

**Effects of Lumbar Extensor Fatigue on Ankle Joint Motion Sense and Postural
Sway**

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ABSTRACT

Falls from heights are a major concern in the occupational setting, and are often the result of a loss of balance. Lumbar extensor fatigue (LEF) increases postural sway which has been associated with degradations in balance. Study one focuses on the effects of fatiguing time and fatigue level on the duration of these increases in postural sway. Measures of postural sway were collected before fatigue and at 3 minute intervals for 30 minutes following fatigue. LEF had a significant effect on postural sway immediately following fatigue but this effect had only minor dependence on fatigue condition. During the 30 minutes following fatigue, the effects of fatiguing time and fatigue level became more apparent. Longer fatiguing time and higher fatigue levels resulted in significantly greater prolonged effects. While it is important to understand the immediate effect of LEF on sway, this study has demonstrated that the prolonged effect of such fatigue should be considered when addressing falls from heights.

Study two attempts to explain the increases in postural sway associated with LEF. The ankle plays a major role in upright standing and degradations in proprioception could contribute to increases in sway, thus the effect of LEF on ankle proprioception was studied. Additionally, the effect of circumferential ankle pressure (CAP) on ankle proprioception was assessed to evaluate it as a potential intervention to improve proprioception. Results showed that both LEF and CAP impaired proprioception. These results may help to explain observed increases in postural sway subsequent to LEF.

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Chapter 1

Introduction to falls from heights and their significance to our society

1.1 Fall statistics

Falls from heights are one of the three leading causes of occupational deaths in the United States, accounting for approximately 700 deaths annually (BLS 2004). In the year 2000, for example, 717 workers died of injuries caused by falls from ladders, scaffolds, buildings, or other elevations (NIOSH 2001). Approximately half of these deaths occurred in the construction industry, which is considered one of the most hazardous sectors of the workforce. Even when death is averted, falls from heights are a major source of injury. An estimated 100,000 workers in the construction industry are seriously injured each year as a result of falls from heights (OSHA 1998).

1.2 Reducing falls from heights

In order to address these falls and attempt to reduce the rate of injury and death, two strategies can be applied; one of fall protection and one of fall prevention. The first strategy, fall protection, aims to protect fallers by attempting to minimize injury severity after a fall has started. The second strategy is to prevent falls through interventions aimed at preventing the initiation of a fall. Fall protection systems do exist, but are not used with sufficient frequency or correctness (NIOSH 2000). This suggests that a reliance on fall protection systems may not be an efficient technique to reduce the number of injuries and deaths resulting from falls from heights. Conversely, a more practical approach to minimizing falls from heights is to prevent falls from occurring.

Before falls can be prevented, an understanding of how falls are initiated is necessary. There is limited information in the literature as to the causes of falls from heights. One report cites the most commonly mentioned cause of falls from roofs was a loss of balance (Hsiao and Simeonov 2001). With the assumption that a loss of balance is a leading cause of falls from heights, strategies to prevent a loss of balance warrant investigation. It is important to investigate factors that can contribute to a loss of balance, to develop strategies to help prevent these falls from heights.

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Chapter 2

Background: Findings of past postural sway research

The simple task of maintaining upright balance is a critical component in performing most daily activities. A momentary loss of balance can place an individual at risk of serious injury or death depending on the situation and circumstances of the incident. Balance control is maintained through inputs from three main systems: proprioceptive, visual, and vestibular (Mirka and Black 1990). The system upon which most reliance is placed in the maintenance of balance depends on conditions and tasks.

2.1 Assessment of balance

Most experimental reports attempting to quantify balance use postural sway as a surrogate measure of balance. Postural sway can be quantified through the use of center of mass and center of pressure data measured from a force plate and/or motion analysis system, although other methods do exist. Through analysis of these measures over a period of time, a quantification of balance can be deduced. An increase in postural sway is assumed to infer an increased risk of a loss of balance. There is at least some evidence which supports this assumption of fall risks related to sway (Lichtenstein et al. 1988; Lichtenstein et al. 1989). This assumption has been applied in the context of another construction task (hanging drywall). Pan et al. (2000) used sway variables along with instability indices which were derived from force plate measurements, to infer risk of workers' losing balance and falling.

2.2 Factors affecting balance

In an attempt to avoid the morbidity and mortality resulting from a loss of balance and subsequent fall from height, many factors that can affect balance have been investigated.

Some of these factors include age (Baloh et al. 1995), sex (Bryant et al. 2005), pathological conditions (Corriveau et al. 2000), medication (Hasan 1992), low back pain (Mientjes and Frank 1999), exposure to vibration (Vuillerme et al. 2002), and dehydration (Derave et al. 1998). Several studies have also reported an increase in postural sway following neuromuscular fatigue. An increase in postural sway has been shown following fatigue in the ankle (Konradsen 2002; Vuillerme et al. 2002; Yaggie and McGregor 2002; Caron 2003; Vuillerme and Nougier 2003), fatigue from repetitive lifting (Sparto et al. 1997), cardiovascular and lower extremity fatigue from running and cycling (Lepers et al. 1997; Nardone et al. 1997; Gauchard et al. 2002) and with localized shoulder fatigue from prolonged overhead work (Nussbaum 2003). Previous work in our laboratory has linked lumbar extensor fatigue to increases in postural sway (Davidson et al. 2004).

2.3 Fatigue, balance, and recovery

Increases in postural sway with muscle fatigue are of interest in addressing occupational injuries and deaths due to falls from heights. Workers who experience muscle fatigue during normal working conditions on a daily basis may be at risk of increased postural sway due to muscle fatigue.

2.3.1 Prolonged effects of fatigue

Fatigue has been shown to affect several physiological measures and the prolonged effect of fatigue on these physiological measures has previously been studied. The prolonged effect of fatigue on muscle strength, as related to maximum voluntary contraction (MVC), and muscle endurance has been studied following different types of fatigue including isometric work (Petrofsky 1981; Sahlin and Ren 1989), heavy dynamic work

(Hakkinen 1993; Linnamo et al. 1998), and eccentric work (Kroon and Naeije 1991; Sbriccoli et al. 2001). Electromyography (EMG) has also been used to study muscle fatigue and its prolonged effects (Elfvig et al. 2002; Dederling et al. 2004). These studies showed shorter prolonged effects than measures of strength and endurance, with effects lingering for only 1 to 6 minutes, while strength was reduced for 2 min to 1.5 hours, and endurance reduced for 4 min to 2 days. The prolonged effect on postural sway following different types of fatigue has been previously studied. These studies have shown a range of effect time duration. The prolonged effects of neck fatigue on postural sway have previously been studied (Schieppati et al. 2003). Fatigue of the neck was induced over a period of 5 minutes by exerting a force corresponding to about 35% of the maximum voluntary effort against a device exerting a head-flexor torque. Postural sway measures showed incomplete recovery in 5 minutes. The prolonged effects of strenuous treadmill walking on postural sway have also been previously studied (Nardone et al. 1998). Fatigue was induced over a period of 25 minutes to near maximum heart rate levels and full recovery of postural sway to basal levels occurred in 15 minutes. The prolonged effect of ankle fatigue on postural sway has also been studied previously (Yaggie and McGregor 2002). Fatigue was induced by performing isokinetic exertions with both the plantar flexors and dorsiflexors. Subjects were considered fatigued when 3 consecutive repetitions were below 50% of the maximum joint torque. Recovery of postural sway measures was shown to return to pre-fatigued levels in 20 minutes.

2.3.2 Analysis to quantify prolonged effects of fatigue

There have been many approaches to quantifying and assessing the prolonged effects of fatigue. Many physiological processes, such as heart rate, breathing depth, systolic blood pressure, oxygen uptake, and blood lactate elimination appear to show recovery processes which occur exponentially with respect to time (Elfving et al. 2002). With this trend, some previous studies have used exponential time dependence to model prolonged effect of several parameters including muscle strength and endurance (Sahlin and Ren 1989), and EMG (Elfving et al. 2002; Dederling et al. 2004). These studies often employ a recovery half time to quantify the time course effects.

Others have used varying methods to test for the difference between recovery measures and the initial level of the physiological marker used for assessment. Nardone et al. (1998) used a one-way repeated measures analysis of variance (ANOVA) to assess changes in postural sway caused by a treadmill exercise. A Newman-Keuls post hoc test to identify the times when postural sway was significantly different from the pre-exercise values was used. Yaggie (2002) also used a repeated measures ANOVA to assess changes in postural sway following isokinetic ankle fatigue.

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Chapter 4

Background: Findings of past proprioception research

Goldshieder (1889) was one of the first to study proprioception by comparing the smallest amount of joint rotation that could be detected in nine joints of the human body. Sherrington (1906) later coined the term proprioception from the Latin *receptus* (the act of receiving) and *propius* (one's own). Proprioception, or proprioceptive acuity (PA), has been defined as the ability to detect sensory stimuli such as touch, pain, pressure, and movements (Lephart et al. 1998).

4.1 Importance of proprioception to balance

Accurate proprioceptive input is a prerequisite for balance control, body orientation and coordination of movements (Kavounoudias et al. 1999). Proprioception is important to maintaining upright posture because changes in joint angles at the ankles, knees, and hip must be detected in order to coordinate limb and body movements necessary to maintain upright posture. In fact, there is evidence that humans can, and do, use proprioception to make reflexive postural adjustments in response to small changes in the position of a limb without even being aware of the changes (Ashton-Miller et al. 2001).

4.2 Physiology of proprioception

The somatosensory system functions to detect sensory stimuli such as touch, pain, pressure and movements such as joint displacement (Lephart et al. 1998). Inputs to this system are received from the peripheral articular and musculoskeletal receptors concerning changes in muscle length, tension, and velocity, in addition to information regarding joint position and motion. The mechanoreceptors are located within the skin,

in the musculotendinous unit and within the bone, joint ligaments, and joint capsule (Lephart et al. 1998, Kavounoudias et al. 1999). Muscle spindles are considered the most important peripheral receptor in the sensation of movement and position in humans, although joint and skin receptors also play a role (McCloskey 1978; Clark et al. 1985). The psycho-physiological measurements of proprioception in humans depend on afferent input from the periphery and its integration with other afferent inputs in the spinal cord and in the brain (Matre et al. 2002). Therefore, factors which alter muscle spindle sensitivity may affect proprioception (Matthews 1988).

4.3 Measures of proprioception

Proprioceptive assessments are typically divided into 2 components, joint motion sense (JMS) and joint position sense (Lephart et al. 1998). JMS, or kinesthesia, is typically assessed by measuring the threshold to detection of passive motion; that is passively moving a joint until motion is detected by the subject. Joint position sense (JPS) is assessed by measuring the reproduction of both passive and active positioning. The subject is required to match a set of index angles which are set by the investigator (Konradsen 2002). A variety of ways to match the index angle have been used including a visual analog scale (Robbins et al. 1995a; Robbins et al. 1995b), matching the index angle with the contra lateral foot (Berenberg et al. 1987), and replicating the index angle with the ipsilateral foot either actively (Glencross and Thornton 1981; Gross 1987; Konradsen et al. 1993; Jerosch and Prymka 1996), or passively (Gross 1987; Konradsen et al. 1993).

4.4 Relationship between proprioceptive measures

Grob et al. (2002) reported a low correlation between JPS and JMS measures, which suggests these measures reflect different aspects of joint proprioception. Joint motion sense measures at the ankle have typically been used in studies comparing postural sway to proprioception while joint position sense measures have often been used to study ankle injuries (Glencross and Thornton 1981; Gross 1987; Boyle and Negus 1998; Holme et al. 1999; Willems et al. 2002).

4.5 Factors affecting proprioception

Proprioception, and in particular joint motion sense measures, have been shown to be sensitive to several factors including joint measured, velocity of rotation (Clark et al. 1985), age (Gilsing et al. 1995; Deshpande et al. 2003), pain (Matre et al. 2002), contraction level (Paillard and Bouchon 1974; Wise et al. 1996), and loading condition. Interestingly, it has been noted that motions can be perceived before the direction of the motion can be identified (Hall and McCloskey 1983).

Joint motion sense has been shown to vary from joint to joint within the human body. The knee and hip for example show the most sensitivity, while the elbow and shoulder show slightly poorer proprioception, and the fingers and toes showing significantly poorer proprioception (Refshauge et al. 1998a; Refshauge et al. 1998b). A wide range of thresholds for detection of motion at the ankle have been reported. Konradsen (2002) reported threshold levels of joint movement at the ankle typically less than 2 degrees. Using a slightly different experimental paradigm, Clark et al (1985), reported that subjects were able to detect a 1.75 degree movement at the ankle with 70% success.

Fitzpatrick et al. (1994) reported much smaller thresholds for detection of motion at the ankle – less than 0.2 degrees.

Active muscle contraction has been reported to produce a more accurate sensation of motion (Paillard and Brouchon 1974; Fitzpatrick and McCloskey 1994). Joint motion sense has also been shown to improve with the rate of joint rotation, that is, the magnitude of the motion required to detect motion decreases as velocity increases (Clark et al. 1985; Refshauge et al. 1998b). Joint motion sense has been shown to worsen with age (Gilsing et al. 1995) and intense experimental muscle pain (Matre et al. 2002). Joint motion sense has also been shown to be sensitive to loading, and in particular weight bearing at the ankle. Thresholds to detection are typically smaller in a weight bearing stance than in a non-weight bearing stance (Clark et al. 1985; Fitzpatrick and McCloskey 1994; Konradsen 2002).

Muscle fatigue has been associated with a loss of proprioceptive acuity in various joints including the human jaw (Christensen 1976), the knee (Lattanzio et al. 1997), and the shoulder (Blasier et al. 1994; Voight et al. 1996; Björklund et al. 2000). Taimela et al. (1999) reported impairment in the ability to sense a change in lumbar position following lumbar fatigue.

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Appendix A

Effects of Circumferential Ankle Pressure on Postural Sway in the Elderly

A.1 Introduction

Falls are a common cause of injury and death in the elderly. Approximately 30% of people over the age of 65 fall once per year. Of these fallers, approximately 24% will sustain a serious injury, 48% are fearful of subsequent falls, and over 25% reduce their activity level due to this fear of falling (Tinetti and Williams 1998). Falls not only are detrimental to those who fall, but are also costly to society. In the year 1995 for example, the sum of medical, rehabilitation, and hospital costs along with the cost of morbidity and mortality was \$64 billion (Englander et al. 1996).

Many approaches can be applied to preventing the mortality and morbidity associated with falls. One approach is fall prevention, that is, avoiding falls through modifying the environment and conditions that favor falls. This approach has been applied to the environment such as improving lighting, flooring surfaces, and installing hand rails. Another approach to avoiding falls by improving conditions is through the use of devices which aid users. Unlike walkers or canes which provide mechanical support to the user, devices which may improve proprioception and somatosensory feedback have been studied. Vibrating soles have been shown to reduce sway measures in elderly adults (Priplata et al. 2003). Circumferential ankle pressure (CAP) has been shown to improve ankle proprioceptive acuity (PA) in individuals with below average PA as well as improve postural sway in those with chronic ankle instability (You et al. 2004). Others have reported that circumferential wrist pressure improved accuracy in wrist position

sense, particularly in elderly individuals with age-related deterioration in PA (Batavia et al. 1999).

If a simple device were able to reduce postural sway (i.e. improve balance), it may help reduce fall rates in the elderly. Therefore, the goal of this study was to assess the use of CAP as a novel device to improve balance in the elderly.

A.2 Materials and Methods

A.2.1 Subjects

Four male and seven female elderly subjects were recruited for participation in this study.

Subjects were community dwellers at the Warm Hearth Retirement Village, Blacksburg, Virginia. The mean age of subjects was 83.5 years, mean weight was 70.5 kg and mean height was 162.6 cm. A subject screening questionnaire was completed to assess medical conditions, injuries, daily activity level, falls experienced and medications being taken.

This questionnaire was not used as to determine if subjects met exclusion criteria, as no inclusion/exclusion criteria were used. Subjects all provided informed consent in accordance with the Virginia Tech Institutional Review Board before participation.

A.2.2 Procedure

Subjects were asked to stand as still as possible on the force plate with their feet as close together as they felt comfortable, arms at their sides, with their eyes closed. Both socks and shoes were removed during the balance trials. Collections were thirty seconds in length and subjects were told when collection began and ended. Subjects were tested in three conditions: one in which CAP was applied to each ankle (Figure 1), one in which an

elastic ankle brace (Futuro-Spiral Lift Ankle Support) was worn on each ankle, and finally a control trial where no devices were worn. Three trials were performed for each condition. The order of application of the conditions was randomized prior to testing. Subjects were allowed to move around between trials and sat for a brief period between test conditions.

CAP was applied using a pediatric blood pressure cuff (Omron, True Gage Cuff, Bannockburn, Illinois) placed just superior to the medial and lateral malleoli (Figure 1). This position was used in an earlier study of CAP (You et al. 2004) and allows free ankle motion while theoretically providing additional tactile stimulation. The cuff was inflated to a pressure of 60 mmHg and monitored throughout the test to ensure that the pressure was held constant. The ankle brace was applied snugly around each ankle joint and an appropriate size for the subject's foot was used.

Trials in which subjects sought assistance or were otherwise not able to stand independently for the entire duration were discarded and rerun. All subjects were able to complete three trials under each condition with their eyes closed with the exception of one who was only able to complete trials in the eyes open condition. This subject was removed from the analysis. Foot placement varied from subject to subject as some subjects were not comfortable placing their feet close together and still maintaining balance with their eyes closed. Foot placement was kept consistent within subjects from trial to trial and device to device however, and noted in the data collection sheet.

Force plate data was collected from an AMTI force measurement system (Watertown, MA) and sampled at 1000 Hz. The data was down-sampled to 100 Hz and filtered with a 4th order 10 Hz low-pass filter. Center of mass (COM) positions in the mediolateral (ML) and anteroposterior (AP) directions were calculated from the center of pressure (COP) data through double integration of COM acceleration and applying boundary conditions as described by Zatsiorsky and King (1998). COM trajectories were subsequently passed through a 3 Hz low-pass filter (zero-phase-lag 4th order Butterworth).

Several measures of postural sway (Table 1) were calculated from the COM and COP signals including eight non-directional measures (sway area, ellipse area, modified ellipse area, path length, mean radius, and maximum radius, peak velocity) and five directional measures in the AP and ML directions (peak velocity, mean velocity, range, mean frequency, and median frequency). The three postural sway values for each condition were averaged together prior to statistical analysis.

A.2.3 Statistics

To determine the effects of CAP and ankle bracing on postural sway, a one-way repeated measures ANOVA was used. The independent measures for this analysis were device worn (CAP, Brace, and no Aid). The dependent measures were the 15 COM and 15 COP sway measures. A significance level of $p < 0.05$ was used for all statistical tests.

A.3 Results

Statistical analysis showed no significant effect of CAP or brace on postural sway in either the COM or the COP measures of postural sway.

A.4 Discussion

Contrary to a previous report (Batavia et al. 1999; You et al. 2004) , CAP was not shown to reduce postural sway. Possible explanations for the discrepancy in results include differences in procedure and subjects. Collection times of 10 seconds were used in the previous study, while thirty second collections were used in this study. It is possible that the effects of CAP on postural sway are greatest during the initial application and diminish with time. More importantly, the difference in stance between the two studies could contribute to the discrepancy in results. You et al. employed a uniped stance, while in this study subjects stood in a biped stance. A uniped stance would most likely challenge the balance control system to a greater degree than a biped stance, and thus magnifying any enhancement due to CAP. While such a challenging stance could possibly produce better results, such a stance was not possible in this study. Subjectively it was observed that subjects were challenged in the biped, eyes closed stance and would not have been able to perform a uniped stance in either an eyes open or eyes closed condition. Another difference lies in the subject pool. In the previous study, improvements in postural sway were shown in subjects who were classified as having impaired proprioceptive acuity and chronic ankle instability. While there is evidence that proprioception degrades with age (Gilsing et al. 1995), no assessment of proprioception was performed in this study.

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A.6 Tables and Figures

Table A1: Results of COP and COM measures of postural sway averaged across all subjects.

Figure A1: Application of CAP



Figure A 1: Application of CAP

Table A 1: 15 measures used to analyze COM and COP data. Results are averaged across all subjects. CAP and Ankle Brace did not have a significant effect on any of the sway measures.

Name	COP Based Measures			COM Based Measures		
	No Aid	CAP	Ankle Brace	No Aid	CAP	Ankle Brace
Ellipse Area (m ²)	0.00059	0.00063	0.00066	0.00039	0.00037	0.00044
A/P Excursions (m)	0.02462	0.02902	0.02769	0.01712	0.01973	0.01975
M/L Excursions (m)	0.03094	0.02962	0.03108	0.02100	0.02028	0.02240
Mean Radius (m)	0.00659	0.00697	0.00693	0.00552	0.00560	0.00583
Max Radius (m)	0.02014	0.02071	0.02096	0.01430	0.01425	0.01538
Path Length (m)	0.59269	0.66874	0.61743	0.20230	0.22889	0.21934
Modified Ellipse Area (m ²)	0.00010	0.00011	0.00012	0.00007	0.00007	0.00008
Peak A/P Velocity (m/s)	0.09579	0.10473	0.09649	0.03554	0.04349	0.03420
Peak M/L Velocity (m/s)	0.06479	0.09141	0.06372	0.04652	0.03754	0.03740
Peak Velocity (m/s)	0.10192	0.12818	0.10409	0.05770	0.05415	0.04958
Sway Area (m ² /s)	0.14261	0.17050	0.16122	0.04119	0.04633	0.04789
Mean A/P Frequency (Hz)	0.38419	0.40601	0.37957	0.21507	0.23797	0.22237
Mean M/L Frequency (Hz)	0.37536	0.38674	0.35998	0.06392	0.06886	0.06545
Median A/P Frequency (Hz)	0.23253	0.26591	0.22864	0.15778	0.17920	0.16168
Median M/L Frequency (Hz)	0.20101	0.22430	0.20322	0.16113	0.17133	0.17874

Appendix B

Data Collection Sheet

Subject name: _____ Date: _____

Time: _____ Order of CAP/No CAP, PF/DF (Circle which is first)

- 1. Obtain informed consent
- 2. Give subject proper clothing in which to change (shorts, tank top) and ask if they need to use the restroom
- 3. Give summary of protocol and demonstrate
- 4. Ask subject to remove socks and shoes
- 5. Collect anthropometric measurements: age: _____
gender: _____ weight: _____ lbs height: _____ cm
- 6. Perform Unfatigued balance measurements:

- Demonstrate balance measurement
- Set collection time to 30 seconds in LabView
- Ask subject to stand on force plate as still as possible with feet together, arms at his/her sides and eyes closed, square with the force-plate
- Refer to Counter-balance Plan for order of CAP/No CAP
- Collect 6 balance trials of either CAP or no CAP; if using CAP, apply CAP device:
 - 3x30 second trials, seated rest, 3x30 second trials (with short rests between each)
 - LabView Collection Numbers: CAP/No CAP

Trial 1 _____
Trial 2 _____
Trial 3 _____
Trial 4 _____
Trial 5 _____
Trial 6 _____

- Collect 6 balance trials of either CAP or no CAP; if using CAP, apply CAP device:
 - 3x30 second trials, seated rest, 3x30 second trials (with short rests between each)
 - LabView Collection Numbers: CAP/No CAP

Trial 1 _____
Trial 2 _____
Trial 3 _____
Trial 4 _____
Trial 5 _____
Trial 6 _____

- 7. Perform Unfatigued Joint Motion Detection Measurements:
 - Give subjects general procedure and demonstrate:

- Ask subject to select the foot to be used for JMD testing, this foot will be used for all JMD tests
- Record foot selected

Right / Left

- Position subject in Biodex Chair and adjust so that:
 - Tibia is horizontal
 - Ankle is aligned with the axis of rotation
 - Start position has ankle at 90 degrees
- Tighten 2 straps (thigh and toes)
- Begin Dorsiflexion or Plantarflexion Joint Motion Detection
 - Apply CAP if CAP is used
 - Set Range of Motion for the direction being tested using Setup
 - Switch to Passive mode and **set speed to 0.25°/sec**
 - Ask the subject to concentrate on his/her foot and press the button when they sense movement
 - Explain that turning on vibration indicates the start of the trial and motion will begin at some random delay thereafter
 - Explain that once motion has been sensed the foot will be repositioned to the start position and the same procedure followed
 - Perform a few practice trials so procedure is understood
 - Ask subject to close his/her eyes
 - Give subject headphones and turn on music
 - Start the massager
 - Start the data collection and record collection number below
 - Start passive movement
 - Once motion has been detected, reset using the blue rotate buttons on Biodex (Outer for DF, Inner for PF)
 - Complete 3 trials for each direction (PF/DF) and each condition (CAP/no CAP) for a total of 4 combinations
 - Let subject get out of chair between CAP and No CAP trials

<u>Direction</u>	<u>CAP/No CAP</u>	<u>Collection</u>
PF	CAP	
DF	CAP	
PF	No CAP	
DF	No CAP	

Female subjects: Protocol Complete

Male Subjects: Continue with Protocol

- 8. Replace socks and shoes for warm-up
- 9. Place harness on subjects and fit them for the roman chair (Place top pad 1" above ASIS)
- 10. Warm-up exercise (2 sets)

- 2 ½ minutes jogging at 4.5 mph
- back stretching
- 5 back extensions

- 11. Remove socks and shoes
- 12. Instruct subjects on back fatiguing protocol and demonstrate
- 13. Perform MVCs: erector spinae (Allow for rest between max)

load cell max: _____ volts _____ volts _____ volts

- 14. Enter erector spinae MVC voltage into Excel spreadsheet
- 15. Begin Back Fatiguing Protocol

Start metronome (30 beats per minute)

Fatiguing Protocol

Fatigue level: _____

Time	% MVC	Voltage	Reps/Minute	Comments
1:	100			
3:				
5:				
7:				
9:				
11:				
13:				
15:				

Linear fatigue protocol:

- Extensions will be done through full 45° range of motion at a rate of approximately 30 reps/min
- Begin with number of repetitions every minute (rem) specified below
- Final MVC defined as two consecutive MVC falling below desired %
- MVC will be measured throughout protocol at exactly 10 seconds after completing every other set using load cell and compared to linear regression of target MVC calculated in Excel Spreadsheet *MVC regression.xls*

Goal MVC	Beginning # of Reps
86.6 %	5
73.3 %	9
60 %	11

Change in repetitions				
Above +5 %	Above Goal	Below Goal	Below -5 %	Below -15%
+ 3	+ 2	+ 1	+ 0	- 1

****Remind subject to keep feet flat and move through full range of motion.****

- 16. Remove harness from subject:

- 17. Perform Fatigued balance measurements:
 - Ask subject to stand on force plate as still as possible with feet together, arms at his/her sides and eyes closed
 - Collect 1 balance trial of either CAP or no CAP; if using CAP, apply CAP device:
 - 30 second trial
 - LabView Collection Number: CAP/No CAP

Trial 1_____
 - Collect 1 balance trial of either CAP or no CAP; if using CAP, apply CAP device:
 - 30 second trial
 - LabView Collection Numbers: CAP/No CAP

Trial 1_____

- 18. Perform Fatigued Joint Motion Detection Measurements:
 - Position subject in Biodex Chair and adjust so that:
 - Tibia is horizontal
 - Ankle is aligned with the axis of rotation
 - Start position has ankle at 90 degrees
 - Tighten 2 straps (thigh and toes)
 - Begin Dorsiflexion or Plantarflexion Joint Motion Detection
 - Apply CAP if CAP is used
 - Set Range of Motion
 - Ask subject to close his/her eyes
 - Ask the subject to concentrate on his/her foot and press the button when they sense movement
 - Explain that turning on vibration indicates the start of the trial and motion will begin at some random delay

- Explain that once motion has been sensed the foot will be repositioned to the start position and the same procedure followed
- Give subject headphones and turn on music
- Start the massager
- Start passive movement
- Once motion has been detected, reset using the blue rotate buttons (Outer for DF, Inner for PF)
- Repeat 3 times for each direction and each condition (CAP/no CAP)
- Let subject get out of chair between CAP and No CAP trials

<u>Direction</u>	<u>CAP/No CAP</u>	<u>Collection</u>
PF	CAP	
DF	CAP	
PF	No CAP	
DF	No CAP	

Appendix C

Data Collection Sheet

Subject name: _____ Date: _____

Time: _____ Order of CAP__ No CAP__ Ankle Support__ (# Order)

- 1. Obtain informed consent
- 2. Complete Subject Medical History Form
- 3. Give summary of protocol and demonstrate
- 4. Set LabView file path to *c:\CAP\subjectname.txt*
- 5. Collect empty trial with bare force plate
- 6. Ask subject to remove socks and shoes
- 7. Perform balance measurements:
 - Set collection time to 30 seconds in LabView
 - Ask subject to stand on force plate as still as possible with feet together without touching and arms at his/her sides and eyes closed. Repeat this message before each trial.
 - Collect 6 balance trials of CAP, no CAP, or ankle support; if using intervention, apply device:
 - 3x30 second trials, seated rest, 3x30 second trials (with short rests between each)
 - Ankle Support/CAP/No CAP (Circle)
 - LabView Collection Numbers:

Trial 1_____

Trial 2_____

Trial 3_____

Trial 4_____

Trial 5_____

Trial 6_____

- Ask subject to stand on force plate as still as possible with feet together without touching and arms at his/her sides and eyes closed. Repeat this message before each trial.
- Collect 6 balance trials of CAP, no CAP, or ankle support; if using intervention, apply device:
 - 3x30 second trials, seated rest, 3x30 second trials (with short rests between each)
 - Ankle Support/CAP/No CAP (Circle)
 - LabView Collection Numbers:

Trial 1 _____
Trial 2 _____
Trial 3 _____
Trial 4 _____
Trial 5 _____
Trial 6 _____

- Ask subject to stand on force plate as still as possible with feet together without touching and arms at his/her sides and eyes closed. Repeat this message before each trial.
- Collect 6 balance trials of CAP, no CAP, or ankle support; if using intervention, apply device:
 - 3x30 second trials, seated rest, 3x30 second trials (with short rests between each)
 - Ankle Support/CAP/No CAP (Circle)
 - LabView Collection Numbers:

Trial 1 _____
Trial 2 _____
Trial 3 _____
Trial 4 _____
Trial 5 _____
Trial 6 _____

Vita

Kevin Michael Pline

Kevin Michael Pline was born June 22, 1980 in Lansing, Michigan. He grew up on his family farm in St. Johns, Michigan with his parents Bruce and Irene and two older sisters Wendy and Melissa. He attended Michigan Technological University and graduated with Highest Honors in May 2003 with a Bachelor of Science in Mechanical Engineering degree. He graduated with his Masters of Science in Mechanical Engineering degree in May of 2005 from Virginia Tech. While he was a student, Kevin ran cross-country and track for Michigan Tech and Virginia Tech. For four summers, Kevin interned for automotive supplier Visteon where he plans to work as a product development engineer in Detroit, Michigan. During his free time, Kevin enjoys many outdoor activities including running, road biking, mountain biking, cross country skiing, downhill skiing, and hiking.