Altered Neuromuscular Control and Ankle Joint Kinematics During Walking in Subjects With Functional Instability of the Ankle Joint

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Background: The ankle joint requires very precise neuromuscular control during the transition from terminal swing to the early stance phase of the gait cycle. Altered ankle joint arthrokinematics and muscular activity have been cited as potential factors that may lead to an inversion sprain during the aforementioned time periods. However, to date, no study has investigated patterns of muscle activity and 3D joint kinematics simultaneously in a group of subjects with functional instability compared with a noninjured control group during these phases of the gait cycle.

Purpose: To compare the patterns of lower limb 3D joint kinematics and electromyographic activity during treadmill walking in a group of subjects with functional instability with those observed in a control group.

Study Design: Controlled laboratory study.

Methods: Three-dimensional angular velocities and displacements of the hip, knee, and ankle joints, as well as surface electromyography of the rectus femoris, peroneus longus, tibialis anterior, and soleus muscles, were recorded simultaneously while subjects walked on a treadmill at a velocity of 4 km/h.

Results: Before heel strike, subjects with functional instability exhibited a decrease in vertical foot-floor clearance (12.62 vs 22.84 mm; \(P < .05\)), as well as exhibiting a more inverted position of the ankle joint before, at, and immediately after heel strike (1.69°, 2.10°, and –0.09° vs –1.43°, –1.43°, and –2.78°, respectively [minus value = eversion]; \(P < .05\)) compared with controls. Subjects with post–heel strike time period (107.91% millisecond vs 64.53% millisecond; \(P < .01\)).

Conclusion: The altered kinematics observed in this study could explain the reason subjects with functional instability experience repeated episodes of ankle inversion injury in situations with only slight or no external provocation. It is hypothesized that the observed increase in peroneus longus activity may be the result of a change in preprogrammed feed-forward motor control.

Keywords: ankle sprain; electromyography (EMG); gait analysis; motor control

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Functional instability (FI) of the ankle joint has been used to describe subjects who experience multiple ankle joint inversion injuries with slight or no external provocation. Functional instability has been reported to be the most common and serious residual disability after ankle sprains.1,2

Freeman et al10 have proposed that the basic mechanism of ankle instability after ankle injury develops due to the lesion of mechanoreceptors in the joint capsule and ligaments surrounding the ankle. This theory is known as articular deafferentation. According to this theory, dynamic stability of the ankle joint depends on the ability of the evertors (peronei) to react quickly to sudden inversion perturbations, to develop sufficient tension to prevent injurious ranges of ankle motion, and thus to prevent sprains of the lateral ligament complex of the ankle. This theory suggests that individuals with FI could have delayed and diminished reflex responses in the evertor muscles of their affected ankles in reaction to an inversion stress because of altered capsular and ligamentous afferent input. However, more current evidence suggests that the dynamic control of ankle stability depends on feed-forward motor control of the central nervous system.21

It has been suggested that inappropriate positioning of the ankle joint before ground contact during walking may have important implications for ankle joint stability.21 Two recent studies have examined gait parameters in subjects...
with ankle instability. Nyska et al\textsuperscript{23} have shown that during the stance phase of gait, subjects with chronic ankle instability exhibited altered kinetics, which the authors concluded was suggestive of a lateral shift of body weight. In a more recent study, Monaghan et al\textsuperscript{22} have shown that subjects with chronic ankle instability exhibited altered ankle joint kinematics and kinetics during overground walking at their self-selected velocities. In this study, the subjects with ankle instability were found to have a more inverted position of the ankle joint before and immediately after heel strike (HS) compared with a control group, as well as a concentric extensor moment, whereas control subjects exhibited an eccentric invertor moment after HS. A limitation of this study was that no EMG data were collected. To date, no study has investigated patterns of muscle activity and 3D joint kinematics simultaneously in a group of subjects with FI compared with a noninjured control group. Examination of simultaneous lower limb 3D kinematics and EMG activity will provide further insight into the neuromuscular control of the lower limb in subjects with ankle instability. The current study aimed to compare the patterns of lower limb 3D joint kinematics and EMG activity of the ankle musculature during treadmill walking in a group of subjects with FI with those observed in a control group. Walking is a functional task requiring precise control of dynamic stability of the ankle joint. In this study, we used treadmill walking to provide a method of testing the dynamic stability and neural control of movement at the ankle joint.

MATERIALS AND METHODS

Subjects

This study was conducted with a total of 24 subjects with FI (FI group) and 22 control subjects (control group). There were 14 male and 10 female subjects in the FI group and 14 male and 8 female subjects in the control group. The FI group was recruited by means of referral from private physical therapy practices before formal rehabilitation was commenced, and the control subjects were recruited from the university population. Age and anthropometrical characteristics of the subjects are shown in Table 1.

Inclusion in the FI group were based on the following criteria, which have been previously used by Caulfield and Garrett\textsuperscript{4,5}: The subject reported a history of a minimum of 2 inversion injuries to 1 ankle that required a period of protected weightbearing and/or immobilization; the subject reported no history of fracture to the lower extremity; the involved ankle was subjectively reported to be chronically weaker, more painful, and less functional than was the other ankle at the time of testing; the subject reported a tendency for the ankle to “give way” during sporting activities; and current subjective complaints were reported to be secondary to history of inversion sprains. None of the FI group subjects were receiving formal rehabilitation at the time of testing. Control group subjects had no history of ankle sprain or fracture of the lower extremity. None of the subjects in either group reported a history of neurological or vestibular impairments.

Table 1: Age, Height, Body Mass, and Body Mass Index of FI and Control Subjects

<table>
<thead>
<tr>
<th></th>
<th>FI Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Age, y</td>
<td>26 ± 6.18\textsuperscript{a}</td>
<td>22.8 ± 4.23</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.7 ± 0.08</td>
<td>1.8 ± 0.08</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>71.5 ± 10.87</td>
<td>70.5 ± 8.14</td>
</tr>
<tr>
<td>Body mass index, kgm\textsuperscript{2}</td>
<td>23.77 ± 0.51</td>
<td>22.68 ± 1.74</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Values are means ± SD. FI, functional instability.

The subjects were acquainted with the aim of the study, instructed about the experimental procedure, and asked to sign an informed consent form before participating in the study, which was carried out in accordance with the principles outlined in the Declaration of Helsinki of the World Medical Association. The ethical committees and research review boards of the university approved the study.

Equipment

Kinematic Data. The CODA mpx 30 (Charnwood Dynamics Ltd, Leicestershire, United Kingdom), which is a general-purpose 3D motion analysis tracking system that tracks the position of infrared light-emitting diode markers, was used to provide information pertaining to 3D segment angular displacement. The infrared light-emitting diode markers were attached to specific lower limb anatomical positions as outlined in the gait analysis setup of the CODA mpx 30 user’s manual. Markers were placed on the lateral aspect of the knee joint line, the lateral malleolus, the heel, and the fifth metatarsal head. Wands with anterior and posterior markers were positioned on the pelvis, sacrum, thigh, and shank. The markers were attached to the skin with double-sided adhesive tape. They were attached to the involved lower extremity in subjects with unilateral FI, whereas the self-reported weaker ankle was studied in subjects with bilateral FI. The left lower extremity was chosen for analysis in the control group. The CODA mpx 30 infrared light-emitting diodes were sampled at a frequency of 200 Hz.

Electromyographic Data. We recorded surface EMG from the rectus femoris, peroneus longus, tibialis anterior, and soleus muscles in each group. The number of muscles recorded in both groups is outlined in Table 2. The EMG activity was inspected by an independent evaluator, who inspected the EMG profiles for any evidence of baseline shift, motion artifact, or 50-Hz interference. If any of the aforementioned were present, the trial was rejected; thus, this accounted for the difference in the number of muscles recorded from each subject. The activity was recorded using preamplified electrodes (model MA-317, Motion Lab Systems, Inc, Baton Rouge, La) applied to lightly abraded skin over the respective muscle belly. Electrode placement was carried out in accordance with the Surface EMG for Non-invasive Assessment of Muscles Research Group recommendations.\textsuperscript{25} The signals were amplified (gain 1000),
band-pass filtered (Blackman 61 dB) at 20 Hz (low) and 500 Hz (high), and sampled at 2000 Hz. The signal was then full-wave rectified and averaged over a 15-millisecond moving window. Sampling of kinematic and EMG data was synchronized.

Test Protocol

Before performing the test, enough time was allowed for each subject to become familiar with the equipment, testing procedure, and treadmill walking. The subjects wore shorts and a T-shirt during testing.

All subjects walked barefoot on an electrically driven treadmill (RTM 500, Biodex Medical Systems Inc, Shirley, NY) at a velocity of 4 km/h, and none complained of any discomfort during the testing procedure. A treadmill velocity of 4 km/h was chosen based on a previous study by Monaghan et al, who, while examining ankle joint kinematics during overground walking, found that subjects walked at a self-selected velocity of between 4 and 5 km/h. Subjects walked for 3 consecutive 10-second periods at the aforementioned velocity.

DATA ANALYSIS

Kinematics

The period from 200 milliseconds before HS to 200 milliseconds after HS was identified for 10 trials for each subject. Heel strike was identified using the method validated by Hreljac and Marshall. Vertical foot-floor clearance was measured by means of tracking the vertical trajectory of the light-emitting diode placed on the base of the fifth metatarsal head. Time-averaged profiles for hip, knee, and ankle joint 3D angular displacements were calculated for each subject. Group mean profiles were subsequently calculated. Differences in the FI and control groups’ time-averaged profiles at 3 time points (50 milliseconds before HS, at HS, and 50 milliseconds after HS) were tested for statistical significance using independent 2-sided t tests. Further analysis was performed for the peroneus longus and soleus muscles during the time period after HS. We chose to further analyze these muscles based on the reported presence of short and long latency reflexes present in these muscles.

The short latency reflex for the peroneus longus has been reported to occur 41 milliseconds after ground contact; therefore, we chose to further analyze the peroneus longus IEMG during the time period from HS to 40 milliseconds after HS. The short latency reflex for the soleus muscle has also been shown to exhibit long latency reflexes, which occur approximately 90 milliseconds after ground contact, so we also chose to further analyze these muscles during the time period from HS to 80 milliseconds after HS.

Electromyography

Data relating to the period 200 milliseconds before HS to 200 milliseconds after HS were extracted from 10 EMG records for each muscle and each participant. After extraction of the relevant data, EMG records were normalized with respect to peak EMG amplitude mean from 10 records for each subject.

We chose to quantify pre- and post-HS muscle activity by means of calculating the integral EMG (IEMG) activity during 2 separate 200-millisecond linear envelopes on either side of HS. This involved calculating the area under the curve during the relevant time period. Integral EMG has been recommended as the most favorable method for quantifying muscle activation when using surface EMG for kinesiological applications. It is expressed in terms of percentage of peak activity related to the linear envelope (%-millisecond). The IEMG was calculated for each subject for both 200-millisecond envelopes before and after HS. Group mean IEMG values for each muscle during the relevant linear envelopes were then calculated. Results are given as group mean and SE of the mean. Differences in the FI and control group IEMG activity in each muscle during the time periods 200 milliseconds before HS to HS and from HS to 200 milliseconds after HS were tested for statistical significance using independent 2-sided t tests. Further analysis was performed for the peroneus longus and soleus muscles during the time period after HS. We chose to further analyze these muscles based on the reported presence of short and long latency reflexes present in these muscles.

The short latency reflex for the peroneus longus has been reported to occur 41 milliseconds after ground contact; therefore, we chose to further analyze the peroneus longus IEMG during the time period from HS to 40 milliseconds after HS. The short latency reflex for the soleus muscle has also been reported to occur between 53 and 46 milliseconds after ground contact, so we also chose to further analyze these muscles during the time period from HS to 80 milliseconds after HS. Further analysis was not undertaken on either the rectus femoris or tibialis anterior muscles, as post–ground contact muscle activity in the rectus femoris has been shown not to be reflexive in nature, and the relative contribution of reflex activity to post–ground contact tibialis anterior muscle activity has yet to be fully established. The level of significance for all analyses was set at
RESULTS

Kinematics

The FI subjects exhibited a statistically significant increase in ankle joint inversion at each of the 3 time points evaluated (Figure 1, Table 3). Effect sizes for group differences were 0.66, 0.77, and 0.55 for the 50 milliseconds before HS, HS, and 50 milliseconds after HS time points, respectively, indicating medium effects due to FI status. There were no significant \( P > .05 \) differences in joint kinematics measured in the hip and knee joints for all 3 planes of movement and in the ankle joint sagittal and transverse planes. As shown in Figure 2, FI subjects exhibited a decrease in vertical foot-floor clearance during the terminal swing phase of the gait cycle. The effect size for group differences in vertical foot-floor clearance was 2.01, indicating a strong effect due to FI status (Table 3).

Integral EMG

Group averaged normalized IEMG activities for each muscle are outlined in Figure 3. We observed a statistically significant increase in peroneus longus IEMG during the post-HS time period \( P < .01 \) in the FI subjects. The effect size for group differences in post-HS IEMG was 1.71, indicating a strong effect due to FI status. Further analysis revealed that these differences were present during the time periods from HS to 40 milliseconds after HS and from HS to 80 milliseconds after HS. There was a trend toward an increase in peroneus longus IEMG before HS in the FI group, but this was outside the level of statistical significance \( P = .05 \). The subjects in the FI group showed an increase in rectus femoris activity before HS \( P < .01 \); however, no differences were noted after HS \( P > .05 \). There were no significant differences between the groups in terms of tibialis anterior or soleus IEMG. Group mean IEMG activity in each muscle during the 200-millisecond periods before and after HS is detailed in Table 4.

DISCUSSION

The principal findings from the present investigation were that the FI group had an increased inverted position of the ankle joint compared with a healthy control group during the terminal swing and early stance phases of the gait cycle. Furthermore, the FI group exhibited a decrease in vertical foot-floor clearance during the terminal swing phase of the gait cycle compared with the healthy control group. These findings could explain the reason subjects with FI experience repeated episodes of “giving way” of their ankle joints in situations with only slight or no external provocation. The FI group also exhibited a statistically significant increase in peroneus longus IEMG after HS, with changes being present as early as during the first 40 milliseconds after HS (Table 5). The timing of this increase suggests that it is the result of pre-programmed feed-forward motor control to coincide with the onset of expected HS, as a possible protective mechanism to counteract the increased inversion position of the ankle joint.

Altered Frontal Plane Kinematics and Decreased Vertical Foot-Floor Clearance

Konradsen and Voigt\(^9\) have provided a biomechanical model that can connect a proprioceptive deficit of the ankle with an increased frequency of ankle inversion injuries in subjects with FI. Using a cadaveric study of simulated gait, they showed that if the foot is inverted to such an extent that the lateral edge of the foot collides with the ground, the propulsive energy of the lower extremity could force the ankle-foot complex to rotate into 40° of inversion, 40° of plantar flexion, and 30° of internal rotation. At this point, the ankle-foot complex has lost its bony restrictions, and when the ankle-foot complex is loaded with body weight at the anticipated time of HS, an inversion torque is produced, thus rendering the ankle joint susceptible to a hyperinversion injury and subsequent sprain. The results of our study (more inverted position and less vertical foot-floor clearance in the FI group) provide in...
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in vivo evidence to support the biomechanical model established by Konradsen and Voigt.20

Inappropriate positioning of the ankle joint before HS has been hypothesized as a potential mechanism contributing to the development of a hyperinversion injury at HS.26 After HS, the line of action of the ground reaction force depends on the position of the foot in relation to the center of gravity and inertia.26 If the ankle joint is held in a more inverted position when HS occurs, an external inversion load is placed on the ankle joint, thus increasing the potential for a hyperinversion injury, and subsequent injury to the lateral ligament complex of the ankle joint is likely to occur. The results of our study support this hypothesis put forward by Tropp.26 The FI group in our study remained more inverted during the terminal swing phase of the gait cycle as well as during the weight-acceptance period after HS. It is unlikely that a protective reflex will be able to respond in time to allow for dynamic stabilization of the ankle joint in this situation, as it has been shown that a combination of the peroneal reflex latency and the electromechanical delay (the time from the beginning of muscle EMG activity to the buildup of force in the muscle) renders dynamic stabilization impossible until approximately 126 milliseconds after HS.21

Altered Peroneus Longus IEMG Activity

When contracted, musculotendinous units generate stiffness, which serves as a dynamic restraint to joint movement.14 The peroneal musculature plays an integral role in controlling the amount of inversion occurring at the ankle joint, thus providing protection against inversion sprain.1 Results of previous studies have suggested that reflex activation of the peroneal muscles does not occur fast enough to protect the ankle from injury in case of sudden, unexpected inversion.14,16,21 Therefore, it has been suggested that if the peroneal muscles are to protect the ankle joint against a sudden, unexpected inversion, preparatory activation before HS is required.21

During normal walking on a level surface, the terminal swing phase requires precise control of dynamic stability of the ankle joint because of the close proximity of the lateral border of the foot to the ground surface.27 Konradsen and Hojsgaard29 have provided indirect evidence of a corrective mechanism occurring due to contraction of the peroneal muscles if the ankle joint inversion is perceived to be too great in transitioning from midswing to terminal swing phase of gait. During this experiment, they observed a reduction in peroneal muscle activation after the application of an ankle support that held the ankle joint in a neutral position of inversion/eversion. The authors concluded that the reduced peroneal muscle activation was the result of a reduced need for eversion corrections. Our study supports this hypothesis put forward by Konradsen and Hojsgaard.29 We noticed a trend toward increased activation in the peroneal muscles during the terminal swing phase of the gait cycle, a time

\[ \text{Figure 3. Group averaged normalized EMG responses for each muscle during walking at 4 km/h.} \]

<table>
<thead>
<tr>
<th>Measure</th>
<th>FI Group</th>
<th>Control Group</th>
<th>P</th>
<th>Group Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle joint inversion/eversion 50 ms</td>
<td>1.69 ± 4.71</td>
<td>−1.43 ± 4.75</td>
<td>.03</td>
<td>0.66</td>
</tr>
<tr>
<td>Ankle joint inversion/eversion HS, deg</td>
<td>2.10 ± 4.28</td>
<td>−1.43 ± 4.60</td>
<td>.01</td>
<td>0.77</td>
</tr>
<tr>
<td>Ankle joint inversion/eversion 50 ms</td>
<td>−0.09 ± 3.68</td>
<td>−2.78 ± 4.93</td>
<td>.04</td>
<td>0.55</td>
</tr>
<tr>
<td>Minimum vertical foot-floor clearance, mm</td>
<td>12.62 ± 7.49</td>
<td>22.84 ± 4.92</td>
<td>.01</td>
<td>2.10</td>
</tr>
</tbody>
</table>

\( ^{a} \text{Values are means ± SD unless otherwise indicated. Inversion is positive unless otherwise noted. FI, functional instability; HS, heel strike.} \)
period during which the ankle joint in subjects with FI was moving toward a more inverted position (see Table 4 for mean ± SD values). The effect size for this trend was 1.17, indicating that there was a strong effect due to FI status. This trend toward increased activity in the peroneal musculature could indicate that these muscles are acting eccentrically to control the rate of inversion occurring at the ankle joint. Furthermore, we also noted an increase in peroneal muscle activation on HS and during the loading phase of the gait cycle in subjects with FI, who simultaneously exhibited an increase in terminal swing phase inversion of the ankle joint.

This increase in peroneal muscle activation may be the result of altered feed-forward motor control. Feed-forward motor control involves planning movements based on past experiences. Altered feed-forward motor control has been exhibited in ACL-deficient athletes. Several authors have demonstrated increased lateral hamstring activity during both the stance phase of walking and cutting maneuvers in ACL-deficient subjects. Increased hamstring activity compensates for ACL deficiency by inhibiting anterior translation of the tibia. This noted increase in hamstring activity is a manifestation of a protective feedforward mechanism to anticipated joint loads, which serves to preserve joint stability.

It is plausible to hypothesize that the increased peroneal activity noted in our study is the result of a protective feedforward mechanism. The results of our study have shown that subjects with FI contact the ground during walking on a level surface in a more inverted position of the ankle joint compared with a healthy noninjured control group. The sensory experience of contacting the ground in a more inverted position, a position that renders the ankle joint more susceptible to inversion sprain, could be used to preprogram protective muscle activity, which is evidenced by an increase in peroneal IEMG. Further evidence of a protective feedforward mechanism is evident from previous work at our laboratory, which has shown that subjects with ankle instability exhibit a concentric evertor moment after HS compared with an eccentric invertor moment observed in a noninjured control group. The authors concluded that the changes in kinetic control observed in the ankle instability group may result as a protective mechanism to prevent ankle sprain, a hypothesis that is confirmed by the increased peroneal IEMG activity observed in the present study.

**Altered Rectus Femoris IEMG Activity**

The altered rectus femoris recruitment indicates that the neuromuscular impairments noted in subjects with FI are not only present in the structures that cross the affected limb but also are manifest more proximal in the kinetic chain, thus providing evidence that there can be central neural adaptations to peripheral joint injuries. Further evidence of proximal joint changes in response to peripheral joint injury in subjects with FI has been demonstrated by Caulfield and Garrett, who showed altered sagittal plane knee and ankle joint movement during single-leg jump landings in subjects with FI. Gribble et al have also

**TABLE 4**
Integral EMG Activity During the 200-Millisecond Periods Before and After HS

<table>
<thead>
<tr>
<th>Muscle</th>
<th>200 ms Before HS to HS</th>
<th>HS to 200 ms After HS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FI Group</td>
<td>Control Group</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>90 ± 25.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>59.78 ± 17.24</td>
</tr>
<tr>
<td>Peroneus longus</td>
<td>51.95 ± 26.99</td>
<td>33.39 ± 15.89</td>
</tr>
<tr>
<td>Tibialis anterior</td>
<td>284.40 ± 172.58</td>
<td>311.41 ± 234.68</td>
</tr>
<tr>
<td>Soleus</td>
<td>52.34 ± 26.96</td>
<td>39.77 ± 20.59</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means ± SD expressed in percentage-milliseconds. FI, functional instability; HS, heel strike.

<sup>b</sup>Significant difference from control subjects.

**TABLE 5**
Integral EMG Activity During the 80-Millisecond Periods After HS

<table>
<thead>
<tr>
<th>Muscle</th>
<th>HS to 40 ms After HS</th>
<th>HS to 80 ms After HS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FI Group</td>
<td>Control Group</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>21.45 ± 13.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.42 ± 5.31</td>
</tr>
<tr>
<td>Peroneus longus</td>
<td>21.20 ± 11.77</td>
<td>21.29 ± 15.38</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means ± SD expressed in percentage-milliseconds. FI, functional instability; HS, heel strike.

<sup>b</sup>Significant difference from control subjects.
demonstrated changes in proximal joint kinematics during a dynamic balance test in subjects with FI. Evidence of altered proximal joint muscle recruitment in subjects with ankle sprain has also been reported by Bullock-Saxton et al, who observed changes in gluteus medius recruitment in subjects with a history of severe unilateral ankle sprain. The exact consequences of this change in rectus femoris activity cannot be fully elucidated as there was not a simultaneous change in hip or knee joint kinematics.

Based on the results outlined above, we believe that gait training should be an integral part of rehabilitation protocols after sprain of the lateral ligament complex of the ankle joint. Oftentimes, gait training is overlooked in the rehabilitation of an acute ankle sprain, and instead emphasis is put on more demanding activities such as jump landing and agility drills. Furthermore, we would suggest that braces and tape may play an important role in the reeducation of agility drills. Furthermore, we would suggest that braces and tape may play an important role in the reeducation of patients after ankle sprain. The exact consequences of this change in rectus femoris activity cannot be fully elucidated as there was not a simultaneous change in hip or knee joint kinematics.

Based on the results outlined above, we believe that gait training should be an integral part of rehabilitation protocols after sprain of the lateral ligament complex of the ankle joint. Oftentimes, gait training is overlooked in the rehabilitation of an acute ankle sprain, and instead emphasis is put on more demanding activities such as jump landing and agility drills. Furthermore, we would suggest that braces and tape may play an important role in the reeducation of patients after ankle sprain. The exact consequences of this change in rectus femoris activity cannot be fully elucidated as there was not a simultaneous change in hip or knee joint kinematics.

CONCLUSION

We have shown that subjects with FI exhibit altered neuromuscular control and kinematics of their ankle joints and in doing so provide direct in vivo evidence to support the biomechanical model of ankle sprain in subjects with ankle instability established by Konradsen and Voigt.  

ACKNOWLEDGMENT

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REFERENCES