Chapter 5

Lumbar Extensor Fatigue and Circumferential Ankle Pressure Impair Ankle Joint Motion Sense

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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. Fatigue of the lumbar extensor muscles has been associated with a degradation of balance, but the mechanism is not well understood. The ankle plays a major role in upright standing and degradations in proprioception at the ankle could contribute to decreases in balance and increased risk of loss of balance. The first objective of this study was to investigate the effect of lumbar extensor fatigue on ankle proprioception (measured as joint motion detection). Additionally, the effect of circumferential ankle pressure (CAP) on ankle proprioception was assessed to evaluate it as a potential intervention to mitigate any loss of proprioception at the ankle with lumbar extensor fatigue. Proprioception was determined with and without CAP, both before and after the lumbar extensors were fatigued. Results showed that joint motion sense was significantly worse following lumbar extensor fatigue compared with the pre-fatigued condition. Application of CAP was also shown to significantly impair proprioception at the ankle. These results indicate that lumbar extensor fatigue impairs ankle proprioception, which may explain observed increases in postural sway subsequent to lumbar extensor fatigue.
5.1 Introduction
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).

Hsiao and Simeonov (2001) reported that the most commonly mentioned cause of falls from roofs was a loss of balance. To develop strategies to help prevent these falls, it is prudent to investigate factors that can contribute to a loss of balance. Localized muscle fatigue is one factor that has been shown to increase postural sway during quiet stance, which implies a fatigue induced degradation of balance. 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).

Similarly, a previous study from our laboratory found an increase in postural sway with lumbar extensor fatigue (Davidson et al. 2004). Lumbar extensor fatigue is at least
anecdotally associated with manual labor, and based on this study, may contribute to some falls from heights. However, it is unclear at this point how lumbar extensor fatigue impairs balance.

Muscle fatigue has been associated with a loss of proprioceptive acuity in various muscles (Christensen 1976; Skinner et al. 1986; Lattanzio et al. 1997b; Bjorklund et al. 2003). Taimela et al. (1999) reported impairment in the ability to sense a change in lumbar position following lumbar fatigue. As such, a loss of proprioceptive acuity in the lumbar extensors with fatigue may result in larger movements at the lumbar spine during quiet standing, and a concomitant increase in postural sway. However, the inverted pendulum model of balance suggests a minor role of the lumbar extensors for maintaining balance in the sagittal plane. Thus, changes in proprioceptive acuity in a muscle group with a “minor role” in balance, such as the lumbar extensors, may not contribute significantly to the increase in sway with fatigue. The ankle musculature, however, does play a dominant role in maintaining balance in the sagittal plane during quiet standing. A degradation of proprioceptive acuity at the ankle with lumbar extensor fatigue could account for the increase in sway with low back fatigue. Thus, the first objective of this study was to evaluate the effect of lumbar extensor fatigue on ankle proprioceptive acuity.

Circumferential ankle pressure (CAP) has been shown to improve ankle proprioceptive acuity in individuals with below average proprioceptive acuity (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 proprioceptive acuity (Batavia et al. 1999). If lumbar extensor fatigue degrades proprioceptive acuity at the ankle, it is possible that CAP could mitigate any deleterious effects of fatigue on ankle proprioceptive acuity. Therefore, the second objective of this study was to investigate the effect of CAP on ankle proprioceptive acuity both with and without lumbar extensor fatigue.

### 5.2 Materials and Methods

Fourteen healthy male subjects participated in the experiment. Their age was 23.6 +/- 2.87 years (mean +/- standard deviation) with mass and height of 83.6 +/- 12.4 kg, and 184.8 +/- 8.8 cm, respectively. Subjects all provided informed consent in accordance with the Virginia Tech Institutional Review Board before participation.

Proprioceptive acuity in this study was quantified by ankle joint motion sense (JMS). JMS, also termed joint kinesthesia, is the angular displacement of a joint necessary to detect joint motion. JMS was measured in all subjects with and without CAP both before and after a lumbar fatiguing protocol. Before the fatiguing protocol, three JMS measurements were performed in plantar flexion and dorsiflexion both with and without CAP. The presentation order of movement direction and CAP condition was counterbalanced so that half of the subjects would get one condition or one direction first and the other half would get the other condition or direction first. After the fatiguing protocol, the same procedure was followed except that only one trial was completed in each direction and each CAP condition in order to minimize recovery from fatigue.
(Davidson et al. 2004). All JMS measurements started two minutes after the fatiguing protocol, and were completed within three minutes.

JMS was measured using a Biodex System 3 Pro dynamometer (Shirley, New York). Subjects were seated supine on the Biodex chair with the thigh of the dominant leg (self-reported) resting on a support pad (Figure 1). The subject’s bare foot was attached to the footplate with a Velcro strap and the lateral malleolus was aligned with the axis of rotation of the dynamometer. In this position, the ankle being tested was in the anatomical position. Subjects were asked to lie back in the chair with their eyes closed to remove any visual cues, and headphones playing music were worn to mask any audio cues produced by the dynamometer. A hand-held massager (Sensa-Touch, Dr. Scholl’s, El Paso, TX) was hung from the footplate to provide a small background vibration to the foot to conceal any vibration associated with operating the dynamometer motor. To measure JMS, the ankle was passively moved by the dynamometer at a velocity of 0.25 deg/sec in either plantar flexion or dorsiflexion. Similar rates of rotation have been used by other investigators (Matre et al. 2002; Matre and Knardahl 2003) and these tests were shown to have excellent repeatability (Deshpande et al. 2003). After the massager was activated, the rotation of the footplate started following a random delay of one to ten seconds to discourage guessing by the subjects. Subjects were asked to concentrate on his ankle and to press a stop button when footplate motion was detected, thereby stopping rotation of the footplate.
CAP was applied using a pediatric blood pressure cuff (Omron, True Gage Cuff, Bannockburn, Illinois) placed just superior to the medial and lateral malleoli. 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 fatiguing protocol has been described in detail elsewhere (Davidson et al. 2004) and will only be summarized here. After a brief warm-up, subjects were fitted to a construction harness and positioned on a 45 deg. Roman Chair (New York Barbell, Elmira, N.Y.). Three initial maximum voluntary contractions (MVC) of the lumbar extensors were performed by having subjects pull against a load cell (Cooper, Warrenton, Va) that anchored the construction harness to the Roman Chair. Subjects were asked to pull evenly and consistently for several seconds for each MVC and not to “jerk” the load cell at the onset of the MVC. Using the load cell data and an estimation of head, arms, and trunk mass and COM position (Zatsiorsky and King 1998) to correct for gravitational force on the upper body, the corresponding torque at the ‘lumbar joint’ (L3) was estimated for all MVCs (Davidson et al. 2004). The largest of the three unfatigued torques was recorded as the unfatigued MVC. The protocol was designed to fatigue subjects to 75% of their MVC by performing a set of back extensions on the Roman Chair each minute for 14 minutes. MVCs collected every two minutes were used to adjust the number of repetitions in each set in an attempt to decrease the MVC force at a roughly linear rate. Subjects were encouraged to pull to their maximum ability during
each MVC, and were allowed to stand and stretch between sets if time permitted. An MVC was also performed at the end of the fatiguing protocol to quantify the subjects’ level of fatigue. Subjects were fatigued to 68.3% +/- 7.2% of their unfatigued lumbar extensor MVC. Once the fatiguing protocol was complete, the harness was removed prior to the JMS measurements.

The angular position of the Biodex arm was sampled at 1000 Hz, low-pass filtered at 10 Hz (4th Order Butterworth filter), and down-sampled to 100 Hz. JMS was quantified as the angular displacement of the Biodex arm (in degrees) between its initial position and its final position after the subject stopped movement. A minimum JMS score of 0.3 degrees was used (Matre et al. 2002; Matre and Knardahl 2003) to exclude the possibility that any subject was able to sense motion by the vibration associated with the start of the Biodex motor despite the masking vibration from the hand-held massager. After visually inspecting the data, one subject who consistently performed under this minimum score was removed from the data set. It has been shown that threshold for perception of passive movement was not dependent on the direction of movement (Deshpande et al. 2003). Comparison of JMS scores for plantar flexion and dorsiflexion from this study also showed no dependence on direction. Thus the three unfatigued trials in each direction were averaged, and then averaged across directions to produce one JMS score for each unfatigued CAP condition. Since only one trial was collected in each direction following fatigue, the two directions were averaged together to produce one JMS score for each fatigued CAP condition.
Prior to the statistical analysis, a standard square root transformation was necessary to obtain a normal distribution. To determine the effects of fatigue and CAP on JMS, a two-way repeated measures ANOVA was used. The independent variables for this analysis were fatigue condition (unfatigued or fatigued) and CAP condition (No CAP, CAP). The dependent variable for this analysis was the square root of the average JMS measure. A significance level of $p < 0.05$ was used for all statistical tests.

### 5.3 Results and Discussion

Both lumbar extensor fatigue and CAP impaired ankle JMS (Figure 2). Fatigue induced a 6.0 % $\pm$ 9.5 % increase in JMS score ($p=0.031$), and CAP induced a 7.7 % $\pm$ 10.6 % increase in JMS score ($p=0.016$). There was no interaction between fatigue and CAP on JMS ($p=0.868$).

The JMS scores found in this study in the unfatigued no CAP condition were 1.14 $\pm$ 0.68 degrees and are comparable to what other researchers have reported in similar studies. 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. Unlike the present study, subjects in their study were standing upright, supporting the weight of the body, and using both ankles simultaneously. These differences likely contributed to the smaller values reported here.
An impairment of joint proprioception with fatigue has been reported for numerous joints (Christensen 1976; Skinner et al. 1986; Lattanzio et al. 1997b; Bjorklund et al. 2003). Joint position and motion is sensed through various mechanoreceptors, including Golgi tendon organs, muscle spindles, and cutaneous receptors (Freeman 1965). Several reports have demonstrated that muscle spindle and Golgi tendon organ activity may be decreased with fatigue (Graham et al. 1986; Lagier-Tessonnier et al. 1993). Similarly, Hiemstra et al. (2001) outlined a fatigue-mediated alteration in joint proprioception, pointing to changes in afferent output from joint and muscle receptors as the cause for impairment. These studies provide a seemingly valid physiological explanation for fatigue-induced loss of proprioceptive acuity when fatigue is induced in muscles acting at the joint of interest. However, the loss of proprioceptive acuity when fatigue is induced in muscles not acting at the joint of interest, as reported here, seems to be novel and remains to be explained.

One possible explanation is that lumbar extensor fatigue disrupted the central processing of proprioceptive signals (Miura et al. 2004). Gandevia (2001) argues that muscle fatigue is the product of both peripheral and central causes; that is, human muscle fatigue does not simply reside at the muscle. He contends that a number of central changes occur during fatigue and affect, among other things, proprioception. Sharpe et al. (1993) reported changes in proprioception at the elbow resulting from fatigue at the ipsilateral elbow and from fatigue at the contralateral elbow. In an attempt to explain changes in proprioception with contralateral elbow fatigue, they hypothesized that the proprioceptive
signals remained unchanged, but the central processing of these signals suffered from fatigue induced changes. In the present study, it is possible that the lumbar extensor fatiguing, though localized in nature, induced central fatigue which contributed to a general decrease in processing of proprioceptive signals and thus a decrease in proprioception. Clearly, more studies are needed to address this observation.

Contrary to previous reports (Batavia et al. 1999; You et al. 2004), CAP impaired proprioceptive acuity. One reason for these conflicting results may be related to differences in measures of proprioception. Two previous studies investigating circumferential joint pressure on proprioceptive acuity (Batavia et al. 1999; You et al. 2004) both used measures of joint position sense (JPS) rather than JMS. JPS is typically measured by determining the error associated with active or passive reproduction of a joint angle (Deshpande et al. 2003). Grob et al. (2002) reported a low correlation between JPS and JMS measures, which suggests these measures reflect different aspects of joint proprioception. Interestingly, studies investigating the effect of taping and bracing on proprioceptive acuity have similar findings. Hubbard et al. (2002) reported a decrease in ankle JMS with ankle bracing, while Heit et al. (1996) and Feuerback et al. (Feuerbach et al. 1994) reported improvements in JPS with ankle taping and bracing. Another possible reason for the conflicting results between studies may be differences in experimental protocols. Studies investigating the effect of taping and bracing on ankle proprioception during a non-weight bearing position have found a loss of proprioceptive acuity (Refshauge et al. 2000; Hubbard and Kaminski 2002), while similar studies employing a weight bearing position have found an improvement in proprioceptive acuity.
(Feuerbach et al. 1994; Robbins et al. 1995b; Heit et al. 1996; You et al. 2004). This suggests that a weight bearing stance could change the effects of taping and bracing on proprioception. Future work is warranted to investigate the relationship between JPS and JMS measures, as well as the interaction between CAP and weight-bearing position.

In order to address the possibility that the warm up exercise contributed to the degradation in proprioception, a follow up study was conducted. From four subjects, JMS measures were obtained as in the initial study, followed by the warm up exercises. The subjects then waited for 15 minutes, as this was the duration of the lumbar extensor fatiguing protocol. A second set of JMS measures was then obtained as in the initial study. The warm up exercise induced a 0.4% decrease in JMS scores (p=0.811) compared to a 6.0% increase in JMS score with fatigue, thus providing evidence that the changes in JMS minimally affected by the warm up exercise.

Three limitations of this study warrant discussion. First, we assumed that the ankle musculature was not fatigued during the lumbar extensor fatiguing protocol. Our experience and subject verbal feedback indicated that the ankles were minimally exerted during the fatiguing protocol, so we feel there is little chance for ankle fatigue to have occurred. Second, we assume that the activation level of the plantar flexors and dorsiflexors during JMS testing was constant across all experimental conditions. This is important because proprioceptive acuity is affected by muscle activation levels (Fitzpatrick and McCloskey 1994). Although subject position on the Biodex was identical for all experimental conditions, we cannot rule out the possibility that
contraction levels were responsible for the increases in JMS because fatigue has been shown to affect activation levels of muscles that are remote to the fatigued muscles (Tani et al. 1973; Gandevia 2001). Third, it is unclear if the 6.0% loss of ankle JMS with lumbar extensor fatigue is clinically significant (i.e. if it puts a worker at a greater risk for a fall). Although there is a physiological rationale for ankle JMS being related to fall risk, future studies are needed to understand the relationship between them.

In conclusion, muscle fatigue of the lumbar extensors decreased ankle JMS. Our results also indicated that the application of CAP decreased ankle JMS. Although this provides a convenient explanation for the previously reported increase in postural sway with lumbar extensor fatigue, this finding is not intuitive. Future studies are needed to better understand the relationship between muscle fatigue, ankle JMS, and balance.

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5.6 Figures

Figure 5.1: Subject seated in Biodex System 3 Dynamometer for JMS testing.

Figure 5.2: Mean +/- SD JMS scores after square root transformation for unfatigued and fatigued condition with and without CAP. The positive slope of both lines illustrates a loss of JMS with fatigue, and the vertical separation of the lines indicates a loss of JMS with CAP. Note that the Y axis does not start at zero.
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