1. **Please write an abstract for this article in a format of *objective*, *design*, *participants*, *interventions*, *main outcome measures*, *results*, and *conclusions*. (60%)**

2. **Please criticize the strength and weakness of this article. (40%)**

Effects of Neuromuscular Training on the Reaction Time and Electromechanical Delay of the Peroneus Longus Muscle (Arch Phys Med Rehabil 2006;87:395-401)

ANKLE SPRAINS ARE A COMMON injury not only in sports but also in activities of daily living. The most common type of sprain is an inversion sprain, and it is estimated that 1 in every 10,000 people sustains this injury every day.[1] In addition, 7% to 10% of hospital emergency department visits involve people with ankle sprains.[1] It is estimated that 40% of all people who incur a single lateral ankle sprain will have chronic symptoms afterward.[2]

One possible explanation for chronic symptoms and subsequent sprains is that the initial sprain creates an unstable joint. This instability may be related to loss of either passive and/or active restraints. Passive restraint is provided by the bones, ligaments, and capsule. Active, or dynamic, restraint is provided by the neuromuscular system. The peroneal muscles are of particular interest at the ankle because they are the primary muscles responsible for everting the foot against an inversion moment.

Researchers have examined several different methods of neuromuscular training in an attempt to decrease the frequency of ankle sprains.[3-7] For a neuromuscular rehabilitation program to be effective, it must reduce the incidence and/or decrease the severity of an ankle sprain. One possible mechanism with which to achieve these goals is to improve the timing of the dynamic restraint mechanism, or in other words, to increase the speed with which support is provided to the joint complex by contractile elements. Another possible mechanism is to increase the magnitude of the muscular contraction to the point where contraction will offset injury, but not overreact to the stimulus, thus causing injury. Many researchers[8-12] question, however, whether the active restraints can react fast enough to reduce injury and whether these active restraints can be improved with training.

Dynamic restraint after injury perturbation is dependent on the reaction time and the electromechanical delay of that muscle. The reaction time is the time between perturbation and electric activity of the muscle.[13] The electromechanical delay is a measurement of the time lag between muscle activation and the muscle's force production.[14] Together these events constitute the response time of a muscle or muscle group. Previous researchers[8-12,15] have not sufficiently tested response time of the peroneal musculature for 2 reasons. First, they have used an ankle inversion mechanism that examines dynamic restraint characteristics while the subject maintains a static postural stance. Most people do not sprain their ankles while standing. To mimic more closely the dynamic mechanism of an ankle sprain injury and the motor patterns active during gait, we developed a runway with built-in trapdoors. This makes possible measurement of reaction time of the ankle evertors while walking, taking into consideration sensorimotor factors that are only present during movement. Second, in the past, electromechanical delay was determined in a partial or

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nonweight-bearing position.[9-11,15] Recently, however, Moru et al[14] tested electromechanical delay by electrically stimulating the common peroneal nerve and measuring the resultant force in a weight-bearing position. This technique resulted in electromechanical delay measurements recorded in a more functional, weight-bearing position such as that experienced during the stance phase of gait. While these estimates of electromechanical delay did not take into consideration movement, they were significantly shorter than those previously recorded[14] in an unloaded position.

These 2 new techniques, dynamic testing of the ankle evertors on the runway and weight-bearing electromechanical delay measurements, may provide a more functional assessment of the active restraint involved during a sudden inversion moment. Using the response time measurements, a neuromuscular training program can be examined to determine its influence on active restraint provided by the peroneal muscles.

Our purpose in this study was to determine if there were any differences in the dynamic restraint characteristics of the peroneus longus, as measured by reaction time and electromechanical delay, in a simulated injury model after a neuromuscular training program.

METHODS

Design

The study was guided by a 2×2 pre-post factorial design. The independent variables were group (training, control) and sex (male, female). Dependent variables were the difference in average pretest and posttest muscle reaction times and the electromechanical delay of the peroneus longus muscle. The covariate was the pretest muscle reaction times and electromechanical delay of that muscle. The covariate variables were used to remove variation in the results that were inherent in the subjects and not caused by the training treatment. Ankle range of motion (ROM) was measured to ensure that all subjects reached approximately 30° of inversion during reaction time testing.

Participants

Thirty-six healthy, physically active, college-age subjects were recruited for this study. Participants had not experienced an ankle sprain in the last year, and not more than 1 sprain to either ankle in their lifetimes. In addition, subjects did not currently have a lower-extremity injury and had no history of a major injury that resulted in severe ligamentous damage, fracture, or the need for surgery or therapeutic treatment to either lower extremity. Subjects were asked to read and sign an informed consent form approved by the institutional review board (IRB) after the study had been described and all questions answered.

Twenty-six subjects completed the study. There were 5 men and 8 women in the treatment group (mean age ± standard deviation [SD], 21.9±2.1y; height, 173.7±11.1cm; weight, 67.4±17.8kg) and 6 men and 7 women in the control group (mean age, 21.8±2.3y; height, 173.7±11.9cm; weight, 70.8±19.4kg). Groups were sex matched through separate randomization of men and women into the treatment or control group.

Six subjects were dropped after initial testing because an adequate response from the peroneus longus muscle to direct stimulation of the common peroneal nerve could not be attained. The remaining subjects were randomly assigned to a treatment (n=15) or a control group (n=15). One subject was dropped from the treatment group after an undisclosed anterior cruciate ligament injury was discovered. One subject each was dropped from the treatment and control groups before data analysis because of equipment error in measurement. Another subject in the treatment group experienced discomfort with the testing methods and did not want to continue. Therefore, data analysis was performed on 13 treatment subjects and 13 control subjects.

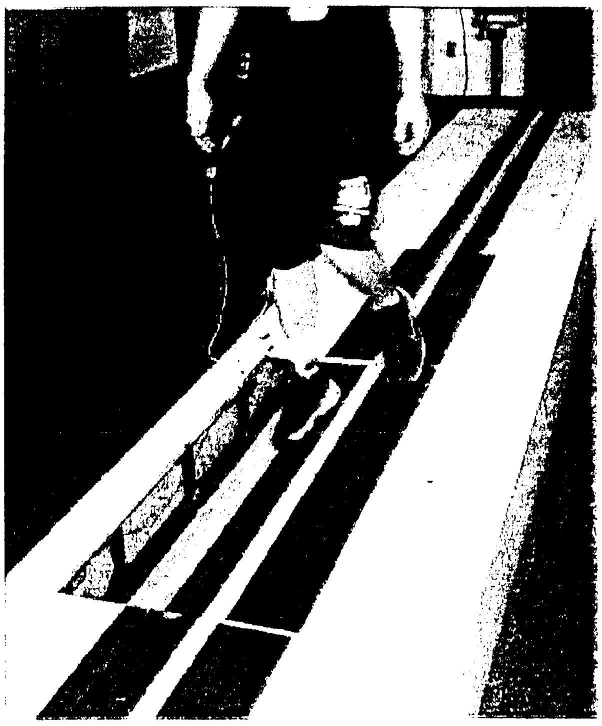

Fig 1. Runway set-up.

Instruments

We used a runway (8.5×.075×.025m, fig 1) consisting of trap doors in the study. The runway consisted of 7 separate 1.22-m segments. There was a bilateral trap door mechanism in segments 3 through 6, allowing for ankle injury mechanisms on either side of the runway. The width of the trap doors was 35cm. An adhesive, nonslip material marked the footpath of the runway and prevented the foot from slipping when the trap door was released. The distance from the center of the nonslip material to the center axis was 12cm. The trap door mechanisms inverted 30° to the selected side when triggered. An electric switch controlled a solenoid that triggered the release of the trap-door supports. Once released, the trap door rested on a spring plunger that held the door in place until the foot contacted the segment, causing it to fall to 30°. The fall of the trap door was marked by the release of an electromagnetic switch.

Electromyographic measurements were collected using surface electromyography (MP150).[a] Signals were amplified (DA100B)[a] from disposable, pregelled Ag-AgCl electrodes. Electromyographic data were collected at 1000Hz. The input impedance of the amplifier was 1.0M, with a common mode rejection ratio of 90dB, high- and low-pass filters of 20 and 400Hz, a signal-to-noise ratio of 70dB, and a gain of 1000. Filtered electromyographic signals were processed using a root mean square algorithm with a 10-ms moving window.

Ankle motion was measured with an electric goniometer (TSD130A),[a] which was secured to the outside of the foot and lower leg to measure inversion ROM. The goniometer was placed over the lateral malleolus and secured to the shoe and lower leg with tape. The time to total inversion was calculated as the time from the drop of the trap door to the time of peak inversion ROM.

Procedures

All subjects reported to the lab approximately 1 week before testing for an orientation session, at which they signed IRB-approved informed consent forms. During this session, subjects practiced walking to a cadence of a metronome set to 100 beats/min. After the subjects became comfortable walking on the runway at the set cadence, we were able to establish each subject's stride length. This was necessary to determine a starting point from which the subject would consistently step with each foot on each of the 8 trap-door mechanisms located in the runway.

After the orientation session, any questions subjects had were answered and subjects were then randomized into either the treatment or control group.

The "dominant leg" was operationally defined as the leg with which the subject would kick a ball. On test day, an area of each subject's dominant leg was shaved, then lightly abraded and cleaned with isopropyl alcohol before the surface electrodes were applied. The electrodes were placed 2cm center to center, parallel to the peroneus longus muscle fibers 4 to 6cm distal to the fibular head. Placement was confirmed by visual inspection of the electromyographic signal during active eversion and walking.

Each subject began a testing session by warming up on an exercise bike for 5 minutes at a moderate intensity. All subsequent data were collected from the subject's dominant leg.

To assess the electromechanical delay, a supramaximal, percutaneous electric stimulus of the common peroneal nerve was used. The stimulation electrode was placed over the common peroneal nerve as it passed superoposterior to the fibular head. Lateral ground reaction force represented the mechanical contribution induced by stimulation.[14] Subjects stood with their test leg on the forceplate over a marked spot and the other leg off the forceplate over a marked spot. Subjects placed their hands on top of a hand railing in front of them to provide support and prevent sway. They were instructed to hold this position while looking straight ahead. Stimulus intensity was increased until a maximum efferent response was observed via electromyography. Using this intensity, the common peroneal nerve was then stimulated 10 times, with a 15-second rest between stimulations. The onset times of the processed electromyographic response and lateral ground force were defined as the point where the signal was 2 SDs higher than the mean resting activity during stance. The electromechanical delay was then defined as the time interval between the onset of the peroneus longus electromyographic activity and the onset of lateral ground reaction force.[14] An example of the computer electromyographic output for electromechanical delay is shown in figure 2.

Electromechanical delay was tested first across all measurement sessions and groups. Electromechanical delay is a static, sensitive measurement that could be affected by the number of trips (30) down the runway and the perturbations during a few of those trips. Also, we felt the electromechanical delay measurements would have little, if any, effect on the reaction time measurements if the measurement was taken in static stance. If electromechanical delay did have any effect on the reaction time measurements, it should occur across all sessions, and the effect would be the same.

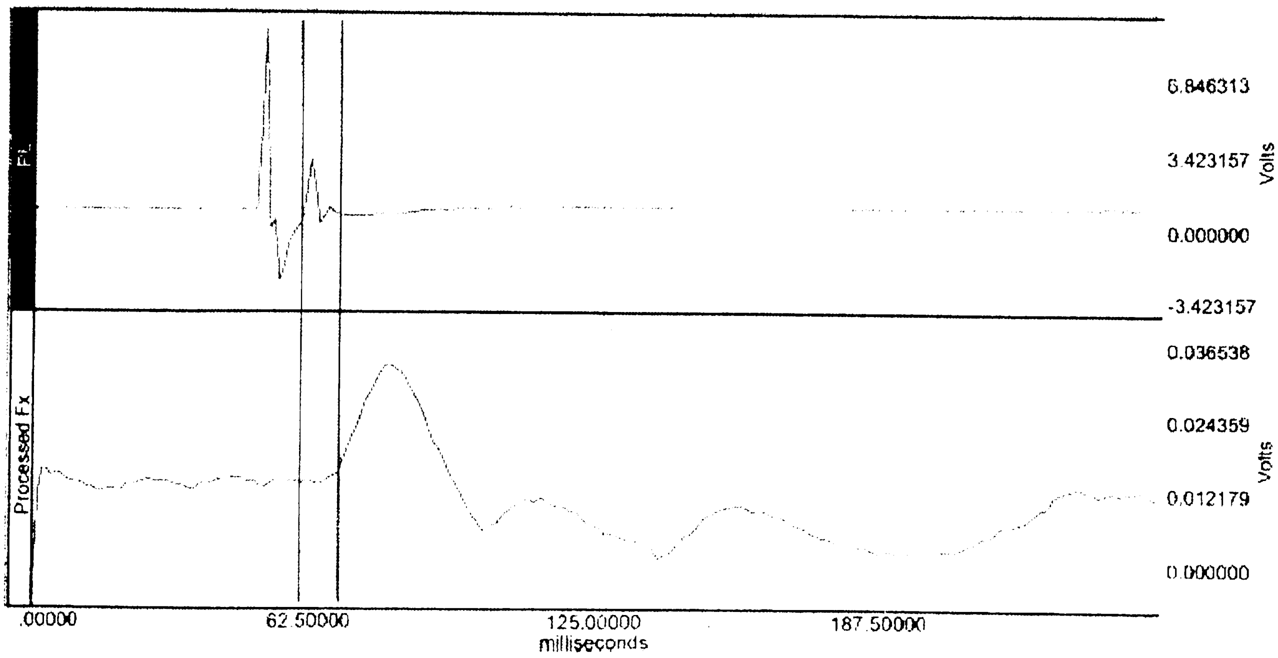

Fig 2. Electromyographic signals for electromechanical delay measurement. The first vertical line marks the point at which the muscle became active (the first spike is stimulus artifact). The second vertical line marks the beginning of the eversion moment. The space/time between the 2 lines represents the electromechanical delay. Abbreviation: PL, peroneus longus.

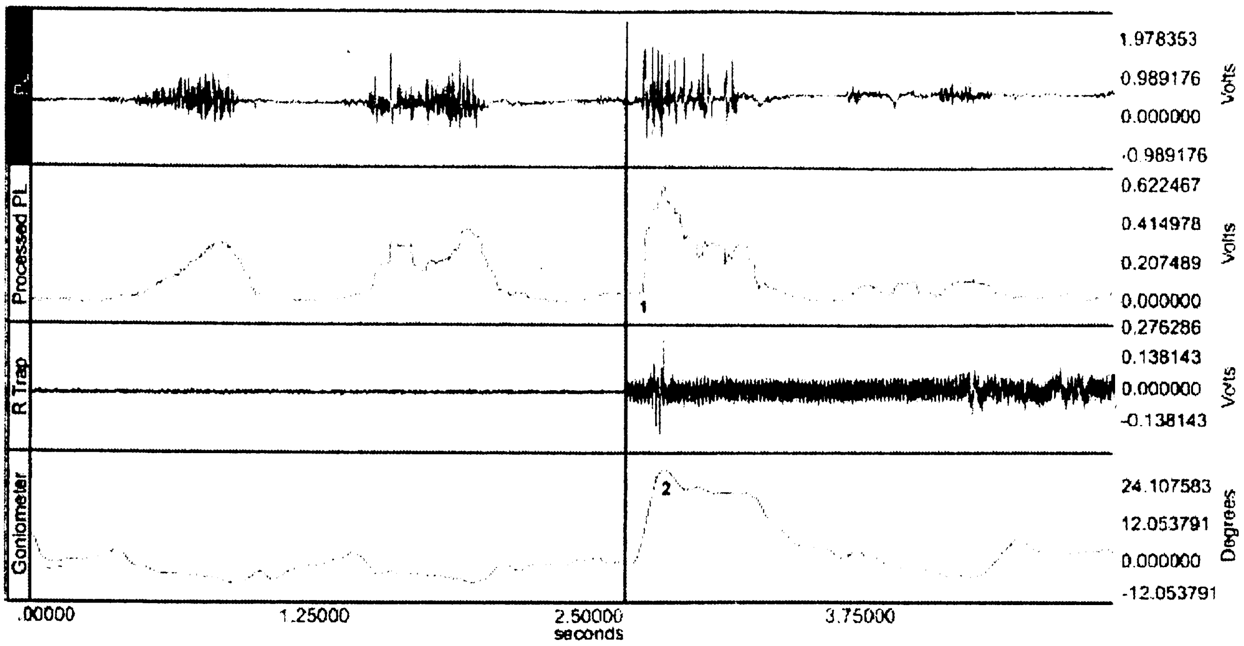

Fig 3. Electromyographic signal for reaction time measurement. The vertical line marks the fall of the trap door and the beginning point used to calculate reaction time. Peroneus longus muscle onset was the second point used to calculate reaction time (1). Peak inversion ROM (2) was used to calculate time to total inversion ROM. Abbreviation: R, right.

Subjects were then prepared for reaction testing on the runway. Each subject wore blinders that obstructed the field of vision below eye level, and headphones connected to a metronome that blocked any sound of the triggering of the trap-door mechanism and gave them the cadence to which they were to step. Each subject then practiced walking the length of the runway several times to recheck the previously determined starting point. Modifications to the starting point were made as necessary.

Subjects were instructed to walk to a sign placed at the end of the runway. The sign was a reference to help subjects walk straight and to alert them as to the end of the runway. An assistant walked behind the subject and off the runway to ensure that they did not step off the runway or lose balance. The subject walked this length 30 times.

Each ankle was randomly tested during a session, but only data from the dominant leg were measured and recorded. This was done to reduce a learning effect from repetitive testing of the dominant leg and to keep a subject from anticipating when or where the trap door would fall. The trap door was triggered 6 times for each leg according to 1 of 2 random sequences. Therefore, in random order, the subject walked the length of the runway 18 times with no perturbation and 6 times with perturbation to each side.

The electromyographic data were collected for from 5 to 7 seconds, depending on how long it took the subject to walk the length of the runway. This allowed for study of muscle activity throughout the entire trial. The peroneus longus muscle was considered active when it exceeded 2 SDs of the peak baseline (standing) activity.[13] Reaction time was considered to be the time from onset of the trap door release to the time the peroneus longus became active. Figure 3 illustrates the electromyographic signal during the reaction time measurement.

Subjects in the control group were instructed to maintain their current activity levels and to return for posttesting in 6 weeks.

Subjects in the treatment group were given a schedule for the neuromuscular training program (table 1). The protocol consisted of warm-up, sensorimotor, strength, and power components. Each session lasted approximately 40 minutes and was repeated 3d/wk for 6 weeks. There was at least 1 day of rest between sessions, and subjects rested for approximately 1

Table 1: Exercise Protocol

Exercise	Weeks 1 and 2	Weeks 3 and 4	Additional Progression	Weeks 5 and 6
Warm-up (min)				
Jump rope	3	3		3
Stretching (s)				
BAPS	2×20	2×20		2×20
Balance (s)				
Single leg	60	90	Pivot balance	90
Dynadisk	60	90		120
BAPS	60	90		120
Strength				
T-band kicks				
Forward	2×30	3×30		3×45
Backward	2×30	3×30		3×45
Step-downs	3×20	3×30		3×45
Power (s)				
Lateral hops	2×30	3×30	Zig-zag hops	3×30
Cool down (min)				
Jump rope	3	3		3

Abbreviation: BAPS, balance activation proprioceptive system.

minute between sets and exercises. Both dominant and nondominant legs were used in the rehabilitation exercises. All training sessions were monitored by trained assistants to encourage the subjects' compliance and maximum effort. No subject missed more than 1 training session, so all were able to complete follow-up testing.

Measurements were repeated within 2 days of completion of the training program. Subjects in the sex-matched control group also repeated the measurements within the same time frame.

Data collected from both electromechanical delay and reaction time measurements were analyzed with separate custom-designed computer software programs, which mathematically determined the electromechanical delay or reaction times. If the computer could not determine for any trial the electromechanical delay or reaction time because of artifact in the electromyographic or instrumentation issues, that trial was dropped. No more than 3 electromechanical delay or reaction time trials were dropped for any subject.

Data Analysis

Muscle reaction times and electromechanical delay were averaged across trials for each testing session and used in data analyses. Data were analyzed using two 2×2 analyses of covariance (ANCOVAs) (covariate pretest score). As expected, the pretest and posttest scores were highly correlated at a 1-sided *P* value of .05 (reaction time Pearson $r=.409$, electromechanical delay Pearson $r=.349$); thus, removing the pretest variation was appropriate to test the incremental effect of the group and sex variables. Group (treatment, control) and sex (male, female) were between subject factors. The use of ANCOVAs permitted the direct examination of the effects of group and sex and eliminated the variation in posttest scores attributable to the subjects' initial pretest scores. The significance level was set at *P* equal to .05 or less.

RESULTS

The training program significantly decreased ($F_{1,21}=4.030$, $P=.029$) the reaction time of subjects after controlling for the effects of the pretest reaction time. While no significant difference existed, the training program resulted in a trend toward an increase in electromechanical delay ($F_{1,21}=4.227$, $P=.052$, power$=.501$, $\eta^2=.168$) after controlling for pretest electromechanical delay scores. For both reaction time and electromechanical delay, there was no significant difference between sexes or the interaction of sex and treatment. Means and SDs for changes in electromechanical delay and reaction time are presented in table 2. Control variable means and SDs are reported in table 3.

DISCUSSION

Treatment and prevention of ankle sprains consumes a large amount of time in medical settings that deal with the physically active. Traditional rehabilitation includes strength, power, and neuromuscular control exercises of the leg muscles. Direct measurement of the efficacy of these exercises in terms of neuromuscular adaptation is limited. Other measurements such as balance and postural sway have dominated the research.[16-22] This study was focused on a direct measurement of dynamic restraint through reaction time and electromechanical delay of the peroneus longus muscle after a 6-week training program.

Table 2: Mean Changes

Variables	Treatment		Control	
	Pre	Post	Pre	Post
Electromechanical delay (ms)	16.6±1.3	17.6±1.1	16.8±1.4	16.7±1.1
Reaction time (ms)	61.9±6.5	57.1±7.7*	63.0±8.3	63.5±6.8

NOTE. Values are mean ± SD.
*Different from the prevalue ($P=.029$).

Table 3: Means of Control Variables

Variables	Treatment		Control	
	Pre	Post	Pre	Post
ROM (deg)	30.8±3.5	32.1±4.1	30.8±3.2	30.9±3.9
Time to peak ROM (s)	.164±.019	.162±.018	.164±.02	.163±.017

NOTE. Values are mean ± SD.

Its major finding was a decrease in reaction time after 6 weeks of training. Unlike several other studies involving training protocols,[7,23] our training program did cause significant changes in reaction time. There are several explanations for this. First, we controlled for the pretest score. This was done on the assumption that subjects who demonstrated a higher pretest reaction time would have more room for improvement than would those with a lower pretest reaction time. Theoretically, people with different pretest reaction times should not be expected to react the same to a training stimulus. In addition, if the variation in pretest score is not accounted for, the effect of the training program cannot be examined because statistical tests would simply evaluate the combined effect of both the pretest score and the training program. Second, we used a training program that incorporated many aspects of rehabilitation and/or training, including strength, power, and neuromuscular control, while previous research[7,23,24] focused on single aspects of rehabilitation.

Other research[7,23,24] into ankle disk training examined the efficacy of a single rehabilitation tool in changing the reaction time of the peroneus longus. None of these studies reported enhanced reaction times of the peroneals. However, Tropp et al[24] followed soccer players with previous ankle sprains who trained with an ankle disk; they found that training decreased the players' incidence of sprains to the same as that of players with no history of ankle injury. Rozzi et al[19] and Hoffman and Payne[17] found postural sway was decreased after ankle disk training. While we did use an ankle disk, we used many other exercises, which may explain the differences.

The mean reaction time ± SD before treatment when both groups were combined was 62.46±7.35ms. In comparison with studies that used an inversion perturbation model during standing, this was faster than some[7,10,15] and slower than others.[11,25,26] Variability in measurements between the studies may be due to the differences in the models (standing vs walking), methodologic differences, and varying definitions of muscle activation onset. None of the studies cited above examined reaction time during walking, and only 2 studies[15,26] examined the reaction time during 100% weight bearing, which is closer to the stance phase of gait. It is probable that the amount of inversion placed on the ankle influences reaction time as well. Only 1 study[15] with a reaction time slower than those in our study inverted to 30°, while all the studies[11,25,26] with faster reaction times than in our study inverted to 30° or greater. It is probable that the amount of inversion stimulus used in testing influenced reaction time.

Nieuwenhuijzen et al[27] recently examined the reaction time of the peroneus longus during walking. Subjects walked on a

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treadmill equipped with a box that fell to 25° when stepped on, causing the ankle to invert. The average reaction time when walking at 6.4km (4mph) was 42ms. While we controlled for the cadence of gait, we did not control for the stride length and the resultant speed. This likely introduced variability into our study because faster speeds of walking have been associated with faster reaction times.[27] Nieuwenhuijzen et al[27] reported an average inversion rate of 403°/s, while our subjects inverted at approximately 191°/s (pooled peak inversion ROM/pooled time to peak inversion ROM). This supports the view that the faster the inversion speed, the shorter the reaction time.[27,28]

The electromechanical delay measurements in our study were approximately 6ms longer than those reported by Mora et al.[14] This might be due to the location of the stimulus. We stimulated the common peroneal nerve prior to its bifurcation posterior to the fibular head, while Mora[14] stimulated the common peroneal nerve at the lateral border of the popliteal fossa, superior to the fibular head. However, our placement would likely result in shorter electromechanical delays, given that all other factors were equal. More likely, differences between these estimates of electromechanical delay are due to data reduction differences, such as filtering and processing of the electromyographic and force signals and operational definition differences of muscle activity and force onset.

The electromechanical delay showed a trend toward an increase due to training while the reaction time showed a significant decrease. These findings were surprising considering that all measurement variables were held constant between testing sessions, and that any change in peroneus longus electromechanical delay would likely be a result of a change in preactivation or gamma motoneuron drive. Likewise, given the set pathway of the reflexive response during reaction time testing, the only way reaction time could change would be by increasing the sensitivity of the muscle spindle. We speculate that the reason for the disparity between measurements is due to the movement patterns during measurements. Electromechanical delay was recorded during static stance, while reaction time was recorded during walking. Muscle spindle sensitivity changes may have been initiated by the movement pattern (walking). Indeed, reports[29,30] support the theory that the muscle spindle system in the ankle flexors and extensors becomes more excitable during the early stance phase of gait. This preactivity during walking likely initiates an increase in muscle spindle sensitivity. Komi[31] speculated that strength and power training could enhance the length feedback component of the muscle spindle, improving muscle stiffness prior to foot contact. However, during normal stance this may not be the case. While Kamen et al[32] found decreased latencies in power athletes compared with endurance athletes during a static measurement, Kyrolainen and Komi[33] and Komi[31] found diminished tendon tap reflexes (in a static position) in 3 of 4 muscles of power versus endurance athletes. We suggest that during gait, changes in muscle length and activity trigger enhanced sensitivity (due to training) of the muscle spindle as was suggested by Komi.[31] However, during static stance these changes may not be evident. In fact, during stance, spindle sensitivity and resultant muscle stiffness may be desensitized due to training as was suggested by Kyrolainen and Komi[33] and Komi.[31] Our data support these ideas. Further, differences in H-reflex modulation between standing and walking have been well documented.[34]

In an injury situation, the response time of a muscle is the reaction time plus the electromechanical delay of that muscle. While there are limitations to reporting response time from these data, we believe it is worth considering the combination of reaction time and electromechanical delay as a functional estimate of dynamic restraint following sudden inversion. Of course, one must consider that we did not measure electromechanical delay during walking (only during stance), and therefore it is not a perfect estimate during such a movement. However, it was measured in a weight-bearing position; in combination with reaction time during walking, it may provide some insight into dynamic restraint. In this study, the time from the drop of the trap door until the person reached 30° of inversion was approximately 150ms, while dynamic restraint was evident at approximately 79ms. From these data it might be concluded that dynamic restraint might be timely enough to prevent inversion injury for the conditions used in this study.

Johansson et al[35] suggested that the "time argument," which contends that dynamic response after perturbation is too slow to prevent injury, has been accepted without considering the state of changeable muscle stiffness at the time of displacement. In other words, preactivation and muscle stiffness will change according to sensory information from joint and muscle position during movement. This is not to suggest, however, that timely dynamic restraint will be evident with faster movement and loading rates. Nieuwenhuijzen[27] suggested that increased loading rates resulted in shorter latencies, but it seems intuitive that the response time would not occur fast enough to provide restraint in many dynamic situations. More data are needed to identify functional restraint characteristics at varying loading rates.

The clinical significance of this study hinges on the time necessary to generate a protective response given a sudden inversion perturbation. By combining the electromechanical delay and reaction time measurement we collected in this study, we can develop a theoretical response time of approximately 78.5ms, that decreased by approximately 5ms after training. It is arguable that a change of 5ms would not be enough to influence the incidence of all ankle sprains. However, given that ankle injuries occur at varying inversion rates, it is possible that a 5ms decrease in response time could play a role in ankle injury prevention under certain loading circumstances. Further, given the average time (150ms) necessary to reach 30° of inversion in this study, it would seem that the peroneals do generate protective and timely tension following sudden inversion while walking. Neuromuscular training may be able to influence ankle injury and/or severity of ankle injury occurring at slower inversion rates, but more data are needed to make conclusions about faster rates as would be the case during running, cutting, and landing.

Our study focused on the training of healthy ankles. Previous research has shown that patients with chronic ankle instability have slower peroneal reaction times.[9,10] Our data suggest that those with slower pretest reaction times showed greater improvement after training. Therefore, it seems likely that if this training program were used in a functionally unstable ankle population, the subjects might also show an improvement in their reaction time.