Original article

The comparison of dynamic postural control and muscle activity in time domain in athletes with and without chronic ankle instability

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Summary

***Introduction*: The objectives of this study were to compare muscle activation time and dynamic postural variables in athletes with and without chronic ankle instability during jump-landing, followed by a choice reaction time task which was provided by the visual stimulus.**
***Methods*: Nineteen athletes [11 healthy athletes and 8 athletes with chronic ankle instability (CAI)] participated in this cross-sectional study. After informing them about the procedure and goals of the study, they started jump-landing protocol in response to the visual stimulus. Muscle activation time and dynamic postural control data were taken using an electromyographic (EMG) machine and force plate, respectively.**
***Results*: The results of the two-way repeated measurement analysis of variance (ANOVA) showed that there were significant differences in athletes with and without CAI for medial/lateral stability index (MLSI; tested leg effect: p=0.006); the pre-motor time of the gastroc-soleus, peroneus longus, and peroneus brevis (interaction effects of the tested leg and the tested group: p=0.001, p=0.015 and p=0.006, respectively) and the pre-motor time of the tibialis anterior (tested group effect: p=0.036).**
***Conclusion*: More attention should be on the muscle activation time because changes in this parameter may be one of the preliminary risk factors for instability, although cohort studies are required to prove it. A more challenging task with more sensitivity for differentiating between stable and unstable ankle is needed.**
Level of evidence: IIIb.

KEY WORDS: chronic ankle instability, dynamic postural control, muscle activation time.

Introduction

Ankle sprain is one of the most common sport injuries[1]. About 70 to 85% of sprains are of the inversion type. It has been reported that 10 to 30% of people with the inversion type of sprain will develop chronic mechanical instability and almost 80% of these people will suffer from recurrent ankle sprain[2]. Therefore, the evaluation and treatment of chronic ankle instability (CAI) is a significant challenge in athletic health care.
Fundamental and clinical studies have been conducted to investigate the preliminary risk factor of recurrence. Despite the recent progress in prevention protocols for the improvement of strength, flexibility, proprioception, and neuromuscular control, the rate of recurrence is still very high and its causes are still unknown[2-4].
Sensory-motor impairments include weakness and muscle dysfunction, changes in static and dynamic postural control, changes in information integration in the central nervous system (CNS) and muscle spindles sensitivity[5]. Proprioception impairments secondary to ankle sprain may disturb the required feedback for suitable functioning of the central motor program. Reduced proprioception may reduce the muscle activity around the ankle joint, especially the evertor muscles; thereby causing failure in the correction of ankle position[6].
The distal leg muscles, such as ankle muscles, are important for walking, maintaining balance, avoiding falls, and sprains[7]. Peroneus longus dysfunction with regard to strength, activity onset, and duration of con-

traction, is a prevalent finding in patients with ankle instability[8-12]. On the other hand, some studies showed no impairments in peroneus longus activity[13-15].

It seems that chronic ankle sprain is associated with altered sensory-motor impairments and these impairments are not detected by the traditional measurements of postural control in the single-limb stance. Instrumental postural control tests, such as those are performed by force plate and are used to examine the spatiotemporal characteristics of the COP and time to boundary (TTB), are more reliable for identifying impairments associated with increased risk of sprains and the recurrent sprains which occurred after acute ankle sprain[16].

After ankle sprain, residual symptoms such as pain and instability exist and remain for a long time[17]. It seems that landing after jumping may provide more specific information in kinematic and kinetic differences between the injured and non-injured legs[18]. But to our knowledge, no study has investigated muscle activation time by choice reaction time task, as provided by a visual stimulus in this study.

Compensatory postural adjustment (CPA) is associated with disturbance after perturbation and is dependent on feedback mechanisms. CPA can be divided into the short and long latency responses after perturbation which led to distinguishing between the reflex and voluntary responses[19]. Therefore, dynamic tasks are more challenging for subjects with chronic instability and may affect postural control strategies.

None of the available methods for the quantification of dynamic postural control can distinguish between healthy and ankle sprained subjects and none of the mathematical equations for the quantification of dynamic postural control is effective[20]. This study considered using a new variable which has a high repeatability and sensitivity[21] for assessing dynamic postural stability. Besides studying muscle activity in time domain, the pre-motor time and motor time parameters were used, which have a more detailed view in comparison with the reaction time to the muscle function. In this study, the forward jump-landing protocol in response to the visual stimulus was applied, not only because it is the most common mechanism of ankle sprain, but because it is more similar to the functional environment of the athletes. The hypothesis of the present study is that the mentioned variables are different in athletes with and without CAI.

Materials and methods

Participants

Eight athletes with CAI (2 females, 6 males, age = 23.75 ± 2.05 years old) and eleven healthy athletes (2 females, 9 males, age = 24.73 ± 3.74 years old) participated in this study. Table I shows the statistics of demographic data of all the participants. All the participants were students studying physical education at the Tehran University, who were playing football regularly; three sessions a week and each session lasted for at least 2 h. Study approval was obtained from the Ethics Committee of Tehran University of Medical Sciences. The study meets the ethical standards of the MLTJ[22, 23].

Inclusion criteria: (a) the ages of athletes ranged from 18 to 32 years (criterion for both the healthy and CAI groups); (b) a history of ankle sprain in one foot (6 months-1 year, needed to have been passed, since the initial injury and the repeated ankle sprain needed to have occurred at least once during this period and the athletes also needed to feel "giving way" in their ankles) and; (c) no pain and restriction in both ankles during the test and negative talar test (b and c were criteria for only the CAI group).

Exclusion criteria: (a) athletes who had history of heart disease, cardiovascular disease, diabetes, visual disturbances, vestibular disorders, neurological disorders, dizziness, cognitive problems and musculoskeletal trauma in the lower limb of any of the athletes; (b) athletes taking medications that affect cognitive and motor function or stimulating drinks such as coffee, alcohol and soft drinks 24 h before the test session; (c) inability to do the test; (d) improper

Table I. The results of Independent *t*-test for the comparison of anthropometric data between healthy athletes and athletes with CAI (11 healthy athletes, 8 athletes with CAI).

Variables	Mean ± SD		Range		Sig. (2-tailed)
	Athletes with CAI	Healthy athletes	Athletes with CAI	Healthy athletes	
Age (year)	23.75 ± 2.05	24.73 ± 3.74	21-28	18-28	0.515
Weight (kg)	60.43 ± 9	66.68 ± 13.45	44.64-73.57	40.73-86.21	0.737
Height (cm)	173.63 ± 10.91	175.27 ± 10.03	156-184	150-183	0.271
BMI (kg/cm^2)	19.97 ± 1.78	21.53 ± 3.10	18.34- 23.48	17-26.31	0.219

SD: Standard Deviation.

record of the EMG activity ;and (d) reluctance of athletes to do the test.
The study was conducted in the Biomechanic Laboratory of the School of Rehabilitation. Before doing the test, the examiner explained the objectives and study procedure to the athletes. Then, they signed off an informed consent form. The initial assessment consists of the personal data questionnaire which includes their name, age, the dominant leg, and the injured leg and the anthropometric measures such as weight, height and BMI.

Experiment task

In the first step, the examiner asked the athletes to perform stretching exercises for the muscles of the lower limbs and walking about 15 minutes on the treadmill, to prevent injury during the test. In the second step, athletes were asked to do the forward jump-landing protocol[24] and the distances covered by forward jumping were measured by the examiner; 75% of the maximum jumping was considered for the final jumping distance. Athletes were instructed to "stand on both feet with your head up and place your hands on your hip joints, jump in the forward direction and then land on your leg (the injured/non-injured leg for the athletes with CAI or dominant/non-dominant leg for the healthy athletes)".
In the final step of the test, athletes were asked to stand at the determined distance for jump-landing which was outside the force plate and were instructed as follows: "Look at the box with green and red lamp in front of your eyes. First you will hear a beep, so go to the squat position. After 3 s, if the green lamp is lit up, jump in the forward direction and land on the right/left leg (on the fore plate). On the contrary, if you see the red lamp, do not jump."
The test was repeated three times for each leg and the mean values of the variables were calculated for the final analysis. It should be noted that the lamps were lit up randomly by the tester.
Eight electrodes (SX230, Biometrics Ltd, Gwent, UK; diameter: 10 mm, bipolar configuration and inter electrode distance: 20 mm) and eight-channel electromyographic (EMG) system (DataLink, Biometrics Ltd., Gwent, UK; CMRR: 96 dB at 60 Hz, input impedance 41012 Ω, gain: 1000, band-pass filter: 20 Hz low cut-off, 450 Hz high cut-off, sample rate: 1 KHz, and Accuracy +/- 0.5% full scale) were used for the recording of electromyography data. After shaving and cleaning the skin with alcohol, electrodes were placed on the belly of the gastroc-soleus, peroneus longus, peroneus brevis, and tibialis anterior muscles in line with the fiber direction, according to SENIAM guidelines (http://www.seniam.org). Thereafter, a ground electrode was attached to the subject's wrist. Fixation was done using the adhesive tape on the electrodes and wrapping the leg with elastic bandage. A Bertec triaxial force plate (Bertec Corp, Columbus, OH, 90 * 90 Series) with sampling frequency of 500 Hz and sensitivity of 10, was used to gather the postural stability data. Feet switches were attached to the heels of the both feet to show the feet contact. These indicators were synchronized with the EMG recording and force plate.

Data reduction

Dynamic postural stability index (DPSI): The DPSI is comprised of the MLSI, APSI, and VSI which is sensitive to changes in all the three directions. The indices are mean square deviations which measure fluctuations around the zero point. These indices were presented by Wikstrom et al.[21].
Vertical time to peak (VTTP). VTTP was established as the time when the vertical force component reached from 10% of the maximum to the maximum.
Anterior/posterior time to stabilization (A-P TTS). To calculate A-P TTS, the anterior/posterior components of GRF are rectified and starting at the peak, an unbounded third order polynomial is fitted to the GRF component. The TTS was determined as the point at which the unbounded polynomial transects the static horizontal lines. This is the method of analysis used by Ross and Guskiewicz[27].
Reaction time: Data Link software was used to analyze the EMG data. The root mean square (RMS) of the raw EMG signals was obtained and the time window of 50 ms was used for smoothing signals so that frequencies below 20 Hz, mostly related to movement noises, were excluded. The premotor time of the target muscles was defined as the time interval between the activation of the visual stimulus and the onset of the EMG activity (10% maximum + minimum of EMG activity before landing). Motor time was defined as the time span between the onset of EMG activity and A-P TTS. Reaction time was also defined as the time interval between activation of the visual stimulus and the onset of the motion which is detectable by the foot switch (Fig. 1).

Statistical analysis

The SPSS software version 19 was used to analyze all the data. For determining the normal distribution of all variables, the Kolmogorov-Smirnov test was conducted. When testing normality, probabilities >0.05 mean the data are normal and probabilities <0.05 mean the data are not normal. Intra-session reliability analysis for all the data was performed by the ICC in each group separately. The entire sample size was analyzed for reliability and the average ICC was reported. The mean value of the three sets of jump-landing was used as the outcome measures. One-way repeated measurement analysis of variance (ANOVA) was used twice: firstly, for comparing the dynamic postural control and muscle activation times data in the dominant and non-dominant legs of healthy athletes and secondly, for comparing those variables in the injured and non-injured legs of athletes with CAI. Two-way repeated measurement ANOVA (2×2) was used to study the interaction of the tested leg and the tested groups (healthy athletes and athletes with CAI). An alpha level of 0.05 was used for all statistical tests.

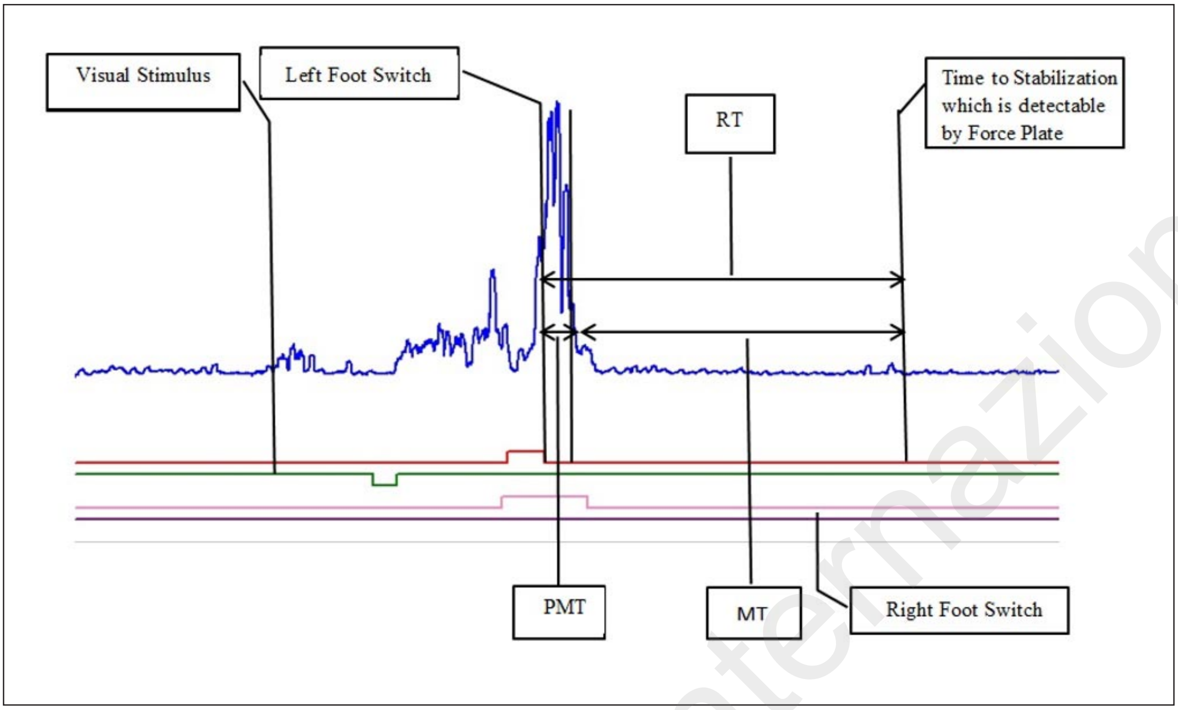

Figure 1. RMS of electromyographic signal of left leg's peroneus longus of a participant who were asked to land on his left leg after green lamp was shown. Pre-motor time (PMT), motor time (MT), and reaction time (RT) are shown on the diagram.

Results

The distribution of all variables regarding both groups (Tab. I) was normal, according to the values of Kolmogorov-Smirnov.

According to Munro's classification of reliability[26], all the postural control variables had high and very high ICC, except for VTTP of the injured leg (ICC = 0.400) and A-P TTS of the injured (ICC = 0.527) and non-injured (ICC = 0.687) legs. In total, except for the pre-motor time of the tibialis anterior, all the muscle activation time variables in the dominant leg had higher ICC than the non-dominant leg. The pre-motor time of all the muscles of the injured leg, except for the tibialis anterior (ICC = 0.576), had high ICC. The pre-motor time of all the muscles in the non-injured leg, except for tibialis anterior (ICC = 0.784), had moderate ICC. The ICC values for the motor time and reaction time of the injured leg were moderate, but were high in the non-injured leg.

The result of this study showed that there were no significant differences in the dynamic postural control variables between the dominant and non-dominant leg of healthy athletes and also, the injured and non-injured leg of athletes with CAI (p>0.05).

The pre-motor time of the gastroc-soleus in the dominant leg was longer than the non-dominant leg of healthy athletes (93.18 ± 50.34 ms *vs* 69.30 ± 33.58 ms, p=0.032, F=6.184, observed power = 0.612).

In athletes with CAI, the pre-motor time of the gastroc-soleus and peroneus brevis of the injured leg was significantly longer than the non-injured leg (134.29 ± 53.93 ms *vs* 92.67 ± 41.14 ms, p=0.026 and 121.67 ± 65.57 ms *vs* 67.08 ± 12.47 ms, p= 0.040; respectively).

The two-way repeated measurement ANOVA (2×2) was used to study the interaction of the tested leg and the tested groups (healthy athletes and athletes with CAI) and the results showed a significant main effect of the tested leg for mean of MLSI (Tab. II). The interaction of the main effects of the pre-motor time of the gastrosoleus, peroneus longus, and peroneus brevis were statistically significant. On the other hand, the main effects of the tested group for the pre-motor time of the peroneus brevis and tibialis anterior were significant (Tab. III).

Discussion

Although, the results of this study showed that the tested leg effect was significant for MLSI, this result was not consistent with the studies of Ross et al. (2004)[27], Dayakidis et al. (2006)[28], De Noronha (2008)[29], Gribble et al. (2009)[2], and Ross et al. (2009)[30].

In the study by Ross et al.[27], the A-P mean sway and the M-L mean sway were not significantly different between groups. Subjects with CAI had longer A-P TTS and M-L TTS after landing, but these variables

Table II. Within-subjects and between-subjects' effect for the study of interaction of the tested leg and the tested group on dynamic postural control variables with two-way repeated measurement ANOVA (11 healthy athletes, 8 athletes with CAI).

Variables	Effects	Sum of square	Df	F	Sig. (2-tailed)	Effect size	Observed power
APSI	Tested leg	0.001	1	1.404	0.252	0.076	0.201
	Tested group	0.000	1	0.040	0.845	0.002	0.054
	Tested leg * group	0.000	1	0.558	0.465	0.032	0.109
MLSI	Tested leg	0.000	1	9.761	0.006*	0.365	0.837
	Tested group	0.004	1	0.938	0.346	0.052	0.150
	Tested leg * group	0.000	1	1.106	0.308	0.061	0.168
VSI	Tested leg	0.000	1	3.105	0.096	0.154	0.383
	Tested group	0.000	1	0.966	0.340	0.054	0.153
	Tested leg * group	0.000	1	0.007	0.935	0.000	0.051
DPSI	Tested leg	0.001	1	3.463	0.080	0.169	0.419
	Tested group	0.003	1	0.487	0.495	0.028	0.101
	Tested leg * group	0.000	1	0.906	0.355	0.051	0.146
VTTP (ms)	Tested leg	1042.702	1	3.298	0.087	0.162	0.403
	Tested group	9.182	1	0.006	0.937	0.000	0.051
	Tested leg * group	0.871	1	0.003	0.959	0.000	0.050
A-P TTS (ms)	Tested leg	11383.005	1	0.020	0.891	0.001	0.052
	Tested group	381077.588	1	0.380	0.546	0.022	0.090
	Tested leg * group	591816.383	1	1.014	0.328	0.056	0.158

ms: millisecond.

were not significantly different during the single leg stance[27]. The only similar variable of the study of Ross et al.[27] and the present study is A-P TTS which was inconsistent between both studies. In the present study, most of the stabilometric variables except for MLSI were not statistically significant in both groups. It was suggested that maybe the forward jump-landing protocol was not enough challenging when compared with the vertical jump-landing. Moreover, participants in the study of Ross et al.[27] were from a population of non-athletes, so it was proposed that maybe assessing athletes requires more complex and harder jumping protocol to challenge their postural stability. A high level of activity after sprain in athletes shows that they develop compensatory mechanisms and except for severe injuries, they will continue their active life-style.

Regarding the tested leg difference in MLSI which is the index for force changes in the medial/lateral direction, the ankle sprain mechanism, the frontal plane assessment of the muscles, and moreover proprioception training which focuses on the frontal plane at most, using lateral jump, V-cut, and defensive shuffle which are having more shearing force in the frontal plane, show the possible differences between the groups. Similarly, Dayakidis et al.[28] used these protocols and found that during V-cut, the stable ankle had greater vertical peak force when compared with the unstable ankle.

In their study, Liu et al.[20] showed that none of the available calculating methods with jump-landing protocol can discriminate between the stable and unstable subjects and this study is somewhat consistent with ours. Therefore, researchers have to focus on

Table III. Within-subjects and between-subjects' effect for the study of the interaction of the tested leg and the tested group on muscle timing variables with two-way repeated measurement ANOVA (11 healthy athletes, 8 athletes with CAI). All of the variables' units are millisecond.

Variables	Effects	Sum of square	Df	F	Sig. (2 -tailed)	Effect size	Observed power
Pre-motor time of gastroc-soleus	Tested leg	729.307	1	1.111	0.307	0.061	0.169
	Tested group	9626.344	1	2.838	0.110	0.143	0.356
	Tested leg * group	9936.465	1	15.133	0.001*	0.471	0.956
Motor time of gastroc-soleus	Tested leg	3156.699	1	0.005	0.942	0.000	0.051
	Tested group	509967.729	1	0.513	0.484	0.029	0.104
	Tested leg * group	752850.067	1	1.280	0.274	0.070	0.188
Pre-motor time of peroneus longus	Tested leg	51.007	1	0.099	0.757	0.006	0.060
	Tested group	972.851	1	0.496	0.491	0.028	0.102
	Tested leg * group	3777.896	1	7.351	0.015*	0.302	0.724
Motor time of peroneus longus	Tested leg	5562.790	1	0.010	0.923	0.001	0.051
	Tested group	433266.364	1	0.434	0.519	0.025	0.095
	Tested leg * group	697798.275	1	1.990	0.289	0.066	0.179
Pre-motor time of peroneus brevis	Tested leg	3234.249	1	2.613	0.124	0.133	0.332
	Tested group	8597.800	1	5.180	0.036*	0.234	0.574
	Tested leg * group	11936.939	1	9.643	0.006*	0.362	0.833
Motor time of peroneus brevis	Tested leg	785.455	1	0.001	0.971	0.000	0.050
	Tested group	455793.557	1	0.426	0.523	0.024	0.095
	Tested leg * group	876126.858	1	1.506	0.236	0.081	0.212
Pre-motor time of tibialis anterior	Tested leg	3327.354	1	2.021	0.173	0.106	0.269
	Tested group	5321.273	1	4.863	0.042*	0.222	0.548
	Tested leg * group	1.565	1	0.001	0.976	0.000	0.050
Motor time of tibialis anterior	Tested leg	6839.328	1	0.011	0.918	0.001	0.051
	Tested group	568147.334	1	0.549	0.469	0.031	0.108
	Tested leg * group	672605.819	1	1.067	0.316	0.059	0.164
Reaction time	Tested leg	1088.656	1	0.002	0.966	0.000	0.050
	Tested group	328810.233	1	0.319	0.579	0.018	0.083
	Tested leg * group	526206.550	1	0.907	0.354	0.051	0.147

3

protocols and calculating methods, because inaccurate dynamic postural measurements make the results of the studies ineffective. Moreover, challenging subjects in the vertical direction in comparison with the frontal and sagittal planes which have less vertical displacement may be harder for the sensorimotor system. The receiver-operating characteristic (ROC) curve is an effective statistical method for examining the diagnostic accuracy of an index and helps to determine the cut-off score for differentiating among the stable and unstable groups.

Benesch et al.[31] compared the reaction time of the peroneal muscle in the right and left leg of the healthy women and men subjects; but no significant difference was observed among the legs. Therefore, the present study recorded similar results as the mentioned study, regarding the peroneal muscle activation time in the dominant and non-dominant legs of the healthy athletes.

Although, the pre-motor time of the gastroc-soleus was different between the dominant and non-dominant legs of the healthy athletes and the injured and non-injured legs of athletes with CAI, but it seems that these differences are to some extent a result of the landing strategy on the force plate. The subjects were asked to land with their sole and not by their toes and as a result of the lack of digital electro-goniometer and motion analysis, there was no way to determine the landing strategy and ankle's angle. Moreover, the ankle's angle during landing affects the muscle activation time and the gastroc-soleus stretch reflex. The dominance differences should also be considered; hence, this result may be ambiguous.

The changes in the pre-motor time of the muscles support the deafferentation theory; however, the cause-effect relationship is still unknown, since this is a cross-sectional study, and the changes which occurred cannot be determined before the ankle sprain or as a consequence of it.

Khin Myo Hla et al. stated that deafferentation may suppress the gamma motor neuron activity and cause changes in the sensitivity of the muscle spindle and as a result, the reaction time and muscle activity intensity changes. Accordingly, the changes in the muscle activation time may be attributed to the changes in the sensitivity of the muscle spindle.

As previously noted, there are disagreements among studies in the field of muscle activation time in individuals with CAI. Using visual stimulus and forward jump-landing protocol instead of sudden induced plantar flexion and inversion during standing and walking, different methods for determining the premotor time, motor time, and reaction time can be the cause of the differences between this study and others. Different settings, various techniques for filtering raw signals and detecting the first EMG signal may be the cause of the controversy among studies. The threshold level is from 2SD to 10SD of the muscle activity before the perturbation in the studies. Therefore, some researchers consider the middle latency loop, which occurs from 49 to 90 ms after the perturbation while others consider the long latency signal, which has substantial magnitude and length and can be suppressed voluntary.

The peroneus longus reaction time is affected by foot structure. Tiberio declared that pronated foot decreases the mechanical advantage of the peroneus longus, because it shortens the muscles length in the pronated situation. In addition to the mechanical differences related to the foot structure, researchers showed that the amplitude of the electromyographic activity differs between the pronated foot and the neutral foot in the stance phase of gait. Denyer et al. (2013) found that the reaction time of the peroneus longus, in subjects with the pronated or supinated foot, is slower than the neutral foot. On the other hand, foot structure differences cause altered sensory feedback[32]. Whereas in this study, there was no control on foot structure, so it can act as a confounder variable. Using the wired EMG system made the jumping quietly difficult and by this surface EMG system, there was no possibility to examine the activation time of the deep muscles of the leg. The present study has 15 different variables which increase the possibility of type-1 error. This is a cross-sectional study with small sample size and the episodes of instability were self-reported by the subjects; so in general, these are some limitations of the present study. One of the inclusion criteria for the present study was "giving way" in the injured leg, but there was no classification for its severity and the level of activity in which it occurs.

Conclusions

According to the results of this study, more emphasis should be on the muscle activation time as a risk factor for reoccurrence, because it might be possible to develop a training protocol to improve the recruitment speed and develop powerful long latency response for the rehabilitation of athletes with chronic ankle sprain. On the other hand, there is need to consider new variables with greater sensitivity for the evaluation of postural stability.

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References

1. Garrick JG. The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. Am J Sports Med. 1977;5(6): 241-242.

2. Gribble PA, Robinson RH. Alterations in knee kinematics and dynamic stability associated with chronic ankle instability. Journal of athletic training. 2009;44(4):350-355.
3. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. Journal of athletic training. 2002;37(4):487.
4. Lima BN, Lucareli P, Gomes WA, Silva JJ, Bley AS, Hartigan EH, et al. The acute effects of unilateral ankle plantar flexors static-stretching on postural sway and gastrocnemius muscle activity during single-leg balance tasks. Journal of Sports Science and Medicine. 2014;13(3):564-570.
5. Hopkins T, Coglianese M, Reese S, Seele MK. Alterations in Evertor/Invertor Muscle Activation and Cop Trajectory during a Forward Lunge in Participants with Functional Ankle Instability. Clinical Research on Foot & Ankle. 2013;2014.
6. Sekir U, Yildiz Y, Hazneci B, Ors F, Aydin T. Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability. Knee surgery, sports traumatology, arthroscopy. 2007;15(5):654-664.
7. Bergamin M, Gobbo S, Bullo V, Vendramin B, Duregon F, Frizziero A, et al. Reliability of a device for the knee and ankle isometric and isokinetic strength testing in older adults. Muscles, ligaments and tendons journal. 2017;7(2):323.
8. Konradsen L, Ravn JB. Ankle instability caused by prolonged peroneal reaction time. Acta Orthopaedica Scandinavica. 1990;61(5):388-390.
9. Karlsson J, Andreasson GO. The effect of external ankle support in chronic lateral ankle joint instability an electromyographic study. The American journal of sports medicine. 1992;20(3):257-261.
10. Löfvenberg R, Kärrholm J, Sundelin G, Ahlgren O. Prolonged reaction time in patients with chronic lateral instability of the ankle. The American journal of sports medicine. 1995;23(4):414-417.
11. Vaes P, Van Gheluwe B, Duquet W. Control of acceleration during sudden ankle supination in people with unstable ankles. Journal of orthopaedic & sports physical therapy. 2001;31 (12):741-752.
12. Fereydounnia S, Shadmehr A, Talebian Moghadam S, Olyaei G, Jalaie S. The effect of choice reaction time task on pre-landing muscle timing in athletes with and without chronic ankle instability. Muscles, ligaments and tendons journal. 2018;8 (2):142-149.
13. Ebig M, Lephart SM, Burdett RC, Miller MC, Pincivero DM. The effect of sudden inversion stress on EMG activity of the peroneal and tibialis anterior muscles in the chronically unstable ankle. Journal of orthopaedic & sports physical therapy. 1997; 26(2):73-77.
14. Fernandes N, Allison GT, Hopper D. Peroneal latency in normal and injured ankles at varying angles of perturbation. Clinical Orthopaedics and related research. 2000;375:193-201.
15. Vaes P, Duquet W, Van Gheluwe B. Peroneal reaction times and eversion motor response in healthy and unstable ankles. Journal of athletic training. 2002;37(4):475.
16. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part I: can deficits be detected with instrumented testing Journal of athletic training. 2008;43(3): 293-304.
17. Van Rijn RM, Van Os AG, Bernsen RM, Luijsterburg PA, Koes BW, Bierma-Zeinstra SM. What is the clinical course of acute ankle sprains? A systematic literature review. The American journal of medicine. 2008;121(4):324-331. e7.
18. Van der Harst J, Gokeler A, Hof A. Leg kinematics and kinetics in landing from a single-leg hop for distance. A comparison between dominant and non-dominant leg. Clinical biomechanics. 2007;22(6):674-680.
19. dos Santos MJ, Gorges AL, Rios JL. Individuals with chronic ankle instability exhibit decreased postural sway while kicking in a single-leg stance. Gait & posture. 2014;40(1):231-236.
20. Liu K, Glutting J, Wikstrom E, Gustavsen G, Royer T, Kaminski TW. Examining the diagnostic accuracy of dynamic postural stability measures in differentiating among ankle instability status. Clinical biomechanics. 2013;28(2):211-217.
21. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. Journal of athletic training. 2005;40(4):305.
22. Padulo J, Oliva F, Frizziero A, Maffulli N. Muscles, Ligaments and Tendons Journal - Basic principles and recommendations in clinical and field science research: 2016 update. MLTJ. 2016;6(1):1-5.
23. Padulo J, De Giorgio A, Oliva F, Frizziero A, Maffulli N. I performed experiments and I have results. Wow, and now? MLTJ. 2017;7(3):403.
24. Shiravi Z, Shadmehr A, Moghadam ST, Moghadam BA. Comparison of dynamic postural stability scores between athletes with and without chronic ankle instability during lateral jump landing. Muscles, ligaments and tendons journal. 2017;7(1): 119.
25. Wikstrom EA, Tillman MD, Borsa PA. Detection of dynamic stability deficits in subjects with functional ankle instability. Med Sci Sports Exerc. 2005;37(2):169-175.
26. Domholdt E. Rehabilitation research: principles and applications. WB Saunders, Philadephia. 2005.
27. Ross SE, Guskiewicz KM. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. Clinical Journal of Sport Medicine. 2004;14(6): 332-338.
28. Dayakidis MK, Boudolos K. Ground reaction force data in functional ankle instability during two cutting movements. Clinical biomechanics. 2006;21(4):405-411.
29. De Noronha M, Refshauge KM, Crosbie J, Kilbreath SL. Relationship between functional ankle instability and postural control. Journal of orthopaedic & sports physical therapy. 2008; 38(12):782-789.
30. Ross S, Guskiewicz K, Gross M, Yu B. Balance measures for discriminating between functionally unstable and stable ankles. Medicine+ Science in Sports+ Exercise. 2009;41(2):399.
31. Benesch S, Pütz W, Rosenbaum D, Becker H-P. Reliability of peroneal reaction time measurements. Clinical biomechanics. 2000;15(1):21-28.
32. Denyer JR, Hewitt NL, Mitchell AC. Foot structure and muscle reaction time to a simulated ankle sprain. Journal of athletic training. 2013;48(3):326.