The Effects of Eversion Fatigue on Frontal Plane Joint Position Sense in the Ankle

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Context: There is limited information on fatigue of the evertors on frontal plane joint position sense (JPS). Objective: To examine the effects of isokinetic concentric-eccentric fatigue of the evertors on frontal plane JPS of the ankle. Design: A 2 × 4 factorial design. Setting: Research Laboratory. Patients or Other Participants: 40 male and female healthy subjects. Interventions: JPS was tested at 10° and 20° of inversion and 5° and 10° of eversion in a nonfatigued/fatigued condition. After fatigue of evertors was determined on an isokinetic device, post fatigue testing of JPS occurred. Main Outcome Measures: JPS absolute error (AE) for inversion and eversion. Results: Main effect for condition and angle were significant with pre/post fatigue. There were overestimation of angles postfatigue with AE greater at 20° of inversion (P = .003), followed by 10° of inversion (P < .001), 10° of eversion (P = .005), and 5° of eversion (P = .005). Conclusion: When the ankle evertors were fatigued, the AE for JPS was significantly higher at all test angles.

Keywords: inversion, eversion, proprioception, active angle reproduction test

Proprioception has been accurately described as any afferent information arising from internal peripheral areas of the body that contribute to postural control, joint stability, and subconscious neural reflex mechanisms, kinesthesia and joint position sense.1 Kinesthesia and joint position sense are very closely related, differing in the fact that kinesthesia consists of the body’s ability to detect changes in motion of a joint while position sense regards the body’s ability to detect static positioning of a joint.1,2 These sensations are felt through the use of afferent information gathered from differing mechanoreceptors found within muscles, tendons, ligaments, skin and joint capsules of the body. This information is integrated by summation, gating, and/or modulation, sent to the brain and then used to create an accurate message of the body’s position in space.1,3–5 Collectively, the efferent response that is generated by this process is referred to as neuromuscular control and is necessitated so that smooth and fluid muscular control may take place. Joint position sense has been studied with the use of dynamometers,6–10 and has been shown to be affected by both injury11–13 and fatigue.7,9,10

Fatigue has been operationally described in different ways throughout the literature.14–17 Commonly, it often is associated with a decrease in muscle function below 50% of capacity. Patikas15 describes neuromuscular fatigue as 50% or
less of maximal voluntary torque produced by a muscle whereas Johnston more
simplistically defines it as less than one half of original strength. Many methods
of producing fatigue can be found in the literature, ranging from sustained static
contraction to the use of an isokinetic dynamometer. Whether the onset of fatigue occurs centrally or peripherally, many researchers have documented decreases in the neuromuscular feedback system of the joint around which the fatigued muscles are located. Joint position sense has been shown to be affected by fatigue with a number of studies examining the relationship between proprioception and fatigue of the ankle. Of the studies reported in the literature, a majority of those studies have focused solely on the relationship between fatigue of dorsiflexors and plantar flexors of the ankle for proprioception at the talocural joint, with only two studies on sagittal-plane joint position sense. Very little has been reported on the effect of fatigue to the ankle evertors on frontal plane joint position sense. Only one study could be found that examined the effects of evertor fatigue on frontal plane motion sense at the ankle. Chang et al induced fatigue to the ankle evertors, and then followed by evaluating ankle inversion motion sense. They found a significant decline in passive ankle motion sense after fatigue, leading one to believe that fatigue of the ankle evertors might have a negative affect on subtalar joint position sense. Furthermore, as this study dealt primarily with inversion joint motion sense, it leads one to question whether the same negative effects of fatigue are evident with inversion and eversion joint position sense.

It has been suggested that fatigue plays a significant role in the occurrence of ankle injuries. Anecdotally, it has been reported that many injuries occur during the latter stages of activity when fatigue is present. Furthermore, ankle inversion injuries are caused by an inability of the peroneal muscles to eccentrically resist the inversion movement. Therefore, the need exists to determine the relationship of evertor fatigue on frontal plane joint position sense. The purpose of this study is to examine how inversion and eversion joint position sense at the ankle is affected by nonfatigued and fatigued conditions of the ankle evertors.

Methods

This was a 2 × 4 factorial design. The independent variables were condition (fatigued evertors and nonfatigued evertors), and position (5° and 10° of eversion and 10° and 20° of inversion). The dependent variable was the degrees of error in active joint angle positioning for eversion (5° and 10°) and inversion (10° and 20°).

Subjects

Forty healthy college-aged subjects (n = 16 males and n = 24 females) from the graduate and undergraduate athletic training program were used for this study. Mean age of subjects was 20.10 ± 2.02 years, height was 169.0 ± 3.61 cm, and mass was 70.50 ± 12.29 kg. Subjects were selected by a sample of convenience. Subjects were excluded if they had any lower extremity injury to the dominant side in the previous six months, had surgery to the dominant lower extremity within the past year, or had a history of chronic ankle instability. Other exclusion criteria included taking any medication that affected balance and any visual or neurological disorders. All
subjects read and signed a written consent form before participating in the study. This study was approved by the university’s Institutional Review Board (IRB) for the protection of human subjects.

**Instruments**

Joint position sense measurements were taken with a custom-designed joint position sense device. This device was patterned after the one developed by Myburgh et al., and later modified by Docherty et al. Docherty’s device was a specially designed goniometer with an electronic digital display to determine joint range of motion (ROM) with modifications to eliminate excessive movement during testing. Motion was detected by 2 BOURNS potentiometers (Newark Electronics, Chicago, IL) set at 100 MHz placed on each axis of the goniometer. For our study, the speed controller was not used as inversion and eversion were placed into position manually. To eliminate triplanar motion, the device is locked so that only plantar flexion and dorsiflexion or inversion and eversion will occur together. In our study the device was locked in the inversion and eversion position. Output was transformed from analog to digital to a computer screen. The output was recorded on a differential amplifier and displayed on a computer monitor using the Biopac Electromyography System (Biopac Systems Inc., Santa Barbara, CA). Acknowledge 3.1 software (Biopac Systems Inc., Santa Barbara, CA) was used to analyze the data.

The Linearity R of the device has been calculated to be .99872. This was derived from the following equation: \( \text{Fit M} = M_0 \times M_1 \times X \). \( M_0 \) is the offset from the intercept as it crosses the X axis. It was equal to .0089. \( M_1 \) is the actual scaling factor, equal to .0079344 V per degree.

Fatigue was induced by use of an isokinetic dynamometer (Kin/Com, Isokinetic International, Harrison, TN). Yaggie and McGregor have shown that the use of an isokinetic dynamometer is safe, valid, and reliable at both creating and measuring varying levels of muscular fatigue.

**Procedures**

Subjects met initially with the researcher at an introductory meeting to complete the informed consent form and the demographic/medical history questionnaire. All those subjects that met the inclusion criteria were invited to participate in the study. Each subject met with the researcher at a Sports Medicine Clinic to complete the fatiguing protocols and goniometric measurements using the dominant foot. The dominant foot was determined by asking the subjects which foot they prefer to use to kick a soccer ball. All fatiguing protocols and joint position sense measurements were completed at the same location to serve as an environmental control. One of the researchers administered and supervised all fatiguing and testing sessions. Subjects were allowed a 5 min window to stretch out their leg musculature according to a stretching protocol. Subjects were tested for degrees of movement using the joint position sense device at 5° and 10° of eversion and 10° and 20° of inversion in the nonfatigued state, as randomly assigned by drawing from four index cards. The subjects were then asked to execute the indicated isokinetic fatiguing protocol. Once fatigue was reached, the subjects underwent a joint position sense test using
the same test angles in the same order as the pretest. The amount of time from the beginning of the fatiguing protocol to the initiation of joint position sense testing was no greater than sixty seconds. Each test angle was tested three times and an average taken for the nonfatigued and-fatigued conditions.

Fatiguing Protocol

The fatiguing protocol used in our study followed the same procedures used by Yaggie and McGregor.14 We concentrated on fatiguing the ankle evertor muscle group, consisting primarily of the peroneus longus and peroneus brevis. Following a three min stretching routine, two practice repetitions, one for concentric and one for eccentric contractions, were performed for familiarization purposes followed by a two min rest. The subject was in an upright seated position on the chair with velcro straps placed on the distal portion of the forefoot, over the metatarsal heads of the dominant foot in the foot attachment (Figures 1A and 1B). The fatiguing protocol consisted of performing concentric-eccentric eversion exercises at maximal effort on an isokinetic dynamometer at a rate of 60°/s. Muscular fatigue was assumed when subjects were unable to complete 3 consecutive repetitions for both concentric and eccentric eversion at 50% or greater of their maximum joint torque.

Joint Position Sense Protocol

The subjects were tested on the joint position sense device, undergoing an active angle reproduction test (Figure 2). The subjects were placed in a supine position, with their knee at 0°, their hip in slight flexion, and their dominant foot and ankle strapped into the device by the use of an elastic foam strap (Conco, Boston, MA) to reduce cutaneous receptor activation. Subjects were blindfolded throughout testing to eliminate any visual cues, and head phones were placed over their ears to eliminate any auditory cues. All subjects were barefoot during testing to avoid positioning errors due to shoes. Each subject’s foot was placed in subtalar neutral and that angle was set as zero. For the purpose of this study, subtalar neutral was defined as having the foot in neither inversion nor eversion.31 The subjects were allowed an orientation period to familiarize themselves with the joint position sense device at 15°of inversion and 5° of eversion.

The test angles were 5° and 10° of eversion and 10° and 20° of inversion. Angles were read from the computer screen and recorded to a ten-thousandth of a degree in the fatigued and nonfatigued conditions. Inversion positions were assigned positive values and eversion positions were assigned negative values for the right leg, and vice versa for the left leg. The subject’s ankle was manually moved to the test angle by one of the researchers. The subjects were held at the test angle for 15 seconds and told to concentrate on that position. They were then taken to the opposite end range of motion and subsequently returned to the predetermined neutral. The subject then manually moved their foot until they felt they had reached the test angle position. The subject indicated when they had reached the desired angle position by using a verbal “yes” indicator. This measurement was recorded. An average of three trials was taken. This process was then repeated for each respective test angle. The difference between the subjects’ repositioning angle and initial test angle was recorded as the absolute error measurement.
Figure 1 — Positioning for isokinetic fatigue testing (1A and 1B).

Figure 2 — Positioning for joint position sense device.
Data Analysis

The absolute error measurement was analyzed to determine if there was a difference between pretest and posttest error over time. The following formula was used to determine the absolute error measurement:

\[
\text{Active Angle Reproduction - Target Angle} = \text{Absolute Error Measurement}
\]

When identifying the nature of the absolute error associated with inversion, the negative values indicated an underestimation of the target angle, whereas a positive value represented an overestimation of the target angle, on the right leg. Conversely, for eversion negative values represented overestimation, while positive values reflected underestimation, on the right leg. The opposite will be true for inversion and eversion on the left leg.

Statistical Analysis

A 2 × 4 Repeated Measures Analysis of Variance (ANOVA) was used to determine if differences existed for condition (fatigue and non-fatigue states) and position on absolute error measurement. Pairwise comparisons were used when significance was noted for main effects. The alpha level for both statistical tests was set at \( P = .05 \). All data were analyzed using SPSS Version 14.0 for Windows. (SPSS Inc., Chicago, IL)

Results

All descriptive statistics for absolute error are presented in Table 1 as means and standard deviations. Results from the 2 × 4 repeated measures ANOVA on absolute error revealed no significant interaction between condition and position \((F_{1,39} = 1.24, P = .272, ES = .031, 1-\beta = .193)\). There was a significant main effect for condition \((F_{1,39} = 47.98, P < .001, ES = .552)\), resulting in an increase in joint positioning error for 10° and 20° of inversion and 5° and 10° of eversion with the fatigue condition. A significant main effect for position was also revealed \((F_{1,39} = 7.17 P = .011, ES = .155)\). There were overestimation of angles postfatigue with AE greater at 20° of inversion \((P = .003, d = -0.60)\), followed by 10° of inversion \((P < .001, d = -0.50)\), 10° of eversion \((P = .005, d = -0.47)\) and 5° of eversion \((P = .005, d = -0.47)\).

Comments

The results of this study have shown that there was indeed a significant difference in joint positioning error for condition and for position when the evertors are fatigued. There was no significant interaction between condition and position, however. Therefore, each of the following hypotheses were accepted that stated ankle joint position sense of the subtalar joint in 10 degrees of inversion, 20 degrees of inversion, 5 degrees of eversion and 10 degrees of eversion will be significantly higher immediately following an isokinetic fatiguing protocol of the ankle evertors than at baseline.
As far as we know, this is the only study that has evaluated frontal plane joint position sense following fatigue of the evertors. Most of the other studies on the effects of fatigue on postural sway and joint position sense at the ankle have fatigued either the plantar flexors,\textsuperscript{18,19,24,33} the dorsiflexors,\textsuperscript{7} plantar flexors and dorsiflexors,\textsuperscript{34} or a combination of all four movements.\textsuperscript{14} There were only three studies\textsuperscript{26,28,35} in the literature that fatigued the evertors. One evaluated ankle inversion kinesthesia following isotonic fatigue of the evertors using an elastic band,\textsuperscript{26} while the other two\textsuperscript{28,35} evaluated the effects of an isokinetic eccentric and concentric evertor fatigue on the stretch reflex in the ankle musculature when responding to sudden ankle inversion perturbation.

Chang et al\textsuperscript{26} evaluated the effects of fatigue of the ankle evertors on ankle inversion kinesthesia. They induced fatigue to the ankle evertors with the use of a one meter long piece of medium strength elastic band. Fatigue was monitored using a subjective rating of perceived exertion and by measuring the subject’s maximal voluntary evertor isometric strength using a dynamometer. After fatigue, subjects were then tested to determine if they could discriminate between 5 degrees of inversion movement at .5 degrees/second and no movement at all. This procedure was performed 15 times in conjunction with 15 trials involving no motion. They found that a modest decrement in evertor muscle contractile force induced by repeated concentric contractions appears to reduce the ability of healthy adults to accurately detect passively induced ankle inversion motion thresholds.\textsuperscript{26}

Although our study and Chang’s\textsuperscript{26} reported adverse effects following the evertor fatiguing protocol in regard to conscious measures of proprioception, it is questioned whether kinesthesia and joint position sense errors from studies are cause for injury concern in the clinical setting. Chang et al\textsuperscript{26} stated that small amplitude passively imposed ankle inversion movements with 5\degree of inversion movement at .5 degrees/second and no movement at all. This procedure was performed 15 times in conjunction with 15 trials involving no motion. They found that a modest decrement in evertor muscle contractile force induced by repeated concentric contractions appears to reduce the ability of healthy adults to accurately detect passively induced ankle inversion motion thresholds.\textsuperscript{26}

![Table 1 Descriptive Statistics for Absolute Error of Test Angles](image)

<table>
<thead>
<tr>
<th></th>
<th>Nonfatigued</th>
<th>Fatigued</th>
<th>t</th>
<th>P</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE Inversion 10\degree</td>
<td>1.56 ± 1.03</td>
<td>2.44 ± 1.94</td>
<td>-3.824</td>
<td>&lt;.001*</td>
<td>-0.60</td>
</tr>
<tr>
<td>AE Inversion 20\degree</td>
<td>2.00 ± 1.72</td>
<td>3.12 ± 1.87</td>
<td>-3.208</td>
<td>.003*</td>
<td>-0.50</td>
</tr>
<tr>
<td>AE Eversion 5\degree</td>
<td>1.36 ± 0.91</td>
<td>1.89 ± 1.11</td>
<td>-3.005</td>
<td>.005*</td>
<td>-0.47</td>
</tr>
<tr>
<td>AE Eversion 10\degree</td>
<td>1.75 ± 1.08</td>
<td>2.32 ± 1.27</td>
<td>-2.948</td>
<td>.005*</td>
<td>-0.47</td>
</tr>
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Key: AE = Absolute Error; t = t-Test; * P-value = 0.05; d = Cohen’s
increased, the observed error away from those respective angles also increased. These results are also consistent with findings from Marteniuk when examining elbow joint angle replication. Whether individuals may be at an increased risk of sustaining ankle inversion injuries if they weight bear when ankle evotor muscle function is compromised by fatigue, remains to be determined.

Previous research on effects of joint position sense at the ankle have all concentrated on position sense of dorsiflexion and plantar flexion. Most studies on the effects of fatigue on postural sway and joint position sense at the ankle have fatigued either the plantar flexors or the dorsiflexors. Of those studies, only two evaluated joint position sense. Fatigue was determined by sustaining an isometric contraction. Forestier assumed fatigue in the anterior tibialis when subjects were unable to maintain a workload equal to 70% of their maximal voluntary contraction for more than fifteen seconds in a series of 40 second contractions with 40 seconds of rest between trials. The results of their study showed that fatigue to the anterior tibialis did decrease the accuracy of plantar flexion (4.3° error at 10°) and dorsiflexion (2.8° error at 20°) joint position sense. This led the researchers to conclude that large amplitude movements in dorsiflexion and smaller movements of plantar flexion produced greater positioning errors following fatigue. Huston et al assumed fatigue in the gastrocsoleus complex when subjects were unable to sustain an isometric contraction with both feet in a plantar-flexed position until exhaustion. On average subjects tended to underestimate the desired angle at 20° of plantar flexion in both nonfatigued (4.74°) and fatigued (6.21°) conditions. Although both researchers fatigued sagittal plane muscle groups, underestimation of joint angle may be cause for concern with ankle injuries. By fatiguing the ankle dorsiflexors and plantar flexors in the sagittal plane, it was assumed the muscles that produce inversion and eversion were fatigued as well. Since the mechanism of a lateral ankle sprain is plantar flexion and inversion, the potential for injury might be evident. Since the subjects were nonweight bearing, however, it has not been determined whether the same underestimation will be evident following fatigue of sagittal plane muscle groups during activity.

The distance traversed by the peroneus longus tendon is very large, giving the muscle its ability to produce an eversion force. Because of the unique ability to produce this force, the peroneus longus with the peroneus brevis both play an integral role in the control of inversion, a protective mechanism against lateral ankle sprains. Important to our study is that we investigated the role of the fatigued ankle evertors on frontal plane joint position sense, rather than fatigue of the dorsiflexors/plantar flexors and invertors on frontal plane joint position sense. Joint position sense is one type of proprioceptive afference. If joint position sense were altered by fatigue, which has been shown in our study, it would result in an altered efferent response. This altered response is validated by the results of previous research. Increase in medial/lateral displacement is a result of an inability for the peroneals to stabilize the joint due to an increase in muscle latency produced by fatigue. In addition, the increase in postural sway, especially medial/lateral displacement, may represent the fatigued muscle not responding to efferent neural signals. This inability of the peroneals to respond to efferent neural signals was also evident in our study as evotor fatigue resulted in an overestimation of all four angles.
Hiemstra et al\textsuperscript{41} stated that decreased force production, increased muscle latency, and less efficient neuromuscular processes have been demonstrated in fatigued muscles when compared with nonfatigued muscles. Perhaps the primary difference between Forestier et al\textsuperscript{7} and Huston et al\textsuperscript{19} studies when compared with Yaggie and McGregor\textsuperscript{14} and our study, was the method by which fatigue was induced and the muscle groups fatigued. Isokinetic fatigue may not be a dynamic protocol nor similar to an actual activity fatigue. Fatigue using an isokinetic protocol produces detrimental affects on frontal and sagittal joint position sense, however. It is therefore reasonable to believe that peripheral muscle fatigue of the ankle evertors was achieved following an isokinetic fatiguing protocol. We feel that the results of our study produced an adverse effect on frontal plane joint position sense, because the subjects were fatigued when they were unable to successfully complete three consecutive repetitions at or above 50\% of maximal joint torque for both evertor eccentric and concentric contractions. By including an eccentric contraction in the fatiguing protocol the action of the peroneal muscles would be compromised. A decrease in eccentric force production as a measure of fatigue is more applicable to the functional activities that give rise to ankle injuries.\textsuperscript{28}

Joint position sense is determined by the integration of afferent information sent to the brain via cutaneous, articular, and muscle mechanoreceptors. The slow activating cutaneous mechanoreceptors and muscle spindles are thought to be the types of mechanoreceptors best suited for determining joint position sense.\textsuperscript{19} To minimize the activation of cutaneous mechanoreceptors, an elastifoam strap was secured around the foot during joint position sense testing.\textsuperscript{19,31}

It has been reported in the literature that the mechanoreceptors in the muscles are most effective at determining joint position sense at mid ranges of motion.\textsuperscript{6,19,42,43} By examining midranges of motion in our study the afferent information regarding joint position sense was minimized as articular mechanoreceptors are believed to be most active at end ranges of motion. Because neuromuscular fatigue would affect the muscle spindles more so than any other type of mechanoreceptor, it would follow logic to test their capacity to determine joint position sense at their most effective angular positioning, midrange. The angles of ten and twenty degrees of inversion, and five and ten degrees of eversion in our study were chosen to represent angles from the early and late midrange of a normal range of motion for inversion and eversion. Although normal range of motion for the subtalar joint is not universally agreed upon, a conservative estimate of normal range of motion for inversion is 20 degrees, while normal range of motion for eversion is 5 degrees.\textsuperscript{44}

**Clinical Implications**

The evertors of the ankle must eccentrically contract to prevent excessive inversion of the hind foot at heel strike. A compromise to their ability to do so may result in improper foot positioning during gait. Our study has shown that when the ankle evertors have been reliably fatigued, their ability to determine inversion and eversion joint position sense is indeed compromised. More importantly, participants were more likely to overshoot their test angle in a fatigued state, putting them at a greater degree of inversion than cognitively perceived. Though any connection or correlation with prevalence of lateral ankle sprains has not been proven, the increased
time to muscle activation of the evertors when fatigued very closely mimics this same phenomenon that is also seen after injury and in chronic ankle instability. Fatigue acts as a paradigm for injury, from which its clinical value is derived.\textsuperscript{14,19,45} If an increased time to muscle activation caused by injury is a precursor to chronic ankle instability, then it might be assumed that a similar increased time to muscle activation caused by evertor fatigue may also be.

Whether a statistically significant difference in ability to detect proper subtalar joint position after fatigue lends to a practical meaningfulness is not clear. However, in this study a moderate to high effect size was evident for condition and position eliminating the chance occurrence of significance. Therefore, an overestimation of the target angle for inversion following muscle fatigue might lead to an increased incidence of inversion ankle sprains, as a result of improper subtalar positioning at heel strike. By eccentrically contracting to control the rate and amount of supination of the rear foot, the peroneus brevis and peroneus longus are primary muscle stabilizers in protection against lateral ankle sprains.\textsuperscript{39,40} Even though the articular surfaces and ligaments are clearly the primary stabilizers of the ankle,\textsuperscript{40} emphasis should be placed upon increasing muscular endurance of the ankle evertors in an attempt to stave off and counteract the deleterious effects of muscular fatigue.

**Conclusion**

The results of our study indicate that there is a significant difference in absolute error of joint position sense at ten and twenty degrees of inversion and five and ten degrees of eversion in fatigued and nonfatigued states. When the ankle evertors were fatigued, the absolute error in joint position sense was significantly higher at all four test angles than when the ankle evertors were not fatigued.

Why this difference was evident may be because of a compromise to the function of musculoskeletal mechanoreceptors of the ankle evertors, namely muscle spindles. Due to fatigue, accurate information about joint position sense is not being relayed to the brain or the fatigued muscle not responding to efferent neural signals.

**References**


