BIOMECHANICAL ANALYSIS OF LABILE SUSPENSION EXERCISES
ON THE LUMBAR SPINE OF FIREFIGHTERS

A Thesis

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by

Bret Edmond Gibson

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by

Bret Edmond Gibson

Approved by:

__________________________________, Committee Chair
Rodney Imamura, PhD

__________________________________, Second Reader
John Hofman, M.S.

____________________________
Date
Student: Bret Edmond Gibson

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__________________________, Graduate Coordinator  ___________________
Daryl Parker, PhD  Date

Department of Kinesiology
Abstract

of

BIOMECHANICAL ANALYSIS OF LABILE SUSPENSION EXERCISES
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Introduction

Using exercise to enhance occupational performance and injury prevention is well documented. In recent years the use of labile suspension exercise devices (i.e. TRX) has become a popular means of exercise used in both performance enhancement and rehabilitative settings. Firefighting is known to be a physically demanding occupation that is associated with a high prevalence of lower back injury. Exercise intervention, namely the inclusion of core training, is a commonly used strategy for injury prevention, performance enhancement, and rehabilitation of the low back. Biomechanical analysis can provide insight to the efficacy of several different dynamic labile suspension exercises.

Purpose

The purpose of this study was to measure the kinematics and electromyographical differences in (EMG) activity of the rectus abdominis (RA), external obliques (EO), and
lumbar erector spinae (LES) of firefighters when comparing a TRX Straight Arm Plank to several different TRX core exercise conditions.

Methods

Six healthy male firefighters were recruited from local fire departments. Each subject performed several different TRX core exercises in randomized order. Mean ± SD EMG activity at the peak phase (p-phase) and Peak EMG was recorded bilaterally for the RA, EO, and LES and compared between a control condition and several other exercise conditions. Dependent samples t-tests were used to detect differences between the exercise conditions.

Results

The results indicated that there were significant differences (p < 0.015) identified in the %MVC at the p-phase of the right EO between the control and both the TRX Alternating Knee Tuck (p = 0.007) and TRX Pike (p = 0.0008). Additionally, each TRX suspension exercise elicited significant differences (p < 0.015) in Peak %MVC between left EO (KT, p = 0.006; AKT, p = 0.005; Pike, p = 0.003) and right EO (KT, p = 0.008; AKT, p = 0.006; Pike, p = 0.0002) when compared to the control condition. The TRX pike elicited the highest mean Peak %MVC for the LE (19% ± 12%), LO (64% ± 19%), RO (84% ± 30%), and RRA (58% ± 17%).

Conclusions

The findings of this study support the notion that labile suspension exercises in general produce moderate to high levels of abdominal challenge, particularly in the EO.
Exercise prescription should take into account and match an individual’s level of fitness, injury history, and training goals. The data collected in this study can help govern exercise selection for the firefighter. The information provided in this research indicates that the TRX suspension exercises can be used as a viable means for strengthening the abdominal wall of firefighters.

______________________________, Committee Chair
Rodney Imamura, PhD

______________________________
Date
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I want to first acknowledge my loving and encouraging wife. Her patience and steadfastness has been integral to my success in life. I truly would not have survived without her unending support. Thank you my love.

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Chapter One

INTRODUCTION

Background

Exercise has long been used for numerous purposes including therapeutic reasons, performance enhancement, rehabilitation, and health and leisure. In the long history of exercise, there has been no shortage of fitness trends and fads. Trends stretch from step aerobics, “6 minute abs”, and yoga to radical training methodologies such as P90X, Insanity, and CrossFit. The recent explosion of social media further perpetuates such trends. However, while the wealth of exercise advice from these fitness communities, fitness marketing strategists, and self-proclaimed fitness gurus is not inherently wrong or faulty, it often is not based on solid scientific foundation. In the context of rehabilitation or performance enhancement, especially in tactical populations, such methodologies might be counterproductive. Training strategies must be scrutinized in light of developing optimal training protocol. Systematic and scientifically backed training protocols should be researched thoroughly. When working with specific populations such as firefighters or police officers, training protocols should produce predictable, consistent, and reliable outcomes. Such procedures should improve numerous performance variables that carry over into their respective occupations.

In recent years, labile suspension systems such as TRX or Rip:60 have become a popular means of exercise (Anderson & Behm 2005). A multitude of lower body, upper body, and full body exercises can be performed with these devices. The unstable environment that these devices produce during exercise allegedly challenges the
skeletomuscular system in a different fashion than alternate forms of resistance training (Mok et al. 2015; Anderson & Behm 2005). With the rise in popularity, it is important to assess the validity and efficacy of these exercises. They should not be flippantly prescribed to individuals who are not prepared to handle the demands of the exercise. Thus, it is imperative to assess various measurements revolved around unstable suspension exercises, including biomechanical variables such as kinematics and EMG. Such measurements will provide insight to the efficacy of these exercises as well as establishing guidelines for prescription for various populations.

Firefighters represent a population that desperately needs specific training protocols tailored to the demands of the occupation. It is known that injuries curtail the careers of many firefighters (McGill, Frost, Andersen, Crosby, & Gardiner 2013). Muscular strains represent one of the most common injuries within these populations, accounting for 57% of all injuries (Karter 2013). Among these muscular injury rates, muscular strains in the low back are most prevalent (Hofman 2012). The International Association of Firefighters stated that nearly one in five firefighters is injured during work related tasks (Hofman 2012). The mechanisms for back injury are widespread. However, much physical stress can be attributed to the protective equipment that firefighters must wear. Firefighters are required to wear personal protective equipment that weighs 50 lbs or more, and rarely have a chance to warm up before active duties and emergencies. The combination of the lack of preparation before active duties and the restrictive protective equipment places stresses on the joints which can lead to chronic and recurring injuries (Hofman 2012). However, training individuals to handle the
common demands of occupation can reduce the rates of injury. The prevention of these injuries would drastically reduce costs such as workers compensation, rehabilitation, and employment lost time. Also, by improving physical performance, firefighters will be able to perform tasks more efficiently.

In efforts to improve locomotive function and fitness, core exercises often get prescribed to individuals. The “core” is generally defined as the muscles that surround and stabilize the spine. There are multitudes of core exercises that can be performed, including labile suspension exercises, which can enhance the performance of these muscles. Not all core exercises are considered advantageous or safe though. The supine sit-up is a common form of a core exercise that trains the rectus abdominis through flexion of the spine. Callaghan and McGill (2001) state that sit ups produce high levels of compression and flexion on the lumbar spine, which are mechanisms for vertebral disk herniations. Such exercises would be a poor choice for a firefighter who has sustained a back injury and is intolerant to high levels of compressive forces on the spine. On the contrary, there are more appropriate exercises that challenge the abdominal wall without placing such excessive demands on the spine. McGill and colleagues (2013) has demonstrated that there are far superior exercises that challenge the abdominal wall without the concomitant spinal cost. Lee and McGill (2015) have shown the benefits of long term isometric training on torso stiffness displaying that it was indeed effective in improving core stiffness. Additionally, McGill (2009) proposes that the abdominal wall is not designed for optimal length change, but rather to function as a spring that bears loads, limits painful micromovements of the vertebrae, and promotes distal limb performance.
Thus, it is important that these muscles are trained in this fashion. There are several suspension core exercises that train the anterior core while promoting a neutral spine and limited lumbar flexion. Biomechanical analysis of these exercises will provide the necessary insight to whether or not these exercises are effective. Furthermore, the analysis will help determine if these exercises can safely be administered to tactical populations with a high prevalence of back injury. Currently there is insufficient data on the multitude of core exercises that can be performed on a suspension system. There are studies on pushing (McGill, Cannon, & Andersen 2013) and pulling (McGill, Cannon, & Andersen 2014a) exercises on labile surfaces and EMG analysis studies on stable versus labile planks (Snarr & Esco 2014). However, there are numerous other core exercises that should be quantified particularly in light of prescribing effective exercises and improving performance.

**Statement of Purpose**

The purpose of the study was to examine the kinematics and muscular activity (EMG) of the lumbar spine while performing several labile suspension exercises in firefighters. Understanding the dynamics of these exercises will have implications in rehabilitation and performance enhancement training programs that modulate the risk of low back pain and injury.

**Statement of Problem**

A wide array of core and abdominal exercises routinely get prescribed to various populations ranging from healthy participants to symptomatic low back pain subjects. Exercise prescription should be governed by injury history, training goals, and current
fitness level. Exercises that may be advantageous for one individual may not be advantageous for another. Given that different exercises place different magnitudes on the lumbar spine, it is essential to measure the effects of such exercises. Such assessments are required to determine injury mechanisms, establish injury-avoidance protocols, and evaluate performance potential. Few studies have evaluated the effects that labile suspension systems place on the torso musculature during dynamic core exercises. The intent of this study was to determine the effects of several dynamic core exercises on the lumbar spine musculature while using a labile suspension system (TRX).

**Hypotheses**

The suspension exercises will elicit a co-contraction of the antero-posterior torso musculature and produce substantial abdominal activation and moderate erector spinae activation. The pike exercise will exhibit the highest %MVC\_p-phase and Peak %MVC in both the rectus abdominis and external obliques during when compared to the control. The average peak MVC for erector spinae will be similar between each exercise.

**Definition of Terms**

1.) Kinematics:

The term used for the description of human movement is kinematics. “Kinematics is not concerned with forces, internal or external, that cause movement, but rather with the details of movement itself” (Winter 2009).

2.) EMG:

The electrical signal associated with the contraction of a muscle is called an electromyogram (EMG).
3.) TRX: A labile suspension system, akin to Olympic rings, used to perform various exercises that challenge the entire musculoskeletal system. Multi-planar and multi-joint movements can be performed against gravity with bodyweight resistance.

4.) $\%\text{MVC}_{p\text{-phase}}$: Percentage of maximal voluntary isometric contraction at the peak phase ($p$-phase) using a 50-frame (0.5 sec) average.

5.) Peak $\%\text{MVC}$: Percentage of maximal voluntary isometric contraction using a 10-frame (0.1 sec) average.

**Limitations**

1.) EMG Feedback: Electrode conductivity issues and signal noise could impair EMG feedback

2.) Lumbar angle was viewed as a rigid segment. Intervertebral flexion displacements could not be measured.

3.) Subjects were all very physically fit. Subjects were familiar with resistance training, but there was no known information regarding their history with using a TRX. Deconditioned populations might have an altered EMG response to the exercises.

**Delimitations**

1.) The results of this study can be generalizable to firefighters.

2.) The firefighters had no requirement of TRX experience.

**Assumptions**

1.) Lumbar angle segments were displayed as rigid segments.
Chapter Two

REVIEW OF LITERATURE

Introduction

The review of literature explores the following areas of study: kinematics, electromyography (EMG), functional anatomy, suspension system devices (TRX), injury mechanisms, occupational demands, and injury prevention. The following sections provide the biomechanical foundation for exercise assessment and prescription, the implications of functional anatomy as it relates to exercise, and the mechanisms of pain and injury that can be prevented through appropriate exercise modulation.

Kinematics

Kinematics are essential to measuring variables such as speed, velocity, angular motion, and acceleration (McGinnis 2005). Limb segment angle calculation is vital in determining variables such as lumbar flexion and hip flexion angles. Given that cyclic lumbar flexion motor patterns, especially under compressive forces, are mechanisms for disc herniations (Leibenson 1996), determining the spine angle will assist in determining the efficacy of respective exercises.

Much research has been done on kinematic variability in the lumbar spine and its associations with pain and injury. Abnormal gait patterns have been suggested to lead to chronic low back pain. Steele et al. (2014) reported that healthy individuals have “low stride-to-stride variability in kinematic patterns,” whereas patients with chronic back pain have “greater stride-to-stride variability at the lumbar spine in all movement planes.” Further research has suggested that “kinematic variability combined with poor erector
spinae activity is associated with chronic low back pain” (Lamoth et al. 2006a). Also, it has been shown that subjects with low back pain (LBP) have less lumbar rotation than non-back pain subjects (Gombatto et al. 2015) and that such motor patterns are associated with reduced lumbar erector strength (Steele et al. 2014). Excessive lumbar extensor activity has also been shown to be linked to low back pain (Hanada, Johnson, & Hubley-Kozey 2011; Vogt, Pfeifer, & Banzer 2003). It appears that poor extensor strength and endurance can lead to either underactivity or excessive activity of the lumbar extensors. Steele et al. (2014) proposes that a reduction in lumbar extensor strength and endurance is the culprit of higher levels of activity in the lumbar extensors and compromised lumbar kinematics during gait in patients with LBP. Hart et al. (2009) further demonstrated that fatigue in the lumbar extensors affects lumbar kinematics in subjects with low back pain. Additionally, Lamoth et al. (2006b) documented that LBP patients display a motor control deficiency during gait which negatively affected coordination and adaptability to velocity changes. While deficits in motor control, coordination, and strength can result in low back pain, low back pain can conversely alter movement patterns (McGill et al. 2013). Pain can result in adopting compensatory movement strategies to accommodate the discomfort. This can be seen in a variety of different contexts such as when an individual sprains an ankle and consequently limps from pain. This changes the mechanics throughout the anatomical linkage (McGill et al. 2013). Since it is hypothesized that the TRX exercises will elicit moderate erector spinae activity and co-contraction of the antero-posterior torso musculature, it could be inferred that the
exercises will strengthen the lumbar erectors and abdominal muscles and assist in reversing the negative effects of poor lumbar extensor activity.

**Electromyography (EMG)**

Recording of EMG data will be measured through electrodes attached to muscle bellies. There are many variables that affect the signaling of EMG data. Such variables include the velocity of shortening or lengthening of the muscle, rate of tension build-up, fatigue, and reflex activity (Winter 2009). EMG data can be paired with kinematic data to determine muscle contribution during exercise. Several studies have evaluated the myoelectric activity during various exercises while using a labile suspension system. One particular study showed that the rectus abdominus was activated to levels ranging from 110-130% of maximum voluntary contraction (MVC) during several anterior core exercises (McGill, Cannon, & Anderson 2014b). In the same study, the suspension system body-saw exercise elicited 103% MVC in the rectus abdominus. Another study showed that suspension push-up exercises elicit greater abdominal myoelectric activity than a standard push-up (McGill, Cannon, & Anderson 2013).

Numerous studies have measured associations between back pain and torso musculature activity. One study reported that during gait subjects without back pain activated their rectus abdominis and internal obliques significantly more than the subjects with chronic back pain (Hanada, Johnson, & Hubley-Kozey 2011). Another study demonstrated that EMG activity in the external obliques during bridging exercises were significantly higher in asymptomatic tennis players when compared to tennis players with low back pain (Correia et al. 2015). Spinal extensor fatigability is also associated with
chronic LBP. In one study, da Silva et al. (2015) reported that both younger and older subjects with chronic LBP displayed more distinct EMG erector fatigue than those without LBP during two different isometric fatigue protocols. The reactivity of muscles appears to play a role in pain attenuation as well. Hodges and Richardson (1996) elucidated that people with LBP tend to display a delay in contraction of several spinal muscles (transverse abdominis and internal obliques) during the onset of movement when compared to subjects without back pain. Subjects with a history of LBP with movement also display similar delayed recruitment patterns in the transverse abdominis and internal obliques with a variety of different limb speeds (Hodges & Richardson 1999). Additionally, Suehiro et al. (2015) reported that subjects with LBP display a delay in bilateral multifidus and contralateral erector spinae contractility during prone hip extension when compared to healthy individuals. This suggests that dysfunction in neuromuscular reactivity seems to be associated with lower levels of spinal stabilization.

On the contrary, there appears to be inconsistencies in information regarding EMG activity and pain. Some researchers have displayed that higher levels of abdominal activity rather than lower levels of abdominal activity can be associated with low back pain. Silfies et al. (2005) documented that subjects with chronic LBP had significantly higher levels of rectus abdominus and external obliques than their counterparts without LBP. Higher levels of back extensor activity have been associated with pain as well. Hanada, Johnson, and Hubley-Kozey (2011) reported that a group of subjects with chronic back pain recorded greater levels of lumbar extensor activity during gait. The implication of the study is that the subjects overly rely on their lumbar extensors for
spinal stability. This coincides with McGill’s (2002) literature which states that overreliance on extensor muscles causes excessive fatigue in the erectors, consequently leading to overuse and pain. McGill further shows that this can be attributed to faulty motor patterns and deficient postural awareness.

It appears that muscular recruitment strategies seem to differ between patients with and without LBP. Some individuals with LBP seem to have higher levels of abdominal activity as a stabilizing strategy for pain modulation and a compensatory pattern for reduced spinal stability. However, other individuals with LBP seem to have aberrant and delayed recruitment patterns in spinal muscles during activities which results in lower levels of spine stability and subsequent low back pain. To date there is no literature that reveals optimal recruitment patterns. However, O’Sullivan et al. (1997) investigated ratios of abdominal activation patterns and found that subjects with LBP have compensatory recruitment patterns when compared to a healthy control group. This study indicated that healthy subjects are able to activate the internal obliques without activating concomitant levels of the rectus abdominus during an abdominal hollowing maneuver. Subjects with LBP, on the contrary, were unable to replicate a similar ratio of abdominal activation. Similar findings were established in another study which showed that chronic LBP subjects had lower external oblique and rectus abdominus ratios. The study emphasized that there were higher levels of rectus abdominus activity compared to internal and external oblique activity in LBP subjects (Silfies et al. 2005).
Functional Anatomy of Lumbar Spine

Comprehension of the functional anatomy of the spine is integral to understanding the mechanisms that lead to pain and injury. It also serves to provide rationale for pain and injury management. The spine is one of the most complex regions of the body. The spine is comprised of a network of bones, joints, ligaments, and muscles that all contribute to spinal movement (Prentice 2010). The intricate relationship between the nervous system and the spine adds to the complexity of this region. The paper will focus on the lumbar spine, sacrum, coccyx, and their active and passive surrounding structures.

Spine Structure, Vertebrae, and Intervertebral Discs

The spine, or vertebral column, consists of thirty three individual bones, known as vertebrae. Twenty four are categorized as movable, or true, and nine are categorized as immovable, or false. The movable vertebrae are further classified as the cervical spine (upper seven vertebrae), thoracic spine (middle twelve vertebrae), and lumbar spine (lower five vertebrae). The immovable vertebrae form the sacrum and coccyx (Prentice 2010). The vertebral bodies consist of a small mass of cancellous bone encased in a shell of cortical bone (McGill 2009).

Fibrocartilaginous structures known as intervertebral discs lie between each vertebrae. Each disk contains an outer layer of fibrous tissue known as the annulus fibrosous, and an inner semifluid nucleus pulposus (Oliver and Middleditch 1991). Discs have “tension-resisting properties of a ligament and compression resisting properties of joint cartilage” (Izzo et al. 2013). The fibers of the annulus control micro movements between vertebral segments and the nucleus pulposus acts as the main shock absorber.
Lumbar Spine, Sacrum, and Pelvis

The lumbar spine consists of five large vertebrae which serve to support the low back. Movement occurs in the lumbar region, but there is much less flexion than extension. The sacrum is formed by the fusion of the five vertebrae and comprises the pelvis with the hip bones. The coccyx, or tailbone, is the most inferior part of the spine and consists of four or more fused vertebrae. The sacrum is attached to the pelvis via numerous fibrous ligaments and tendons (Prentice 2010). The lumbar spine is fixed to the sacrum which is attached to the ilium of the pelvis. The pelvis provides a platform for the spine (McGill 2009).

Active and Passive Structures

The musculature surrounding the spine is also a complex network of systems that serve to produce and prevent motion about the spinal column (McGill 2009). The muscles that flex and extend the spine and rotate the vertebral column can be classified as either superficial or deep (Prentice 2010).

On the posterior aspect of the spine, there are superficial muscles known as the erector spinae which attach and extend vertically on each side of the spinal column. The erector musculature can be split into three columns known as the longissimus group, iliocostalis group, and spinalis group (Prentice 2010). The muscles can be further categorized into lumbar and thoracic components which each display unique architectural (Bogduk 1980) and functional differences (McGill & Norman 1987). The thoracic components of longissimus and iliocostalis spread in a line parallel to the compressive axis of the spine. This is advantageous for performing both lumbar and thoracic extension.
without accruing excessive compressive forces on the spine (McGill 2009). The lumbar components, on the contrary, have a posterior shear component. This structural design allows for resistance to anterior shear forces when in a neutral spine. In lumbar flexion, the structure loses its shearing line of action, and becomes vulnerable to anterior shear forces (McGill, Hughson, & Parks 2000).

The latissimus dorsi is another superficial posterior spinal muscle that spans from the lumbar spinous process to the humerus. It is a large muscle that wraps around the rib cage, encompasses the lumbar erectors, and serves as the body’s “natural” back belt. The structural design of this muscle functions as a very large extensor moment arm. Aside from adducting and internally rotating the humerus, it performs both lumbar extension and spinal stabilization roles (McGill 2002; Oliver & Middleditch 1991; Prentice 2010).

There are numerous deep active structures that surround, support, and stabilize the spine. The quadratus lumborum, for instance, is a deep posterior muscle that lays dorsal to the iliopsoas muscle and attaches the rib cage to the pelvis. It is essentially involved in all spinal activities. It bilaterally extends and laterally flexes the spine (Oliver & Middleditch 1991), and compresses and stabilizes the spine in an upright position (McGill 2009). The deepest muscles of the back are smaller structures that are arranged longitudinally and connect at adjacent vertebrae. These muscles include the multifidus, interspinalis, rotatores, semispinales” (Prentice 2010). The multifidus muscles extend up the spine in segments and run parallel to the compressive axis (McGill 2009). The multifidi along with the other deep muscles are involved in extending and stabilizing the spine (Oliver & Middleditch 1991).
The gluteal musculature, along with the torso muscles, plays a significant role in spinal stability. The gluteus maximus main function is to provide hip extension and external rotation. The gluteus medius and minimus main function is internal rotation and abduction of the hip. However, all of these gluteal muscles play a significant role in stabilizing the hip and spine during single leg stances, gait, or change of direction (McGill 2009).

The anterior portion of the spine is comprised of the abdominal wall musculature. The rectus abdominis, external and internal obliques, and transverse abdominis form the abdominal wall and extend longitudinally from the ribcage to the pelvis. Each muscle group plays a role in creating movement about the spine including flexion, lateral flexion, and rotation of the torso. Additionally, abdominal contraction creates compression of the abdominopelvic cavity (Prentice 2010). The abdominal structures also function harmoniously to prevent motion in all planes by resisting extension, lateral flexion, and rotation. For instance, when standing and pushing an object or load, the spine must stiffen with an abdominal contraction. In this instance, there is no motion about the spine, but the abdominals nevertheless activate to resist motion (extension) about the spine. Lastly, the abdominals are well designed to serve as a “short-range stiff spring” which “enhances torso stiffness to eliminate energy leaks for efficient transmission of power and stores and recovers elastic energy” (McGill 2009). For example, when the torso stiffens while throwing a punch, more mechanical energy can be transferred to the musculature responsible in the punch.
The iliopsoas muscles are comprised of the large psoas muscle and iliacus. The psoas muscle plays a significant role in spinal function given its attachment points on the lumbar spine (Oliver & Middleditch 1991). These muscles serve as a hip flexor and lumbar spine stabilizer when active (McGill 2009). The muscular system incorporates a complex interplay of all these structures to create fluid and coordinated locomotion.

Ligaments are the inert structures that attach bones together to form joints (Prentice 2010). They serve as passive stabilizers by restricting motion (Oliver and Middleditch 1991). The ligaments surrounding the lumbar spine are generally denser and thicker than the ligaments higher up on the spine. The anterior longitudinal ligament prevents anterior separation of the vertebral bodies during extension and stabilizes lumbar lordosis. The posterior longitudinal ligaments resist posterior separation of the vertebrae. The short and thick ligamenta flava is an elastic tissue that prevents the intervertebral discs from excessive range of motion. The interspinous and supraspinous ligaments connect to the spinous processes of the vertebrae and resist separation of the spinous processes during flexion. The intertransverse and transforaminal ligaments are less dense in nature and serve as connective tissue. The thick and powerful iliolumbar ligaments stabilize the lumbosacral complex (Oliver & Middleditch 1991).

**Suspension System Devices (TRX)**

Labile suspension systems are exercise devices which allow for multi-planar and compound movements against gravity while using bodyweight as resistance (Mok et al. 2015). The devices consist of handle straps and stirrups at the ends of a suspension cable. It can be attached to a stable overhead surface (i.e., ceiling or wall) anchor point. The
intensity of an exercise on a suspension device can be manipulated by changing the inclination of the body from an upright position. Some research has elucidated the activation profiles of various core exercises while using a suspension apparatus. Various suspension system exercises have been shown to elicit greater core musculature activation levels when compared to similar exercises on stable and unstable surfaces (Mok et al. 2015; Vera-Garcia, Grenier, & McGill 2000). Another study showed that abdominal muscle activation was greater in several suspension plank exercises when compared to a floor based plank (Byrne et al. 2014). Muscular activity and spinal loads have also been quantified during suspension pushing and pulling exercises (McGill, Anderson, & Cannon 2013). These studies have revealed that the labile suspension exercises generally produced higher levels of abdominal activity but were still sparing of the spine.

**Injury Mechanisms**

The lumbar spine, devoid of musculature, is an inherently unstable structure that buckles under compressive loads of only 90 N (Cholewicki & McGill 1996). The spine routinely undergoes compressive loads of 6000 N during demanding daily tasks. Such loads subject the spine to a high risk of injury. Pain and injury sustained to the spine can be the result of congenital or idiopathic (mechanical or traumatic) causes (Prentice 2010). Injuries range from acute to chronic pain, vertebral fractures to dislocations, muscular strains to ligamentous sprains, myofascial pain, contusions, spondylolysis to spondylolisthesis, and herniated disks. However, “most low back injuries are not the result of single exposure to a high magnitude load, but instead cumulative trauma from
sub failure magnitude loads” (Liebenson 1996). Low back injury can be greatly attributed to a history of disproportionate loading which steadily lowers tissue failure tolerance (McGill 1998). Additionally, cycles of repeated flexion motion is correlated with disc herniations (Callaghan & McGill 2001), especially if coupled with lateral bending and twisting (Adams, Dolan, & Hutton 1987). Repetitive twisting of the spine has been shown to slowly delaminate the fibers of the annulus, which can lead to a herniation (McGill 2009). This process is exacerbated under compressive and torsional loads.

Injuries to the posterior elements have been shown to be related to cyclic full flexion and extension (Burnett et al. 1996), as well as excessive shear forces (Liebenson 1996). Large compressive loads can lead to microfractures across the growth plate on the vertebrae. Microfractures to the trabeculae can also lead to “secondary plate fractures, schmorles nodes, and disc herniation” (McGill 2009).

In the context of firefighting, musculoskeletal injury mechanisms are often associated with “direct trauma, falling episodes, being struck by an object, carrying heavy objects/patient transport, overexertion, physical training, and fire operations” (Abel, Palmer, & Trubee 2015). In a study performed by Poplin et al. (2012), lifting exertions, such as patient transport, accounted for over three-quarters of all sprains and strains, which predominantly occurred in the low back. Thus, the lumbar spine region is of utmost concern when training firefighters to withstand the occupational demands.

**Occupational Demands of Firefighting**

Tactical populations, particularly firefighters, have physically rigorous occupations. The significant mental and physical demands of firefighting can cause
various negative health side effects to firefighters. Cardiovascular disease, respiratory conditions, and musculoskeletal injury are among some of the common ailments associated with the occupation.

Normal firefighting duty hours include long periods of down time in which many firefighters are sedentary. Apart from fighting structural fires, firefighters routinely respond to medical emergencies, hazardous materials, motor vehicle accidents, and rescue situations (Hofman 2012). In 2009, 65% of department calls were in response to medical aid, whereas only 5% of calls were in response to actual fires (Hofman 2012). Firefighters also routinely undergo tasks in an array of different environments. Fire suppression operations appear to induce the most severe physiological responses. Brown and Stickford (2007) demonstrated that the search and rescue operations elicited the highest mean and maximal heart rates and relative maximal heart rates. Maximal heart rates reached up to 170 bpm in these environments. Fire attacks and ventilation operations also elicited relatively high heart rates, reaching up to 163 bpm. Some of these elevated heart rates were sustained up to 20-40 minutes. Many of the physical tasks encountered in these scenarios require “whole-body-kinetic chain movements, which result in unpredictable loads and load transfer, resulting in musculoskeletal injury” (Abel, Palmer, & Trubee 2015). Smith (2011) reported that firefighting duties have also been shown to cause significant drops in plasma volume due to profuse sweating. This is associated with hyperthermia, dehydration, and a reduction in stroke volume which increases cardiac strain and impairs cognitive performance. Such demands also inevitably
lead to physiological fatigue which can lead to poor performance and increased injury risk (Dennison et al. 2012; Smith 2011).

Much physical stress can be attributed to the protective equipment that firefighters must wear. Firefighters are required to wear unwieldy personal protective equipment that weighs 50 lbs or more and rarely have a chance to warm up before active duties and emergencies (Hofman 2012). It has been shown that the protective equipment even significantly limits range of motion while negatively impacting gait (Park et al. 2015). Firefighters are required to perform various tasks while on duty such as pulling hoses and ceilings, carrying ladders, transporting equipment, extinguishing fires, and victim search-and-rescue, all while wearing cumbersome protective gear (Levels et al. 2014). Fire operations often include slippery surfaces, space limitations, and limited visibility. The restrictions or limitations of mobility in such environments may increase the loads on firefighters and put them at higher risk for injury.

Some research has been provided on the biomechanical analysis of fire ground tasks. Abel, Palmer, and Trublee (2015) have compiled a detailed analysis of muscle and joint actions during common firefighting duties. The abdominal musculature is heavily recruited in various tasks including stair climbs with hose packs, hose hoists, walking and kneeling hose pulls, lifting exertions, forcible entry, victim drags, and breach and pull.

**Injury Prevention**

Given the severe physical demands of firefighting, researchers have sought to quantify appropriate standards for muscular strength and endurance for firefighting duties (Smith 2011). It has been shown that being physically fit is correlated to lower levels of
injury risk and higher levels of job performance in firefighters (Rhea, Alvar, & Gray 2004). Since the lumbar spine is an inherently unstable structure, training the spinal muscles is essential in injury prevention. The spinal column and muscles ultimately work in unison to bear compressive, shear, tensional and torsional loads on the spine to resist buckling (Leibenson 1996). Spine stability is achieved with “balanced” stiffening from the entire musculature surrounding the torso, including the rectus abdominis and the abdominal wall, quadratus lumborum, latissimus dorsi and the back extensors of longissimus, iliocostalis and multifidus (McGill 2009). Merely “training single muscles generally does not enhance stability but creates patterns that when quantified result in less stability.” Muscles, therefore, should not be trained in isolation. Rather, co-activation, or stiffening, of the spinal muscles will result in a more stable spine. Panjabi (1992) conceptualized a spinal stabilizing system that is comprised of three subsystems that all contribute to creating spinal stability. These subsystems include the spinal column and ligaments (passive stabilizers), spinal muscles (active stabilizers), and the neural system. The congruous interplay of all these systems serves to stabilize the spine under normal conditions. However, McGill (2009) states that modern living does not groove the muscular system. Rather, in many people the muscular system loses its integrity. Thus, it is vital that the muscular system be routinely challenged to prevent stagnation.

Exercise type and intensity must be carefully selected for each individual, especially for those with troubled backs. There is a small margin of safety when choosing exercise intensity for those with spinal issues. The dosage of exercise required to elicit positive adaptation is very close to the load that will make an injury worse (McGill
2009). Liebenson (1996) states that to prevent injury, the training adaptation must match the progression of exercise intensity. Thus, as an individual adapts to a particular stimuli, increases in intensity are necessary to stimulate further adaptation. Additionally, “exposure to load must also be temporarily removed so that normal healing/adaptation process can fulfill its objective of increasing the failure tolerance of the tissues” (Liebenson 1996). This can pertain to including scheduled bouts of rest and recovery which can maximize adaptations.

It has been documented that firefighters require a balanced level of fitness which includes a blend of aerobic fitness, anaerobic capacity, and muscular strength and endurance (Smith 2011). The array of physical demands placed on firefighters is associated with risk of injury. Thus, exercise prescription should be governed by an individual’s fitness level, injury history, and training goals. Exercises should produce enough challenge to elicit adaptation without placing excessive stress on the individual. Exercises that replicate movement patterns associated with injury mechanisms should be avoided.
Chapter Three

METHODOLOGY

Overall

Six subjects performed several “core” exercises on a labile suspension system while muscle activity and 3D body segment motion was recorded.

Subjects

There were six subjects. Each subject is currently enlisted in a local fire department, considered healthy, and does not have any recent history of disabling musculoskeletal injuries. Each subject was familiar with resistance training. Subjects completed a written consent form that was approved by California State University of Sacramento.

Equipment

3D Body Segment Kinematics and Marker Placement

10 reflective markers were bilaterally adhered to the skin on the following anatomical landmarks: lateral femoral condyles, greater trochanters, anterior superior iliac spine, lateral rib (T12-L1 height), and acromioclavicular joints. The VICON motion capture system tracked the 3D coordinates with a sampling rate of 100 Hz. Data was smoothed with a Butterworth filter via the Vicon system. Lumbar spine and hip kinematics were calculated for each exercise.

Electromyography

Six channels of EMG was collected by placing electrode pairs bilaterally over the following muscles: rectus abdominis (RA), external oblique (EO), and lumbar erector
spinae (LES). The MyoSystem 2000 EMG/VICON system tracked the muscle activation patterns with a sampling rate of a 100 Hz.

Each subject performed maximal voluntary isometric contractions (MVC) for each muscle group. MVCs were used for normalizing the data for each participant. Several normalization techniques were used to achieve maximal isometric activation while minimizing risk of back injury (McGill, Andersen, and Cannon 2015; Vera-Garcia, Moreside, and McGill 2010). The abdominal muscles were measured from a sit-up position with the knees and hips flexed at 90°. The torso was positioned approximately 45° to the horizontal. The subjects’ feet were manually anchored by a research assistant or secured under a fixed object. The rectus abdominis were normalized to a maximal isometric flexion resistance. The external obliques were normalized to a twisting manual resistance. The MVC for lumbar erector spinae involved a resisted maximal extension in the Biering-Sorensen position. Muscle activation profiles and intensities were taken for each exercise and were reported as %MVC. The Average %MVC_{p-phase} was measured by taking a corresponding 50-frame %MVC average of the peak phases (p-phase) between both repetitions (Figure 1, top). P-phases were determined by the maximum lumbar spine angle in the pike exercise and maximum thigh angles in the knee tuck and alternating knee tuck exercises. A 10-frame average was used for Peak %MVC_{avg} (see Figure 1, bottom).
Exercise Description

Three different popular TRX “core” exercises were quantified and compared to a TRX Plank (see Figure 2). They were categorized as a TRX knee tuck (KT), TRX alternating knee tuck (AKT), and TRX pike. Subjects were required to place their hands in a fixed position on the floor for each exercise. Subjects’ feet were secured to the suspension system for each exercise. Each exercise was randomly prescribed. Each subject underwent a familiarization process for each exercise. The TRX Plank (control)
was performed prior to the other exercise conditions. Subjects were required to hold the plank for eight seconds. The knee tuck exercise required the subject to pull the knees and hips into full flexion, pulling the knees towards the midline of the torso (see figure 3, top). Each subject was coached to generate the movement primarily with the abdominals and hip flexors while reducing movement in the spine and preventing excessive lumbar flexion. The alternating knee tuck was performed in a similar fashion, but rather than tucking the knees bilaterally, the movement was performed by tucking each knee unilaterally while alternating each leg (see figure 3, middle). Similar coaching cues were used. The pike exercise required full flexion at the hip without flexion in the knees. The torso angle shifted upwards as the hips were pulled into flexion (see figure 3, bottom). Neutral spine angle was encouraged during each exercise. Two repetitions were performed with a 2:2 second cadence on the concentric and eccentric portion of each exercise. It was noted that although the subjects were all familiar with resistance training, there was no known information regarding their prior experience with TRX suspension training.

Figure 2. TRX Straight Arm Plank (control)
Figure 3. Knee Tuck (top), Alternating Knee Tuck (middle), Pike (bottom)

Statistical Analysis

Data was reported as mean ± SD for the %MVC<sub>p-phase</sub> and Peak %MVC for each of the six muscles groups during each exercise condition. Dependent t-tests (p = 0.015) were used to detect differences between the TRX Plank (control) condition and each of the TRX core exercises.
Chapter 4
RESULTS

The purpose of the study was to examine the kinematics and muscular activity (EMG) of the lumbar spine while performing several labile suspension exercises in firefighters. Understanding the dynamics of these exercises will have implications in rehabilitation and performance enhancement training programs that modulate the risk of low back pain and injury. There were a total of six subjects involved in the study.

**Average \( \%MVC_{p-phase} \)**

Muscle activation profiles at peak phase for each muscle group are presented in Table 1. The pike exercise elicited the highest mean \( \%MVC_{p-phase} \) for the LO (45% ± 24%) and RO (53% ± 18%). Differences in mean left and right oblique activity are shown in Table 2. The dependent t-test indicated no significant differences (\( p < 0.015 \)) between the TRX plank and TRX Knee Tuck for each muscle group. Significant differences were identified in the RO between the TRX plank and both the TRX Alternating Knee Tuck (\( p = 0.007 \)) and TRX Pike (\( p = 0.0008 \)).
Table 1. Mean and standard deviation of %MVC at the peak phase

<table>
<thead>
<tr>
<th>Mean Values</th>
<th>Exercises</th>
<th>Knee tuck (KT)</th>
<th>Alt. Knee Tuck (AKT)</th>
<th>Pike</th>
<th>Plank (control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.Erector</td>
<td>11% (4%)</td>
<td>11% (4%)</td>
<td>12% (4%)</td>
<td>10% (5%)</td>
<td></td>
</tr>
<tr>
<td>R.Erector</td>
<td>10% (4%)</td>
<td>10% (4%)</td>
<td>9% (5%)</td>
<td>9% (4%)</td>
<td></td>
</tr>
<tr>
<td>L.Oblique</td>
<td>39% (16%)</td>
<td>39% (16%)</td>
<td>45% (24%)</td>
<td>30% (16%)</td>
<td></td>
</tr>
<tr>
<td>R.Oblique</td>
<td>36% (18%)</td>
<td>37%* (11%)</td>
<td>53%* (18%)</td>
<td>22% (4%)</td>
<td></td>
</tr>
<tr>
<td>L.Rectus A.</td>
<td>42% (25%)</td>
<td>35% (30%)</td>
<td>35% (34%)</td>
<td>44% (25%)</td>
<td></td>
</tr>
<tr>
<td>R.Rectus A.</td>
<td>32% (11%)</td>
<td>34% (11%)</td>
<td>26% (15%)</td>
<td>31% (13%)</td>
<td></td>
</tr>
</tbody>
</table>

(*) Significantly different (p < 0.015) than plank condition

Figure 4. %MVC at Peak Phase: Left and Right Obliques (LEO and REO)
Peak %MVC

Peak muscle activation profiles for each muscle group are presented in Table 3. The pike elicited the highest mean Peak %MVC for the LE (19% ± 12%), LO (64% ± 19%), RO (84% ± 30%), and RRA (58% ± 17%). Significant differences were identified in the LO (KT, p = 0.006; AKT, p = 0.005, Pike, p = 0.003) and RO (KT, p = 0.008, AKT, p = 0.006, Pike, p = 0.0002) between the control condition and exercise conditions. Significant differences were also observed in the RRA between the TRX Plank and each of the TRX Knee Tuck (p = 0.002) and TRX Pike (p = 0.005) conditions.

<table>
<thead>
<tr>
<th>Table 2. Mean and standard deviation of peak %MVC</th>
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<tr>
<td>Mean Values</td>
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<tr>
<td>L.Erector</td>
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<tr>
<td>L.Rectus A.</td>
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<tr>
<td>R.Rectus A.</td>
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(*) Significantly different (p < 0.015) than plank condition
Chapter 5
DISCUSSION

General Findings

The findings of this study support that the TRX suspension exercises provide a significant abdominal challenge, namely in the LO and RO for each exercise condition. The external obliques have several functions including roles in trunk flexion, torso twisting, lateral bending, and lumbar stabilization (McGill 2002). The obliques appear to be involved in producing trunk flexion torques and lumbar stabilization across each exercise condition, while additionally resisting rotation during the alternating knee tuck condition. Greater levels of oblique activation during the pike exercise may be attributed to increased stability demands at various points of the exercise. This is congruent with Hildenbrand & Noble’s (2004) findings which state that the external obliques assist the rectus abdominis with torso flexion when greater forces are required.

There are degrees of muscle activity associated with every task. The data presented in this study coincides with preexisting research that the instability of labile suspension exercises in general elicits increased abdominal activation patterns (Byrne et al. 2014; McGill, Cannon, & Anderson 2014a). The exercise conditions used in this study also produced LES activity that was comparable to similar labile suspension exercises in other studies (Snarr & Esco 2014; McGill, Cannon, & Anderson 2014b).

Injury Prevention Implications

Given the high prevalence of low back injury in firefighters (Hofman 2012), appropriate exercise intervention needs to be evaluated. It is generally accepted that
increasing core strength can significantly reduce the incidence of lower back injuries (Abel, Palmer & Trubee 2015; Snarr and Esco 2014). Nevertheless, exercise prescription should match an individual’s level of fitness, injury history, and training goals. The data in this study could be useful as a diagnostic tool for exercise progressions and regressions. The information provided can assist in determining exercise selection based off a continuum of differences in exercise intensity. Based on EMG activations alone, appropriate progressions could range from lower intensity exercises such as the TRX Straight Arm Plank to more challenging variations, when warranted, such as the TRX Pike.

Exercise prescription should engrain generalizable movement patterns that are linked to a lower injury risk (i.e. neutral spine versus spine flexion). In an article regarding exercise based performance enhancement and injury prevention in firefighters, Frost et al. (2015) states that the degree to which exercise adaptations transfer is likely task specific, but that firefighters who received “movement-oriented exercise instructions and feedback were less likely to use “risky” movement behaviors in unrehearsed tasks.” Within that frame of logic, the TRX exercises not only produced substantial abdominal challenge and torso stability in the firefighters, but subjects were also coached to preserve a neutral spine, which is a spine sparing strategy (McGill 2009). This appears to coincide with the kinematic data which reveal that relatively small lumbar angular displacements occurred throughout the knee tuck and alternating knee tuck exercises (~26.3 degrees, 12.3 degrees respectively). Intervertebral angular displacements could not be measured directly, but the small angular displacements can be linked to a neutral position. Larger
angular displacements occurred during the pike exercise, but neutral position was still maintained from a visual standpoint. In light of known lumbar spine injury mechanisms, these exercises could be viewed as superior in terms of spinal safety when compared to exercises such as the common sit-up. The common sit-up imposes large compressive demands while going through end-range lumbar flexion, both which are mechanisms for lumbar herniations (McGill 2002). However, several similar labile suspension core exercises have already been shown to impose relatively small compressive loads on the spine (McGill, Cannon, & Anderson 2014b) especially when compared to the sit-up which imposes approximately 3300 N of compression on the spine with each repetition (McGill 2002). The firefighter would greatly benefit from substituting the contraindicated sit-up exercise with a more spine-friendly exercise such as the TRX Knee Tuck.

**Performance Enhancement Implications**

The exercises can also be used to improve occupational performance. As aforementioned, various fire ground activities require substantial torso stabilization. A walking hose pull and forcible entry tasks both require isometric and dynamic contractions of the rectus abdominus, obliques, and transverse abdominus (Abel, Palmer, and Trubee 2015). The TRX exercises certainly provide sufficient abdominal challenge to strengthen the musculature used in such tasks. The obliques, in particular, are significantly activated throughout the different TRX exercises. It would benefit the firefighter to strengthen this musculature, so that they possess the requisite physical ability to safely and effectively perform job task simulations.
Additionally, it has been suggested that to stimulate motor learning, retention, and the transfer of training, the movements performed (i.e. alternating knee tuck) should be kinematically similar to the tasks of interest (i.e. ladder climb). It is known that the abdominal wall is vitally important during firefighting duties. It has been shown that many fire ground tasks are performed in the sagittal plane and require isometric contractions for torso stabilization and unilateral ankle, knee, and hip extension (Abel, Palmer, Trubee 2015). For instance, in a stair or ladder climb with a hose pack, the rectus abdominus, external obliques, and transverse abdominus all work together to stabilize the torso, while the lower extremities go through unilateral ankle, knee, and hip extension and contralateral ankle, knee, hip flexion with each step. Similar muscle recruitment patterns can be seen in the TRX alternating knee tuck (torso stabilization combined with unilateral knee and hip flexion). Thus, by strengthening the musculature with exercises similar to job specific tasks, firefighters may be able to perform job tasks more efficiently.

**Conclusion**

Firefighters’ frequent exposure to physically demanding job tasks requires high levels of torso stability. This warrants the inclusion of effective core training in firefighting training programs. The exercises presented in this study appear to produce substantial levels of abdominal activity, particularly in the EO. The data indicate that they can be used as a viable means of exercise to strengthen the abdominal wall in firefighters. Firefighters with a history of low back injury should nevertheless use caution when selecting exercises.
Considerations for future studies

Further research can elucidate the spinal demands of the exercises proposed in this study. Quantification of spine velocities and accelerations can ascertain the level of stress placed on the lumbar spine. McGill (2009) documents that (mechanical) power is the product of force and velocity, and that “power generated in the spine is specific to angular motion of the vertebrae”. He adds that power in the back increases the risk of injury, and that higher spine velocities correlate with high risk of back troubles (McGill 2009). It would prove beneficial to measure such metrics during the suspension exercises to validate whether or not high levels of spine velocity are present.
APPENDIX A

HEALTH HISTORY FORM

AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire

Assess your health status by marking all true statements

History
You have had:

_________________ a heart attack
_________________ heart surgery
_________________ cardiac catheterization coronary
_________________ angioplasty (PTCA)
_________________ Pacemaker/implantable cardiac defibrillator
_________________ rhythm disturbance
_________________ heart valve disease
_________________ heart failure
_________________ heart transplantation
_________________ congenital heart disease

Symptoms:

_________________ You experience chest discomfort with exertion
_________________ You experience unreasonable breathlessness
_________________ You experience dizziness, fainting, or blackouts
_________________ You take heart medications

Other health issues

_________________ You have diabetes
_________________ You have asthma or other lung disease
_________________ You have burning or cramping sensation in your lower legs when walking short distances
_________________ You have musculoskeletal problems that limit your physical activity
_________________ You have concerns about the safety of exercise
_________________ You take prescription medication(s)
_________________ You are pregnant

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Cardiovascular risk factor

_________________ You are a man older than 45 years
_________________ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal
___________________ You smoke, or quit smoking within the previous 6 months
___________________ Your blood pressure is >140/90 mm Hg
___________________ You do not know your blood pressure
___________________ You take blood pressure medication
___________________ Your blood cholesterol level is > 200 mg/dl
___________________ You do not know your cholesterol level
___________________ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)

___________________ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3x per week)

___________________ You are >20 pounds overweight

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You will benefit from using our facility with a professionally qualified exercise staff to guide your exercise program.

___________________ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility including our facility that meets your exercise program needs.

APPENDIX B

INFORMED CONSENT FORM

Biomechanical Analysis of Labile Suspension Exercises on the Lumbar Spine of Firefighters

You are invited to participate in a research study which will involve the measurement of several abdominal exercises using a TRX suspension system. My name is Bret Gibson, and I am a graduate student in the Kinesiology Exercise Science department at California State University, Sacramento. You were selected as a possible participant in this study because of your association with the Firefighting Department and the widespread need to improve training protocol for tactical populations.

The purpose of this research is to investigate the biomechanical variables of several different labile suspension abdominal exercises on the lumbar spine (lower back). Quantifying the biomechanical variables will provide insight to the efficacy of these exercises in relation to spinal safety and rehabilitation. Given the high prevalence of back injuries in firefighting, I will examine these exercises to validate their effectiveness and safety to spinal health. If you decide to participate, you will be asked to initially perform a muscular strength and endurance screen. This screen will determine whether or not subjects possess the requisite abdominal strength and endurance to perform the exercises for the study. Eligible candidates will then perform three different exercises while using the TRX suspension system. These exercises include a knee tuck, an alternating knee tuck, and a pike. Each subject will undergo a familiarization process before performing the exercises. Several measurements will be recorded during the study, including joint angles and muscle activity patterns. Reflective markers will be adhered to various landmarks on your body. A sophisticated series of cameras will detect the various reflective markers to generate stick figure representations of your movement patterns. Additionally, electrodes that measure muscle activity will be adhered to the muscles surrounding the spine. Any data and information collected will be confidential and secured in the campus database. Your participation in this study will last 60-90 minutes.

There are minimal risks associated with performing the exercises in the study. Such risks include the possibility of experiencing minor lower back pain and/or incurring muscular strain. On the contrary, there are benefits associated with the research. The study will provide quantitative data for these exercises which will provide context for the appropriateness of exercise prescription. Such data can be used to compare loads by other exercises that are reported elsewhere. The results will highlight whether or not these exercises are suitable choices of exercise to use for performance enhancement and injury rehabilitation purposes.

If you have any questions about the research at any time, please call me at (916) 607-1307 or email me at bretgibson@csus.edu. If you have any questions about your rights as
a participant in a research project please call the Office of Research Affairs, California State University, Sacramento, (916) 278-5674, or email irb@csus.edu.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The data obtained will be maintained in a safe, locked location and will be destroyed after a period of three years after the study is completed.

Your participation is entirely voluntary and your decision whether or not to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you are free to discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Your signature below indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled, that you will receive a copy of this form, and that you are not waiving any legal claims, rights or remedies.

If you desire to see your results after the study, you will be provided with a copy of the data collection and analysis.

You will be offered a copy of this signed form to keep.

_________________________________________________
Print Name

_________________________________________________
Signature

___________________________
Date
REFERENCES:


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