The effect of fatigue and habituation on the stretch reflex of the ankle musculature

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Abstract

Many ankle injuries are said to occur when athletes are in a fatigued state; therefore, studies investigating the role that fatigue plays in ankle injuries are warranted. Furthermore, the contributions of the stretch reflex in countering the injury mechanism are still unclear. We hypothesized that (1) fatigue would impair the reflex response, (2) there would be no differences between genders, (3) habituation would be present, and (4) fatigue would exacerbate the effect of habituation. Forty healthy subjects participated and were divided into treatment and control groups. Stretch reflex measurements were taken for the tibialis anterior (TA), peroneus longus (PL), and peroneus brevis (PB) muscles in response to a rapid inversion perturbation. A fatigue intervention was administered to the treatment group, while the control group sat quietly. Post-test measurements were recorded within 5 min and reflex latency (RL) and amplitude (RA) were calculated. RA decreased significantly, however a significant improvement was noted in RL in the PL and PB muscles. The effect that peripheral fatigue has on RL should not be considered a cause of ankle injuries. However, the diminished RA may suggest reduced dynamic stability after fatigue. Habituation was present and was exacerbated by fatigue, indicating that reflex testing is affected by fatigue and habituation, which must be taken into consideration in future studies.

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1. Introduction

Ankle injuries are the most common orthopaedic injury incurred during sport participation (Garrick, 1977). Specifically, lateral ankle sprains, which involve the lateral ligament complex, are among the most common injuries seen in both sports and everyday life (Beckman and Buchanan, 1995; Ebig et al., 1997; Garrick, 1977; Willems et al., 2005). The disruption of the lateral ligament complex often leads to mechanical instability, peroneal muscle weakness, and a decrease in neuromuscular control mechanisms about the joint, leaving it particularly susceptible to further injury (Beckman and Buchanan, 1995; Benesch et al., 2000; Ebig et al., 1997; Fernandes et al., 2000; Hertel, 2000; Johnson and Johnson, 1993; Konradsen, 2002; Konradsen et al., 1998; Mora et al., 2003). In fact, recurrent sprains have been reported in over 70% of patients who had previously sustained an inversion ankle sprain (Braun, 1999; Yeung et al., 1994). Recurrent sprains, residual disability, a feeling of “giving way”, and a sensation of joint weakness characterize functional ankle instability, a condition that often arises secondary to ankle trauma (Beckman and Buchanan, 1995; Fernandes et al., 2000; Konradsen et al., 1998; Konradsen and Ravn, 1991). Repeated ankle sprains associated with functional ankle instability have been linked to an increased risk of osteoarthritis (OA) and articular degeneration (Buckwalter et al., 2004; Gross and Marti, 1999; Harrington, 1979). Given that the majority of ankle OA cases occur secondary to ankle injury, it may be inferred that preventing ankle injuries will lead to a decreased incidence of ankle instability, and subsequently ankle OA, and the
associated disability. Due to the significant amount of time lost from sport, work, and leisure-time activities, research on the factors that contribute to ankle injuries is warranted.

Neuromuscular control can be defined as the interaction between the nervous and musculoskeletal systems to produce a desired effect, specifically in response to a stimulus. During activity, dynamic and static restraints work together, via open-loop, reactive, and voluntary mechanisms, to maintain correct joint alignment in response to forces imposed on the joint (Moore et al., 2002). In the ankle specifically, the lateral ligaments are highly innervated by mechanoreceptors (Hertel, 2000; Myers et al., 1993; Konradsen et al., 1998; Konradsen and Ravn, 1991; Larsen and Lund, 1991; Mora et al., 2003; Myers et al., 2003; Santilli et al., 2005; Shima et al., 2005), reflex amplitude (RA) (Gruneberg et al., 2003; Myers et al., 2003; Santilli et al., 2005), and electromechanical delay (Moore et al., 2002; Mora et al., 2003; Yeung et al., 1999) yet there is a great deal of controversy in the literature as to the exact role that this reflex plays in preventing ankle sprains. Given the inconsistency of the results in studies involving subjects with unstable ankles and the lack of research on the body’s normal response to inversion sprain mechanisms, studying the peroneal muscle reflex of normal subjects in response to stress may be beneficial in determining the cause of ankle sprains and long-term dysfunction, as well as lead to preventative initiatives and improved treatment measures.

With an increase in participation rates of females in sporting activities since the passing of Title IX, a dramatic discrepancy in injury rates between genders of ACL injuries has been documented (Moore et al., 2002). This gender bias in injury rates has generally been attributed to neuromuscular and biomechanical factors, however little work has been done at the ankle joint. Moore et al. (2002) found a difference between males and females in total motor time in response to a patellar tendon stretch, however this difference was attributed to electromechanical delay as opposed to premotor time. Furthermore, Benesch et al. (2000) found no differences between genders in peroneal reaction time. While it is generally accepted that no differences should exist between the genders in RL or RA, little research is available evaluating the effect of fatigue on reflex response between genders.

Habituation can be described as a decrease in response amplitude (RA) to a repeated, non-noxious stimulus and is a type of non-associative learning (Kandel et al., 2000). It has been found that large, automatic reactions (reflex responses) to unexpected movements of a supporting platform are progressively attenuated as the perturbation is repeated (Keshner et al., 1987; Stelmach et al., 1989). This habituation of the reflex response is a functional mechanism that allows a subject to minimize energy expenditure, once the individual is aware that the stimulus is, in fact, non-noxious (Keshner et al., 1987). While habituation is known to occur in both the upper (Floeter et al., 1998) and lower (Keshner et al., 1987; Stelmach et al., 1989) extremities, few studies have evaluated this phenomenon in the stretch reflex of the ankle musculature. Gruneberg et al. (2003) monitored habituation of the reflex responses during landing on inverting and non-inverting platforms and found that habituation was not present. However, no studies are available that monitor habituation while just standing on an inverting platform.

Some suggest that fatigue plays a significant role in the occurrence of ankle injuries (Gribble and Hertel, 2004; Huston et al., 2005; Ochsendorf et al., 2000; Pasquet et al., 2000; Yeung et al., 1999). Anecdotally, many injuries occur during the latter stages of activity when fatigue is present. 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 (Avela et al., 2001; Gribble and Hertel, 2004; Harkins et al., 2005; Moore et al., 2002; Ochsendorf et al., 2000; Pasquet et al., 2000; Van Lent et al., 1994; Yaggie and McGregor, 2002; Yeung et al., 1999). No studies have evaluated the reflex response times or amplitudes of the ankle musculature to ankle inversion stress before and immediately after isokinetic fatigue.

Generally, isokinetic fatigue has been defined as a force production decrease below 50% of the peak force, which is determined either from a pre-test maximal isometric contraction or peak force observed during the first three to five contractions in the fatigue protocol (Ochsendorf et al., 2000; Wikstrom et al., 2004; Yaggie and McGregor, 2002). Isokinetic force output is significantly greater for eccentric (ECC) than concentric (CON) muscle actions, while EMG activity is significantly greater for CON than ECC actions. In other words, ECC muscle activity can produce more force with less stimulation, effectively decreasing the amount of energy required to perform the task (Pasquet et al., 2000). Under fatigued conditions, CON muscle actions result in a greater loss of force than ECC actions (Pasquet et al., 2000). Therefore, in this study, fatigue was measured via a decrease in ECC force production because ECC muscle actions are more resistant to force reductions due to fatiguing exercises (Smith and Newham, 2007). Furthermore, ankle inversion injuries are caused by an inability of the peroneal muscles to eccentrically resist the inversion movement (Mora et al., 2003). Traditionally, isokinetic fatigue protocols have utilized CON movements solely, whereas unique to this study, fatigue was measured by decreases in ECC force production.

While many studies have evaluated peroneal reaction time, comparing healthy and injured ankles (Beckman and Buchanan, 1995; Ebig et al., 1997; Fernandes et al.,

2. Materials and methods

2.1. Subjects

A total of 40 subjects were recruited from the university community. All subjects filled out an ankle inclusion questionnaire. In order to be included, the subjects had to be free of any lower extremity injury and have never suffered an injury on their dominant ankle in their lifetime. All subjects gave their written informed consent approved by the Human Subjects Review Board (HS 06-077) before participation in the study. Subjects were divided into a treatment (Tx) group (10 males/10 females) and a control (Ctl) group (10 males/10 females). Subject demographic data are presented in Table 1.

2.2. Instrumentation

2.2.1. Electromyographic data

EMG activity was recorded using bipolar surface electrodes (Ag–AgCl, 6 mm contact diameter, 2 cm spacing). The raw EMG data were collected and amplified (input impedance 10 MΩ, gain 5000×, common mode rejection ratio >115 dB) using a Bortec AMT-8® EMG system (Bortec Biomedical Ltd., Calgary, Alberta, Canada). The EMG signals were collected using a laptop computer with a 12-bit analog-to-digital converter (6024-E, National Instruments Corp., Austin, TX), at a sampling rate of 1000 Hz, using custom designed LabVIEW software (version 7.1, National Instruments Corp., Austin, TX) to synchronize and save the data for future analysis.

2.2.2. Ankle inversion perturbation

The sudden inversion perturbation was produced by a device constructed and used by Beckman and Buchanan (1995) (Fig. 1). The platform was constructed such that each ankle could be inverted independently. Pneumatic actuators drove the platforms, while the angle of inversion was measured by potentiometers located at the axis of rotation. The platforms were inverted to 25°–30° of inversion at a velocity of 400–700°/s, about an axis located near the subtalar joint and midtarsal joint axes (Beckman and Buchanan, 1995). Device movement was initiated using a custom trigger that delivered a TTL (Transistor–Transistor Logic) pulse with a duration of 100 ms.

2.2.3. Isokinetic dynamometer

The Kinetic Communicator (Kin Com) 125-AP isokinetic dynamometer (Chattecx Corp., Chattanooga, TN) was used to induce fatigue. The dynamometer was operated in isokinetic mode, and thus quantified resistive force generated by the subject, concentrically and eccentrically, at a preset angular velocity for the eversion motion at the ankle.

2.3. Procedures

Each subject reported for testing on one occasion that lasted approximately 1 h. Once consent was obtained, age, mass, and height were measured and recorded, followed by a stationary bicycle warm-up for 5 min. Electrode placement was established via finger and handbreadths as detailed by Perotto (1994) over the tibialis anterior (TA), peroneus longus (PL), and peroneus brevis (PB) muscles. Specific patches of skin on the lower leg were

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subject demographic data (mean ± standard deviation)</th>
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<tr>
<td></td>
<td>Tx Male (n = 10)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.7 ± 2.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>175.8 ± 5.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.2 ± 10.1</td>
</tr>
</tbody>
</table>

Fig. 1. Inversion perturbation device as pictured by Beckman and Buchanan (1995).
shaved (if necessary), abraded, and wiped with an alcohol pad prior to electrode placement. The adhesive electrodes were oriented parallel to the direction of the muscle fibers and affixed to the leg. The EMG leads were connected to the EMG pack that was fastened around the waist and connected directly to the EMG system.

The subject then stood barefoot on the ankle inversion device (Fig. 2a) with the feet placed comfortably on the platforms facing away from the researcher to eliminate any visual stimulus with regard to the trigger switch. The subject was asked to stand normally on the platforms and remain facing the wall for the duration of the pre-test. Each subject was given the opportunity to feel the sudden inversion perturbation once on each leg before data acquisition began. Once the subject felt comfortable on the device, the pre-test commenced and 10 trials were administered randomly on both the dominant and non-dominant ankle with 10–20 s between trials. Based on pilot work, 10 perturbations was determined to be a sufficient number of trials to reduce any effect of between trial variability in the data and visually observe the effect of habituation. Data were collected for 2 s prior to and after the perturbation. Based on visual inspection, trials were discarded if EMG activity increased in the 2 s prior to movement onset. Limb dominance was determined by asking with which leg the subject would kick a ball. Only the dominant limb pre-test trials were analyzed.

Prior to fatiguing the evertors, the subject was positioned on the Kin Com isokinetic dynamometer for inversion/eversion movements of the dominant leg, with the knee in 45° of flexion and the foot firmly fixed to the shoe plate (Fig. 2b). A warm-up, consisting of several submaximal repetitions, was performed to familiarize the subject with the CON–ECC eversion movement. The subject then performed three CON and three ECC maximal isokinetic repetitions at a velocity of 120°/s. Using the “overlay” feature on the Kin Com, each repetition was performed separately with a 5 s delay between repetitions. The repetitions were averaged and a peak torque was determined for the ECC muscle action, from which 50% of the maximal ECC force production was calculated. The subject then performed continuous CON and ECC eversion ankle movements, to isolate the peroneal muscles, at 120°/s until the ECC force production dropped below 50% of maximal ECC force production for three consecutive repetitions. It was at this point that the subject was considered fatigued and the exercise was terminated. Ctl subjects were positioned on the Kin Com, but they did not perform any exercises/strength testing on the device. They were asked to remain seated quietly for 5–7 min to simulate the time necessary to complete the fatigue protocol.

Once the fatigue protocol was completed, the subject was positioned back on the ankle inversion perturbation device barefoot in the same manner as the pre-test. To reduce the effect of recovery, 10 post-test trials were conducted on the fatigued (dominant) leg only. For all Tx subjects, the first post-test trial was conducted within the first minute following the fatigue event and all 10 post-test trials were completed within 5 min of the termination of the fatiguing event.

2.4. Data reduction

The EMG data were band-pass filtered (2nd order, zero-lag, Butterworth filter, with cut-off frequencies of 10 Hz and 500 Hz) and rectified. The onset of motion was determined as 10 standard deviations above the baseline potentiometer reading, while the onset of muscle activity was determined as 10 standard deviations above baseline EMG activity. The RL was determined as the time difference between movement onset and EMG onset. Since no criterion based on deviations from baseline activity will ever be correct in all cases, all data were visually inspected to assure that the determination of EMG and movement onset was an accurate representation of the real onset times. Data were adjusted manually to reflect the real onset time, if it was obvious that the calculated time did not represent the correct value. A separate analysis was performed to extract the RA, in which EMG recordings of the dominant leg (pre- and post-test) were rectified and linear enveloped (low-pass filter at 7 Hz) and the peak value (amplitude) of the reflex response was extracted. All RA data were normalized to the first pre-test trial for each subject.

2.5. Statistical analysis

To evaluate and identify any differences in RL and RA before and after fatigue and between groups and genders, separate $2 \times 2 \times 2$ mixed multivariate analysis of variance (MANOVA) models, with repeated measures on the last factor, were performed. The factors in these statistical tests were Group, Gender, and Test (pre- and post-fatigue). The dependent variables were muscle RL and RA for each muscle tested (TA, PL, and PB).

![Fig. 2. Subject positioning on the (a) ankle inversion device and (b) Kin Com isokinetic dynamometer.](image-url)
To evaluate habituation of the reflex response, a 2 × 6 mixed MANOVA, with repeated measures on the second factor, was used. The factors in this statistical test were Group and Trial (1st, 6th, and 10th trial of both the pre- and post-test). The dependent variables were RA for each muscle tested (TA, PL, and PB). To evaluate whether habituation was attenuated with fatigue and/or rest, a 2 × 2 (Group × Trial) mixed MANOVA, with repeated measures on the second factor, was used. The dependent variables in this analysis were the RA values from the 1st trials of both the pre- and post-test. The α-level was set at 0.05, a priori, for all statistical tests.

3. Results

3.1. Reflex latency

All RL data are presented in Table 2. A significant main effect for Test was noted [F(3, 34) = 3.594; P = 0.023] in the PL [F(1, 36) = 9.697; P = 0.004] and PB [F(1, 36) = 10.788; P = 0.002] muscles, but not the TA [F(1, 36) = 3.457; P = 0.071]. There were significant decreases (quicker response time) in the RL for both PL and PB in the post-test, demonstrating improvements, rather than the hypothesized deficits. These main effects represent pooled values across groups and genders. There was a trend towards significant differences between the groups [F(3, 34) = 2.635; P = 0.065]. No other significant differences were noted, supporting our secondary hypothesis that no significant differences exist between genders in terms of RL about the ankle joint.

3.2. Reflex amplitude

All RA data are presented in Table 3, while RA data from two representative subjects (one Tx and one Ctl) are depicted in Fig. 3. A significant Test × Group interaction was found [F(3, 34) = 10.841; P = 0.000] in the PL [F(1, 36) = 29.576; P = 0.000] and PB [F(1, 36) = 18.826; P = 0.000] muscles, but not the TA [F(1, 36) = 0.718; P = 0.403]. This indicates that the RA was relatively similar in the pre-test vs. the post-test in the Ctl subjects, while the Tx subjects displayed a marked decrease following the fatigue protocol. This is supported by a significant main effect for Test [F(3, 34) = 57.719; P = 0.000] in all three muscles (p < 0.05). Also, a significant main effect for Group was noted [F(3, 34) = 3.689; P = 0.021] in the PB muscle [F(1, 36) = 11.214; P = 0.002], but not the TA [F(1, 36) = 0.367; P = 0.548] and PL [F(1, 36) = 1.468; P = 0.234] muscles.

3.3. Habituation

Habituation data are represented in Fig. 4. For the 2 × 6 MANOVA, a significant Group × Trial interaction [F(15, 24) = 2.624; P = 0.017] was found for the PL [F(5, 8) = 5.340; P < 0.001] and PB [F(5, 8) = 5.954; P < 0.001] muscles, indicating a dishabituation of the reflex in the Ctl subjects during the 5–7 min rest period. Furthermore, a significant main effect was noted for Trials [F(15, 24) = 29.500; P < 0.001] for all three muscles, TA [F(5, 8) = 48.244; P < 0.001], PL [F(5, 8) = 25.091; P < 0.001] and PB [F(5, 8) = 20.316; P < 0.001], indicating a habituation of the RA over time.

For the 2 × 2 MANOVA, a significant Group × Trial interaction [F(3, 36) = 5.237; P = 0.004] was found in the PL [F(1, 38) = 5.773; P = 0.021] and PB [F(1, 38) = 16.282; P < 0.001] muscles, but not the TA [F(1, 38) = 1.335; P = 0.255]. This demonstrates that following the rest period, control subjects returned to near baseline levels, while the fatigue group continued to decline in the RA (habituate) following the fatigue protocol. It is important to note that this was only true for the PL and PB muscles. Significant main effects were also noted for Group [F(3, 36) = 5.237; P = 0.004] and Trial [F(3, 36) = 25.717; P < 0.001].

4. Discussion

4.1. Reflex amplitude

With the aim of reducing the incidence of ankle injuries, the most pertinent finding in this study was the decrease in RA following fatigue. Supporting our hypothesis that RA will decrease after fatigue, we indeed found a significant Test × Group interaction. This indicated that the fatigued
Table 3  
Reflex amplitudes (RA) normalized to the 1st pre-test trial within each subject (mean ± standard deviation)

<table>
<thead>
<tr>
<th></th>
<th>TA</th>
<th>PL†</th>
<th>PB†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Tx</td>
<td>Male</td>
<td>64.0 ± 15.1</td>
<td>33.4 ± 19.8</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>62.5 ± 26.2</td>
<td>35.9 ± 21.2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>63.2 ± 20.8</td>
<td>35.2 ± 20.1</td>
</tr>
<tr>
<td>Ctl</td>
<td>Male</td>
<td>67.0 ± 23.5</td>
<td>33.9 ± 14.4</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>63.4 ± 19.0</td>
<td>47.5 ± 22.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>65.2 ± 20.9</td>
<td>40.7 ± 19.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>64.2 ± 20.6</td>
<td>37.9 ± 19.8</td>
</tr>
</tbody>
</table>

† Significant Group × Test interaction (P < 0.05) for those muscles, indicating that the Ctl subjects displayed little difference between their pre-test and post-test scores, while the Tx subjects demonstrated a marked decrease in RA following the fatigue protocol.

Fig. 3. Bandpass filtered and rectified (not linear enveloped) EMG recordings of the PB muscle in two representative subjects, a Tx subject and a Ctl subject. (a) The Tx subject’s 2nd pre-test trial; (b) the Tx subject’s 2nd post-test trial; (c) the Ctl subject’s 2nd pre-test trial; and (d) the Ctl subject’s 2nd post-test trial. Fatigue substantially decreased the RA in the representative Tx subject, while the Ctl subject demonstrated little change.

Subjects showed a marked decrease in RA, while the Ctl subjects remained virtually the same in the post-test relative to the pre-test. This suggests that fatigue may impair an individual’s ability to correct for an unexpected ankle inversion in a fatigued state. In work by Moore et al. (2002), decreases were noted in females in RA of the patellar tendon tap reflex following fatigue. Furthermore, Myers et al. (2003) found similar decreases in muscle protective responses when subjects were injected with a solution to simulate edema and they concluded that dynamic stability may be compromised due to the decrease in the reflex response. This may help explain the anecdotal evidence that many injuries occur later in competition, when athletes are fatigued.
4.2. Reflex latency

On the other hand, contrary to our hypothesis, RL significantly decreased (improved) in the peroneal muscles in the post-test compared to the pre-test. Since no significant Group × Test interactions were noted, one possible explanation is that a learning effect took place in which all subjects became more comfortable on the device throughout the testing, resulting in a facilitation of the reflex and therefore an improvement in RL. We attempted to counteract this by allowing the subjects to experience the perturbation prior to testing, however it may not have been a long enough familiarization period to adequately eliminate this possibility. This possibility will be discussed further in Section 4.3. Another possible explanation lies in the methodology. Both limbs were perturbed in the pre-test, while only the dominant (fatigued) leg was tested in the post-test. This was done to allow post-testing to take place as soon as possible following the fatiguing event. However, this implies that all subjects knew which leg would be perturbed in the post-test, but not in the pre-test, which may have led to a condition of relatively increased inhibition in the pre-test, due to the increased uncertainty, resulting in higher (slower) reflex latencies. Our hypothesis of no differences between genders in terms of RL was confirmed, as expected based on previous work (Moore et al., 2002).

It is interesting to note that only the PL and PB were significantly different in terms of RL in the post-test vs. the pre-test, but not the TA. Upon further inspection of the data, it became apparent that the Ctl group improved
The decrease in RA over time indicates that habituation of the stretch reflex response was present in this study. It is known that repeated, non-noxious stimuli can stimulate the non-associative learning known as habituation (Kandel et al., 2000). The body learns that the stimulus is not harmful and adapts its response to the stimulus to conserve energy. Therefore, a high anxiety level present at the onset of testing followed by increased familiarization with the device throughout a testing protocol, may help to explain this habituation. Furthermore, based on the Group \( \times \) Trial interaction for the PL and PB muscles in the 2 \( \times \) 2 MANOVA, a decrease was noted in the RA following the fatigue protocol, while the Ctl group demonstrated dishabituation following the brief rest period. This indicates that fatigue may exacerbate the decline in RA due to habituation. Therefore, the effects of fatigue must also be considered during reflex testing.

Habituation is an important phenomenon that must be accounted for in future research on the stretch reflex response of the ankle musculature. In this study, the delay between successive trials was 10–20 s. Over 10 consecutive trials, the effect of habituation was a decrease in RA of 20–50% from the first trial, depending on the muscle tested. The decrease in the TA was more drastic than the decrease in the peroneal muscles, most likely due to the fact that the perturbation stretched the peroneals more than it did the TA muscle. The fact there was any response in the TA was most likely due to general descending excitation to stabilize the joint. Therefore, the response was not a “necessary” response to an inversion stretch, which helps explain the more drastic and continued habituation seen in the TA. Furthermore, based on the results of the 2 \( \times \) 2 MANOVA, it is apparent that there is a dishabituation seen in the peroneal muscles during the rest period taken by the Ctl subjects. Therefore, one can conclude that a period of 5–7 min will eliminate the effect of habituation in this testing protocol. Unfortunately, a “plateau” effect was not noticeable upon inspection of the RA over time data, therefore a conclusion cannot yet be drawn as to how many trials are needed to properly familiarize and habituate the subjects with the testing protocol.

4.4. Limitations

One might contend that the isokinetic fatigue protocol utilized in this study did not produce fatigue. Gutierrez et al. (in press) utilized the same isokinetic fatigue protocol used in this study and reported significant decreases in muscle force production, peak muscle activation, and median frequency following the fatigue intervention. However, there is argument as to whether or not isokinetic fatigue protocols can simulate the “real-life” (functional) fatigue that occurs during sport participation. Another limitation is that this study could have better controlled external factors during the stretch reflex testing via the use of blindfolds and earplugs. The testing environment was generally quiet, and the subjects were asked to remain quiet throughout the testing protocol, however occasionally normal laboratory interruptions were present during the testing protocol. An additional limitation is that we did not monitor what percent of body-weight was supported by each limb, which may have influenced steady-state muscle activation and subsequently, the reflex response. Finally, better consistency between pre-test and post-test, in terms of limb tested, is desirable.

One novelty of this study is the definition of fatigue: the subject was considered fatigued when a 50% decrease in ECC force production was noted in three consecutive trials. Given that ECC muscle actions are more resistant to force losses due to fatigue and the role of the ECC action of the peroneal muscles when attempting to resist the inversion perturbation, using a decrease in ECC force production to measure fatigue is more applicable to the functional activities that give rise to ankle injuries.

5. Conclusions

A decrease in RA was found following fatigue, indicating that dynamic stability might be affected with fatigue. However, RL decreased (improved) in the post-test relative to the pre-test in all subjects. This may be due to a variety of factors, both real and experimentally derived. A larger, better-controlled study is needed to definitively determine if fatigue affects RL of the ankle musculature.
more, a study involving a functional fatigue protocol, which better simulates the general (central) fatigue experienced during sporting activities, is also warranted. Additionally, experiments including electromechanical delay, time to peak torque, and preparatory EMG profiles in response to an inversion perturbation, may offer a better understanding of the effects of fatigue on the stretch reflex response. Finally, the effects of habituation must be considered during ankle inversion perturbation testing.

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