and take consideration of International Society of Biomechanics (ISB) recommendation (Wu & Cavanagh, 1995) for coordinate system definition. Four markers will be affixed at the corners on the top of a box during lifting tasks.

The spine will be model and separated into 3 segments: the upper trunk (upper thoracic spine region) from C7 to T8, the middle trunk (lower thoracic spine region) from T9 to T12, and the lower trunk (lumbar region) from L1 to L5. Local coordinates system for each trunk segment also follows the same algorithm of the lower extremity. An example of the spine model is shown in Figure 3.2. Cardan angles will be used for the joint angles about all three axes for the joints composed by adjacent trunk segments (Grood & Suntay, 1983). Thus, for example, rotations of the upper trunk is represented as relative rotation of the upper trunk to middle trunk. Rotation sequence is z-y-x, which is extension (+)/flexion, right (+)/left bending, and left (+)/right axial rotation respectively.

Force Platform

One AMTI™ force platform (Advanced Mechanical Technology, Inc., Watertown, MA) will be used to record GRFs and GRMs. The force platform is embedded in the floor. Participants will stand on the force platform performing tasks of the study, and signals will be collected at 1200 Hz.

Object for Lifting Tasks

A 5 lbs square box with handles at the sides will be used for the lifting tasks in the study.

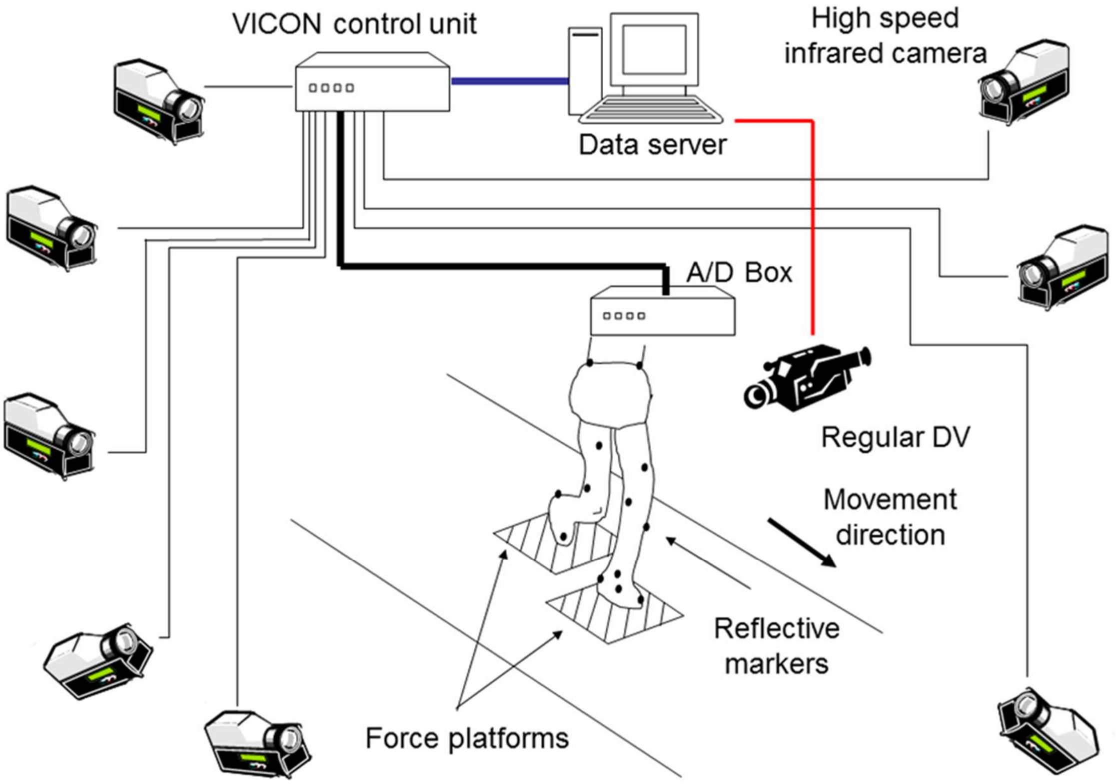

Figure 3.1 Diagram of experimental setup for a gait trial.

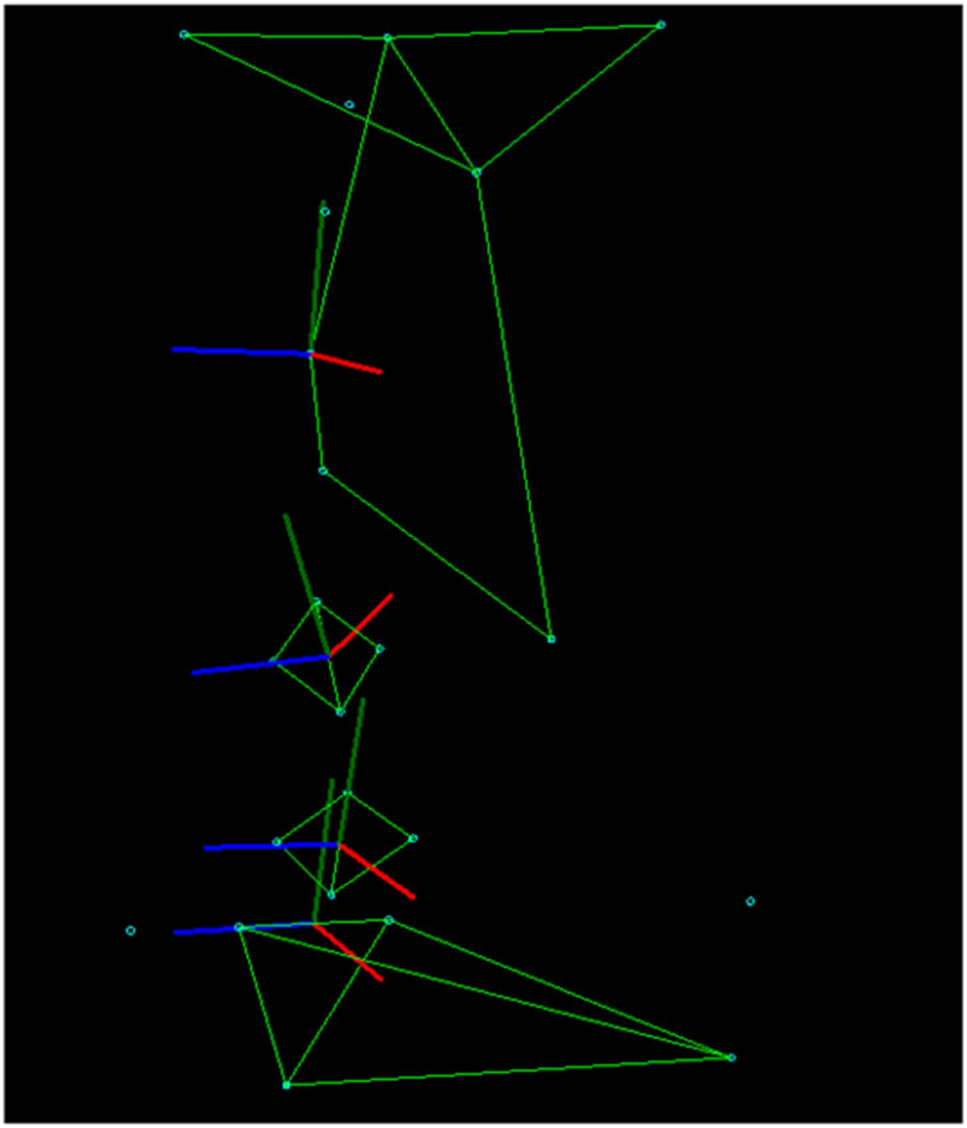

Figure 3.2 Spine model of the study. The blue dots are markers attached on the body and green lines connect between markers to illustrate the body segments. The thick red (anterior (+)/posterior axis), green (superior (+)/inferior axis), and blue (right (+)/left axis) lines are the coordinate systems of the trunk and pelvis segments.

DATA ANALYSIS

Data Reduction and Analysis

All collected experimental raw data was analyzed by a developed program written in Matlab® R2014a (The Mathworks, Inc. US). All marker raw data was smoothed by generalized cross-validatory spline (GCVSPL) smoothing techniques (Woltring, 1986) using program codes from the International Society of Biomechanics website (http://isbweb.org/c/isb/pub/files/orig_website/software/sigproc/gcvspl/reina/source.html). All analog raw data will be filtered by Butterworth filter. Parameters for both smoothing/filtering algorithms will be later decided based upon the characteristics of the data.

The interval of interests/analyses of each ROM task started from the initiation of the movement of a given direction, and ended when the trunk returned back to its initial position and ceased movement. For the lifting tasks, the interval started when the trunk flexion began in straight leg lifting trials. In bent leg lifting trials, the interval started when the knee flexion began. Both ended when the body returned to an upright posture and stopped moving.

Kinematic dependent variables were calculated from joint angle curves of trunk segments, including maximum angular displacement of the middle trunk and low trunk for all tasks. Kinetic dependent variables will be calculated from the force platform data, including maximum anterior/posterior displacement, maximum anterior/posterior velocity of pressure (COP) trajectories, and total displacement (sum of all trajectories).

Statistical Analysis

The difference of each dependent variable between groups was detected by 1-way ANOVA. When a difference existed, post-hoc pair-wise comparisons were conducted and Bonferroni correction was applied to minimize family-wise errors. The significance level was set at $\alpha = 0.05$. All tests were conducted using SPSS software (IBM Corp., Version 21.0. Armonk, NY).

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LIST OF APPENDICES

APPENDIX A

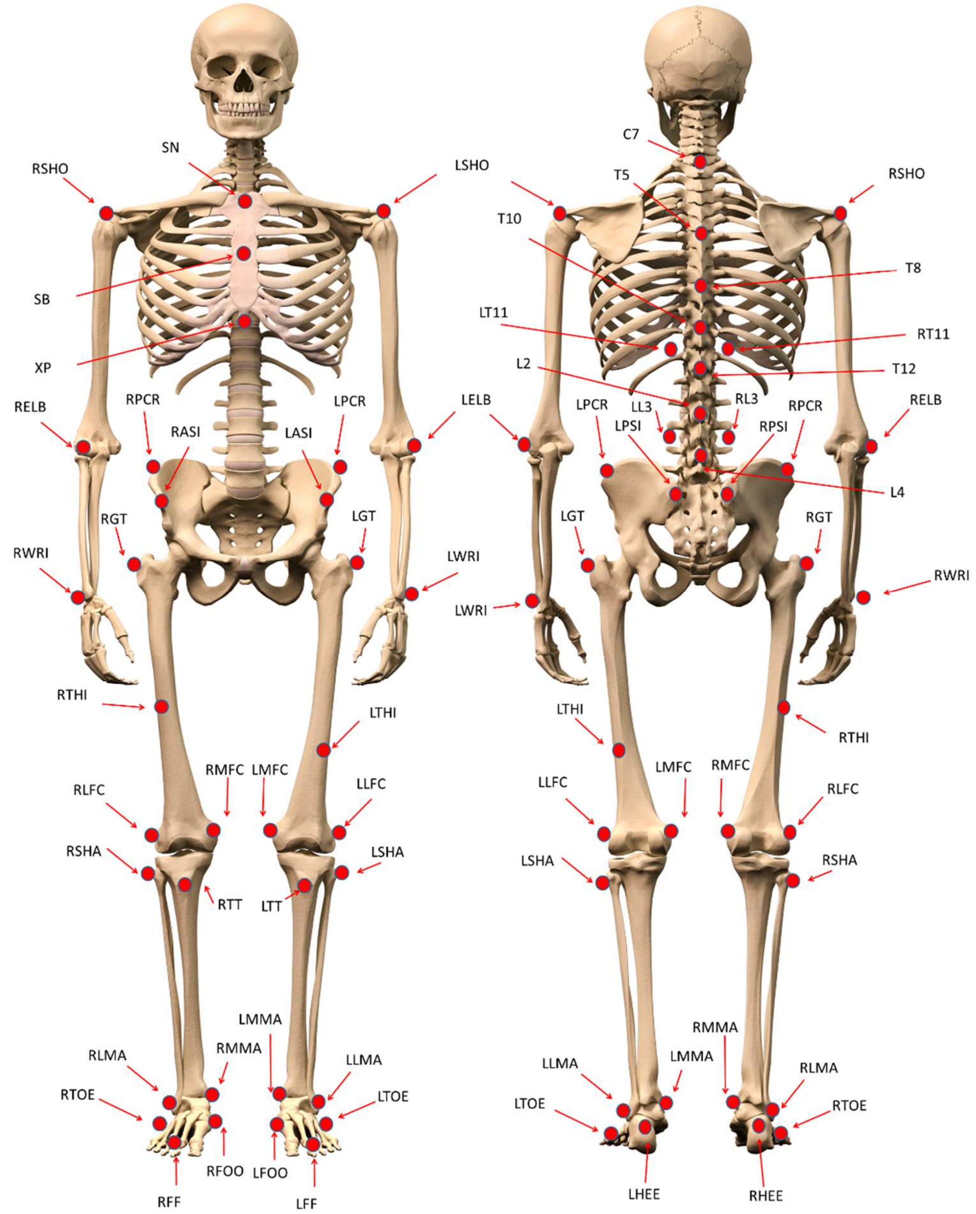


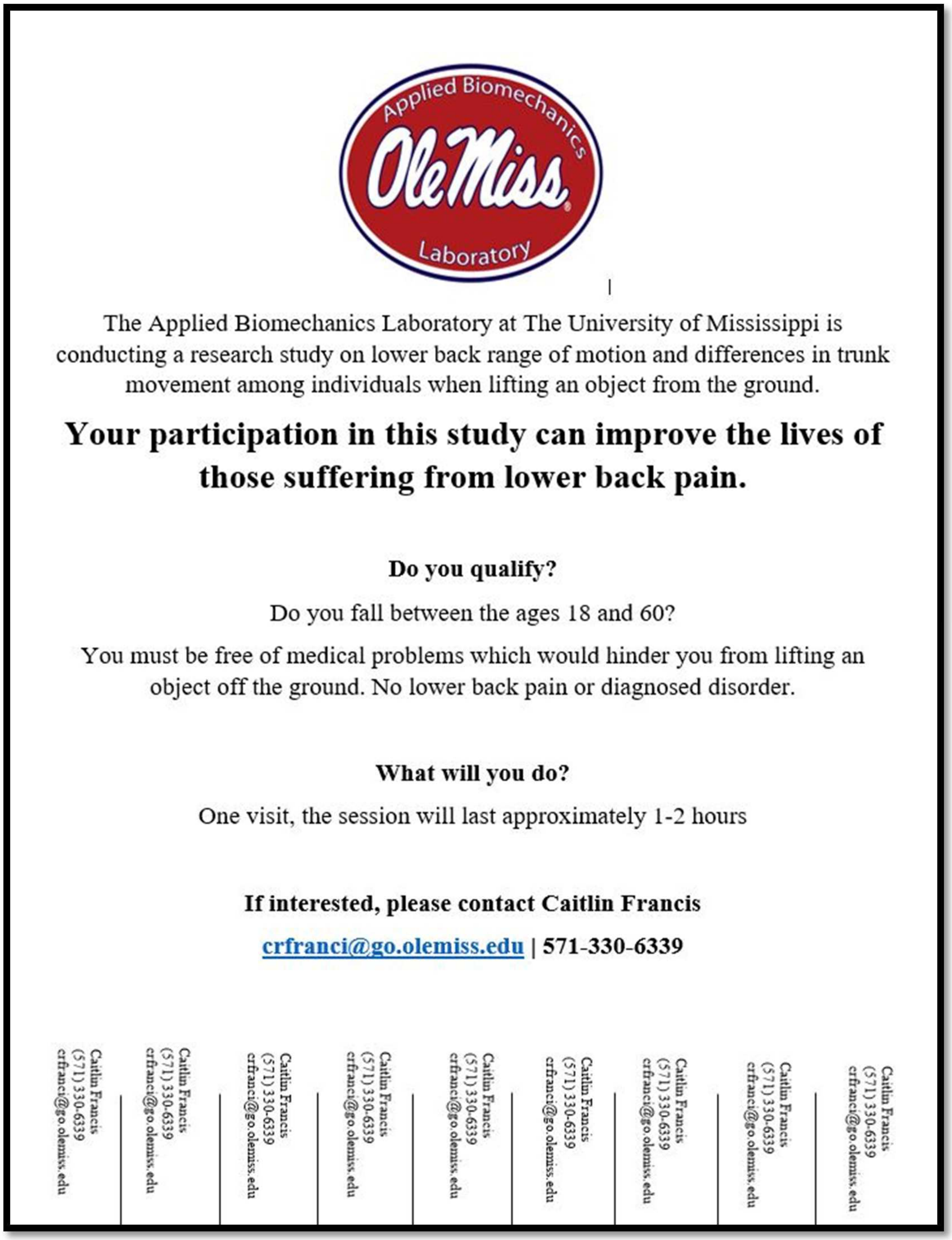
Figure A1. Marker Placement

Table A1. Marker Placement Description

	Marker Placement	
Number	**Abbreviation**	**Marker Description**
1	SN	Sternum
2	SB	Sternum body
3	XP	Xiphoid process (optional)
4	ACL	Left acromioclavicular joint
5	ACR	Right acromioclavicular joint
6	RELB	Right elbow olecranon process
7	LELB	Left elbow olecranon process
8	RWRI	Right wrist (between radius and ulna styloid process)
9	LWRI	Left wrist (between radius and ulna styloid process)
10	C7	5th cervical spinous process
11	T5	5th Thorasic spinous process
12	T8	8th Thorasic spinous process
13	T10	10th Thorasic spinous process
14	T12	12th Thorasic spinous process
15	LT11	3cm left of 11th thorasic spinous process
16	RT11	3cm right of 11th thorasic spinous process
17	L2	2nd lumbar spinous process
18	L4	4th lumbar spinous process
19	LL3	3cm Left of the L3 spinous process
20	RL3	3cm Right of the L3 spinous process
21	LASI	Left ASIS
22	RASI	Right ASIS
23	LPSI	Left PSIS
24	RPSI	Right PSIS
25	LPCR	Left top point of pelvis crest
26	RPCR	Right top point of pelvis crest
27	LGT	Left greater trocanter
28	RGT	Right greater trocanter
29	LTHI	Left thigh wand marker
30	RTHI	Right thigh wand marker
31	LLFC	Left lateral femoral epicondyle centre
32	RLFC	Right lateral femoral epicondyle centre
33	LMFC	Left medial femoral epicondyle centre
34	RMFC	Right medial femoral epicondyle centre

35	LTT	Left tibial tuberosity
36	RTT	Right tibial tuberosity
37	LSHA	Left shank wand marker
38	RSHA	Right shank wand marker
39	LLMA	Left lateral malleolus
40	RLMA	Right lateral malleolus
41	LMMA	Left medial malleolus
42	RMMA	Right medial malleolus
43	LHEE	Left heel
44	RHEE	Right heel
45	LTOE	Left fifth metatarsal
46	RTOE	Right fifth metatarsal
47	LFOO	Left Navicular tubercle
48	RFOO	Right Navicular tubercle
49	LFF	Left middle foot of 3rd distal metatarsal
50	RFF	Right middle foot of 3rd distal metatarsal

APPENDIX B



Applied Biomechanics
Ole Miss
Laboratory

The Applied Biomechanics Laboratory at The University of Mississippi is conducting a research study on lower back range of motion and differences in trunk movement among individuals when lifting an object from the ground.

Your participation in this study can improve the lives of those suffering from lower back pain.

Do you qualify?

Do you fall between the ages 18 and 60?

You must be free of medical problems which would hinder you from lifting an object off the ground. No lower back pain or diagnosed disorder.

What will you do?

One visit, the session will last approximately 1-2 hours

If interested, please contact Caitlin Francis

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APPENDIX C

Consent to Participate in Research

Study Title: *Spine Lifting Biomechanics between Individuals Varying in Weekly Activity Level*

Investigator	**Faculty Sponsor**
Caitlin R. Francis	Yang-Chieh Fu, Ph.D.
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☐ By checking this box I certify that I am 18 years of age or older.

The purpose of this study

The aim of this study is to identify biomechanical patterns and significant differences in lifting biomechanics among individuals who meet the criteria for a sedentary lifestyle, moderately inactive lifestyle, moderately active lifestyle, and an active lifestyle.

What you will do for this study

You will schedule a time to visit the University of Mississippi biomechanics laboratory.

1. Upon arrival for the scheduled appointment the participant will fill out an EPAQ2 questionnaire, a health questionnaire and measures for height, weight and other anthropometric measurements.
2. You will have markers placed on the body and perform a very brief warm up for the core of the body.
3. Followed by trunk range of motion tasks.
4. You are then instructed to pick up the 10 lb. box just like you are lifting a box in a supermarket.
5. You are then directed to lift box 5 times with knee flexed and 5 times with knee straight.

The EPAC2 questionnaire is to evaluate physical activity level based on occupation, recreation and household activity. The health questionnaire is to ensure there are no health issues which may impact the results of the study. The anthropometric measurements will assist in analysis of the results.

Videotaping / Audiotaping

You will be videotaped while you perform the tests during the ‘Tests day’ so that we can reference the movement on camera to the marker data collected. There will also a digital camera recording your motion, which might consist of your face and/or body, for qualitative use only. This recording will be studied by the research team for use in the research project.

Time required for this study

This study will take approximately 1-2 hours for a single session.

Possible risks from your participation

There are no anticipated risks involved in this study. The weight of the object lifted from the ground is similar to that of lifting groceries from the ground. Should there be no previous health problems – minimal risk is involved.

Benefits from your participation

You should not expect benefits from participating in this study. However, you might experience satisfaction from contributing to scientific knowledge. The study may provide valuable information for a community or the general population, from this participants will indirectly benefit from their contribution.

Confidentiality

All information in the study will be collected from you anonymously: it will not be possible for anyone to associate you with your performance.

Confidentiality and Use of Video Tapes:
This will allow the experimenters to check reliability of marker data is matching the performance of the individual.

1. Only experimenters on the research team will have access.
2. Tapes will be kept indefinitely.
3. Tapes will be locked in a file cabinet in a locked office.

You will not be identified by name in any publication of the research results unless you sign a separate form giving your permission (release). The key registry and identifiable videotapes will be destroyed after 2 years after the end of the study, which is expected to be Spring 2018).

Right to Withdraw

You do not have to volunteer for this study, and there is no penalty if you refuse. If you start the study and decide that you do not want to finish, just tell the experimenter. Whether or not you participate or withdraw will not affect your current or future relationship with the Department of Health, Exercise Science and Recreation Management, or with the University, and it will not cause you to lose any benefits to which you are entitled.

IRB Approval

This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions or concerns regarding your rights as a research participant, please contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, then decide if you want to be in the study or not.

Statement of Consent
I have read the above information. I have been given an unsigned copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

Signature of Participant Date

Printed Name of Participant

Signature of Researcher Date

NOTE TO PARTICIPANTS: DO NOT SIGN THIS FORM
IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED

CHAPTER IV: RESULTS

PARTICIPANT INFORMATION

A total of 26 participants completed the study. One participant was excluded due to meeting the exclusionary criteria for waist circumference, as well as two other participants due to data collection failure. Data collection failure for one participant was due to issuficient force platform set up, and another data collection failure was due to missing markers on the pelvic crest. Table 4.1 represents the physical characteristics of the participants, and Table 4.2 is participant classification. Males and females were closely distributed with a total 10 males and 13 females included in data analysis. Mean age for males and females were extremely similar with males averaging age 24 and females averaging age 25. Table 4.3 presents mean waist circumference and mass of each group.

Table 4.1. Participants Weight and Waist Circumference. Participants mean waist circumference (cm.) and mass (kg) by group.

	Subjects (n)	Waist Circumference (cm)		Mass (kg)	
		Mean	SD	Mean	SD
Active	5	74.4	5.22	62.94	6.87
Moderately Active	6	82.92	10.81	79.8	16.71
Moderately Inactive	8	80	7.83	71.46	13.5
Inactive	4	73	4	70.175	11.89

SPINE KINEMATICS

Flexion range of motion results indicates no significant difference between all groups for the lower trunk. For the middle trunk flexion range of motion, participants who were classified in the inactive group had statistically different, smaller range of motion (p=0.014, Table 4.4). This population was also lowest in range of motion for the lower trunk, but, again, this was not statistically significant.

Table 4.2. Average Flexion Range of Motion. Average flexion range of motion with middle trunk and low trunk relative to pelvis between groups. * indicates significance ($p < 0.05$)

	Middle Trunk (°)		Low Trunk (°)	
	Average	SD	Average	SD
Active	64.5	11.5	45.9	7.9
Moderately Active	67.8	11.8	45.1	7.6
Moderately Inactive	59.7	3.5	43.4	10.0
Inactive	*50.6	12.8	37.8	9.5

Following collection, the lifting movement was isolated for the reach phase and the lift up phase. Variables analyzed for each phase consist of maximum middle trunk flexion displacement and maximum lower trunk flexion displacement. At all trunk level, maximum trunk flexion displacement had more decrement in active group than in inactive group. Although the inactive group seemed to exhibit more flexion displacement than the moderately active and moderately inactive groups, no significant differences existed ($p > 0.05$).

In reaching phase of straight lifting form and bent lifting form, mean displacement was very similar among groups with one exception. The active group in the reaching phase of bent leg lifts had significantly higher middle trunk flexion displacement (*p*=0.005, Table 4.6). In both straight and bent lifting form, there is a consistent trend in displacement between groups.

The lifting phase has little difference in mean displacement of both the middle trunk and lower trunk among all groups with one exception. The middle trunk displacement of the active group in bent leg lifting form. Similar to the reaching phase, the active group has a tendency to have greater displacement (p=0.023,Table 4.8).

Table 4.3. Spine Kinematics for Reaching phase of Straight Leg Lifts.

	Maximum Middle Trunk Flex Displacement (°)		Maximum Low Trunk Flex Displacement (°)	
	Average	SD	Average	SD
Active	48.95	24.18	37.20	18.22
Moderately Active	55.06	11.61	33.62	13.72
Moderately Inactive	36.56	15.34	31.58	7.33
Inactive	45.91	7.91	36.05	1.92

Table 4.4. Spine Kinematics for Reaching Phase of Bent Leg Lifts. *indicates significant difference (*p*<0.05)

	Maximum Middle Trunk Flex Displacement (°)		Maximum Low Trunk Flex Displacement (°)	
	Average	SD	Average	SD
Active	*44.31	8.46	37.03	15.42
Moderately Active	21.55	11.99	32.81	11.69
Moderately Inactive	24.32	11.52	36.23	12.98
Inactive	29.47	7.28	36.51	7.94

Table 4.5. Spine Kinematics for Lift Up Phase of Straight Leg Lifts.

	Maximum Middle Trunk Ext. Displacement (°)		Maximum Low Trunk Ext. Displacement (°)	
	Average	SD	Average	SD
Active	49.84	21.50	38.01	19.96
Moderately Active	51.93	28.41	35.21	19.55
Moderately Inactive	44.58	15.71	33.91	10.79
Inactive	55.20	13.89	41.23	4.30

Table 4.6. Spine Kinematics for Lift Up Phase of Bent Leg Lifts. *indicates significant difference (*p*<0.05)

	Maximum Middle Trunk Ext. Displacement (°)		Maximum Low Trunk Ext. Displacement (°)	
	Average	SD	Average	SD
Active	*44.98	10.06	34.79	16.18
Moderately Active	29.92	18.20	28.64	14.58
Moderately Inactive	29.01	7.56	25.11	6.97
Inactive	35.23	11.07	35.44	3.96

FORCE PLATFORM

Center of pressure (COP) variables of five trials per participant of force platform data collected consisted of maximum anterior-posterior (AP) displacement, total displacement, maximum anterior velocity for reaching phase, and maximum posterior velocity for lift up phase. Data was isolated for the reaching phase as well as for the lift up phase.

COP maximum AP displacement is very similar between the bent leg lifts and the straight leg lifts, as well as between the reach and lift up phases. Total displacement was similar between all groups with no notable group interactions (Figure 4.8). Lastly, maximum anterior velocity was largely consistent between groups.

Table 4.7. Center of Pressure Variables for Reaching Phase of Straight Leg Lifts.

Reach Straight	Max A-P Displacement (mm)	Total Displacement (mm)	Max Anterior Velocity (mm/s)
Active	73.9 ± 21.7	150.1 ± 33.7	233.7 ± 39.8
Moderately Active	78.2 ± 29.1	146.6 ± 31.5	256.7 ± 65.5
Moderately Inactive	68.0 ± 21.0	131.4 ± 15.3	221.6 ± 51.5
Inactive	57.3 ± 11.2	141.7 ± 44.4	246.5 ± 52.8

Table 4.8. Center of Pressure Variables for Reaching Phase of Bent Leg Lifts.

Reach Bent	Max A-P Displacement (mm)	Total Displacement (mm)	Max Anterior Velocity (mm)
Active	72.9 ± 22.1	150.1 ± 32.5	301.5 ± 57.7
Moderately Active	64.1 ± 25.2	146.8 ± 31.0	243.7 ± 58.3
Moderately Inactive	55.3 ± 27.3	129.7 ± 22.1	239.2 ± 64.9
Inactive	58 ± 18.4	153.9 ± 54.9	287.1 ± 139.9

Table 4.9. Center of Pressure Variables for Lift Up Phase of Straight Leg Lifts.

Lift Up Straight	Max A-P Displacement (mm)	Total Displacement (mm)	Max Posterior Velocity (mm/s)
Active	77.5 ± 24.6	165.3 ± 13.3	387.9 ± 71.9
Moderately Active	92.9 ± 25.2	178.6 ± 45.0	384.7 ± 104.4
Moderately Inactive	85.2 ± 15.4	160.6 ± 26.1	335.9 ± 99.0
Inactive	78.7 ± 16.6	182.2 ± 42.1	325.2 ± 130.7

Table 4.10. Center of Pressure Variables for Lift Up Phase of Bent Leg Lifts.

Lift Up Bent	Max A-P Displacement (mm)	Total Displacement (mm)	Max Posterior Velocity (mm/s)
Active	77.8 ± 25.5	159.9, +/- 26.0	281.6 ± 73.9
Moderately Active	64.1 ± 26.4	152.5, +/- 21.5	241.5 ± 45.1
Moderately Inactive	71 ± 38.9	171.1 ± 82.6	252.8 ± 57.3
Inactive	61.6 ± 17.9	172.3, +/- 21.8	224.5 ± 40.7

PERCENT RANGE OF MOTION

The inactive group exhibited the highest percent flexion range of motion in most categories, however, none of the variables were statistically significant. No difference in percent range of motion between Moderately Inactive and Moderately Active. Interestingly, the active group had the highest percent range of motion of all groups in the mid-spine during the reaching phase of the bent lifting form as well as lifting phase of bent lifting form (p=0.023, Table 4.13; p=0.044, Table 4.15).

Table 4.11. Percent Flexion Range of Motion for Reaching Phase of Bent Leg Lifts. *Indicates significant difference ($p<0.05$).

	Mid Percent ROM		Lower Percent ROM	
	Average	SD	Average	SD
Active	*69.52	13.56	75.79	21.91
Moderately Active	41.6	13.31	67.27	6.31
Moderately Inactive	40.03	18.53	62.14	20.5
Inactive	41.47	13.76	75.4	21.21

Table 4.12. Percent Flexion Range of Motion for Reaching Phase of Straight Leg Lifts.

	Mid Percent ROM		Lower Percent ROM	
	Average	SD	Average	SD
Active	74.58	34.21	78.91	30.9
Moderately Active	78.8	10.71	79.17	22.02
Moderately Inactive	60.6	25.54	75.59	24.48
Inactive	85.4	22.22	85.12	13.1

Table 4.13. Percent Flexion Range of Motion for Lifting Phase of Bent Leg Lifts.

	Mid Percent ROM		Lower Percent ROM	
	Average	SD	Average	SD
Active	*73.64	25.58	75.43	32.24
Moderately Active	43.38	24.21	65.55	36.11
Moderately Inactive	48	11.84	60.82	24.41
Inactive	63.74	15.51	82.97	6.28

Table 4.14. Percent Flexion Range of Motion for Lifting Phase of Straight Leg Lifts.
*Indicates significant difference ($p<0.05$)

Straight	Mid Percent ROM		Lower Percent ROM	
	Average	SD	Average	SD
Active	76.2	28.6	80.5	33.7
Moderately Active	75.8	39.4	77.9	39.3
Moderately Inactive	74.1	25.8	77.7	17.7
Inactive	101.4	24.2	97.2	15.5

CHAPTER V: DISCUSSION

Adequate biomechanics maintain acceptable intervertebral tissue strain, spinal compression, and stability. This is achieved through proper kinematics between the pelvis and multi-segmental lumbar spine. Previous evidence suggests that prolonged sitting or inactivity could lead to deleterious effects on the body's musculoskeletal system, likely impacting spine movement patterns (ref). Therefore, it is necessary to determine if individual whose lifestyle is largely inactive, yet participate in a regular physical fitness regime, exhibit improved spine biomechanics. Furthermore, it is also necessary to determine how this population's spine biomechanics compare to individuals with a largely active lifestyle. The current study aimed to investigate the effect of a largely inactive lifestyle, independent of regular participation in recreational physical exercise, on spine kinematics, center of pressure, and range of motion. Results show evidence of a tendency for greater range of motion and greater flexion displacement of the active sample. The inactive sample findings unexpectedly indicated a tendency for increased flexion displacement compared with the moderately active and moderately inactive groups.

RANGE OF MOTION

Flexion ROM was hypothesized to be similar between the active group and moderately active group and also to be similar between the inactive group and moderately inactive group. However, both the active and moderately active group range of motion was predicted to be greater compared with both inactive and moderately inactive groups. Results indicated no statistical difference in range of motion between active, moderately active, and moderately inactive groups. However, the inactive group was lowest of all groups in both flexion range of motion for the middle trunk and lower trunk with a statistically significant difference in middle trunk range of motion. These results suggest that the exercise the moderately inactive sample regularly participates in may be benefitting their spine flexibility.

JOINT KINEMATICS

It is apparent that abnormal kinematics are a marker of musculoskeletal pathology (Kong, et al., 2009; Shum, et al., 2007). Although range of motion is a common diagnostic tool, joint kinematic coordination is also an indicator of low back risk of injury (Kong, et al., 2009; Shum, et al., 2007). Given the expected range of motion to increase with increased activity level; middle trunk and lower trunk displacement, relative to the pelvis, was anticipated to be greater among both the active and moderately active groups when compared to both the moderately inactive and inactive groups in bent lifting form as well as straight lifting form. Furthermore, displacement was expected to decrease between groups as activity level decreased. Displacement of the lower trunk was hypothesized to be greater when compared to the middle trunk, particularly during straight leg lifts.

Reaching Phase

Findings indicate minimal kinematic differences between all groups during the reaching phase of straight leg lifting. However, in the reaching phase of bent leg lifting; results show the active group to have notably greater middle trunk flexion displacement. The biomechanics of different forms of lifting from ground level predetermine the use of the spine. In bent leg lifting, one can reach the object by flexion of the hip, knee, and ankle joints; but is limited in straight lifting. Therefore, flexion of the spine joints, or trunk segments, plays a major role to accomplish the task. Individuals must utilize maximal spine range of motion regardless of activity level. The difference in bent leg lifting of the reaching phase between the active group compared to all others may be explained by possible weaker or insufficient core muscle strength, tighter joints, and/or tighter hamstrings within the lower activity level groups (Lee, et al., 1999, Scarborough, et al., 1999). These findings are consistent with our hypothesis.

Lift Up Phase

The lifting phase of straight leg lifts for the inactive group resulted in greater angular displacements of both the maximum middle trunk and lower trunk compared to all other groups. Although the difference is very slight, this nevertheless may be indicative to insufficient soft tissue support in the case that they are unable to maintain stability when unable to bend at the knees (Hunt, et al., 2001). Also, consistent with the findings during the reaching phase of the bent leg lift, the lift up phase of bent leg lifting showed highest middle trunk flexion displacement with the active group compared to all other groups. Yet, because this finding was not statistically significant, further research is necessary.

Bent Leg Lifting Form Compared With Straight Leg Lifting Form

When comparing bent leg lifting form with straight leg lifting form, the middle trunk had significantly less displacement compared with the lower trunk in both the reach and lift up phase of the lift among all groups with the exception of the active group. The spine is a closed kinematic chain; and the angular displacement is calculated as a relative rotation to the pelvis. Therefore, ideally the middle trunk's flexion should be less than or equal to lower trunk's movement. Uniquely, these results differ from typical movement. The most likely explanation of this finding is that with lack exercise, the compensation of spine kinematics didn't happen at the lower trunk, but rather, the middle trunk during bent lifting. This phenomenon may be due to a protective mechanism used by the groups lower in activity level compared with the active group.

With this reduction of middle trunk kinematics, in order to complete the task, it should reflect on the upper trunk kinematics or lower limb extremity kinematics. Having said that, the current study does not report that data which makes it difficult to fully explain this interesting event.

FORCE PLATFORM

Measurement of COP reflects the movement of one's center of gravity (COG). Thus, the COP was predicted to be greater among the moderately inactive and inactive groups compared with the active and moderately active groups. Assuming the more inactive an individual is, the less control they will have over maintaining their COG. The findings indicate the COG sagittal plane movement is similar between groups despite different lifting forms. However, in the reaching phase of both lifting forms, participants who met the American Heart Association guidelines for physical activity, compared with those who did not, demonstrated a shorter COP AP displacement and slower COP velocities. When combined the reduced middle trunk flexion displacement, these results indicate that the individuals who do not meet AHA guidelines prefer to use a strategy of reducing trunk kinematics to lower their body in order to reach the box and then lift with a similar pattern. In consonance with joint kinematics results, COP results support that a protective mechanism is evident with decreased exercise. What's more, reduced muscle strength, due to lack of exercise, could also foster a lack of stability. Yet, this is not clear as this study did not measure muscle strength.

COP velocity was also hypothesized to be greater among the moderately inactive and inactive groups compared with the active and moderately active groups. Again, reasoning for this prediction being the more inactive an individual is, the less control they will have over maintaining their COG. However, the results show no statistically significant difference of COP velocity between groups in both phases of lifting and in both lifting forms. Although no statistical difference existed, it is worth noting there was a tendency for individuals of lower activity levels compared with the active group to present a slower velocity during lifting. This tendency is not in agreement with the original prediction. It is possible the slower velocities are indicative of a protective mechanism among these groups.

PERCENT RANGE OF MOTION

Mean percent range of motion of the middle and lower spine was similar between groups yet the inactive group was consistently highest in the two lifting phases and the two lifting forms. As previously stated, the inactive group had the lowest flexion range of motion compared with all other groups. In order to successfully lift the box they needed to use a much higher degree of their total flexion range of motion. This may indicate a higher risk of injury for individuals classified as inactive. Especially when an inactive participant performs a lift at a higher flexion velocity, there will be more change to over stretch soft tissue of the spine and injure the lower back (Mokhtarinia, et al., 2016). Another reason being, decreased flexibility limiting range of motion can lead to abnormal stress on distant tissues and structures from the initial site of inflexibility (Mokhtarinia, et al., 2016). Furthermore, healthy joints are in part reliant on movement through a full range of motion in order to increase blood supply, nutrients, and synovial fluid which assists in maintenance of cartilage and other structures within the joint (Shapiro & Risbud, 2013).

Interestingly, the active sample percent range of motion was highest of all groups in the middle spine during the reaching phase and lifting phase of bent form lifts. This could be attributed to a slight variation in the bent form which they used to pick up the box. Possibly, the active group bended slightly deeper to pick up the box, using more of their flexion range of motion. Future research which measures knee kinematics could confirm whether active individuals use a fuller range of motion due to lower bending in the knee.

CONCLUSION

This study set out to assess the impact of lifestyle as well as recreational activity on spine biomechanics. The main finding of this thesis is that the participants classified as inactive did exhibit significant differences in some variables indicating a greater risk for potential injury. This result is broadly consistent with other lifting studies evaluating activity level and high risk motion patterns. However, there were no significant differences in those classified as occupationally inactive, yet met AHA guidelines for physical activity and participants classified as occupationally active yet did not meet the AHA guidelines. The results did not support the original hypothesis in which those classified as occupationally inactive, yet met AHA physical activity guidelines, would result in values very similar to those classified as inactive, and statistically different from the active occupation groups. Nonetheless, this study reinforces the recommendation for the introduction of preventative programs to avoid a largely inactive lifestyle.

Much of the data was not significant between groups. However, tendencies were more common. The small sample size was a limitation of the study that may have led to a lack of statistically significant differences. Readers must be cautious when interpret and apply findings for their needs. Also, the majority of participants were under the age of 30 and many had only maintained an inactive or active lifestyle for one year. Maintaining a particular lifestyle for longer would likely have resulted in greater differences between groups. In order to recruit a population which has maintained one or the other lifestyle would likely require recruiting older adults who have maintained a particular lifestyle for possibly 5 or 10 years. The results did not include a comparison of knee kinematics. To better understand the range of motion and displacement observed at the spine it would have been greatly beneficial to compare knee kinematic data.

FUTURE RESEARCH

A more comprehensive understanding of biomechanics among individuals with different physical activity levels and lifestyle activity levels will not exclusively benefit health professions but also the general population. A continuous analysis on lower extremities and upper trunk segment, joint kinetics, and force platform data will further support findings in the study and/or giving more insight to physical therapist, orthopedic physicians, and exercise scientists. Future studies should address limitations in the current protocol. A larger sample size may reveal whether the tendencies observed could be significant differences or if there is actually less of a tendency. Furthermore, setting the inclusionary criteria for active lifestyle or inactive lifestyle to a minimum two years may result in greater divergence between groups. Many of the participants of the current study reported having only maintained an inactive or active lifestyle for just one year. Furthermore, the age of the participants in the present study was fairly young. The detrimental effects of long duration inactivity would likely be greater after not just more years of inactivity but with age as well. A study comparing inactive sedentary occupation workers in their 20s compared with those in their forties or fifties may be necessary to determine long term effects within the same group classification.

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