The effect of choice reaction time task on pre-landing muscle timing in athletes with and without chronic ankle instability

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Summary

***Introduction*: The assessment of neuromuscular control strategies, especially investigating muscle timing and anticipation in muscles, is important to improve our knowledge about ankle instability and preliminary mechanisms of it. The goals of the present study were comparing reaction time, its components and anticipation time in athletes with and without chronic ankle instability after 'go signal' provided by visual choice reaction time task.**
***Methods*: Nineteen athletes [11 healthy athletes, 8 athletes with chronic ankle instability (CAI)] participated in this cross-sectional study with research laboratory setting. The subjects started forward jumping protocol while electromyographic data were recorded from their leg muscles included gastroc-soleus, peroneus longus, peroneus brevis, and tibialis anterior.**
***Results*: The results of two- way repeated measurement ANOVA revealed no significant difference in athletes with and without CAI except for pre-motor time and motor time of peroneus longus (interaction effects of the tested leg and tested group: P=0.032, F=5.434; and P=0.040, F=4.937, respectively).**
***Conclusion*: Some differences in timing of peroneus longus were seen, so it suggest that clinicians should pay extra attention to muscle timing and consider its recovery in rehabilitation protocols. Besides it seems that some of the non-significant results might be related to neuromuscular adaptation that occurred in field athletes. Further study with larger sample size was suggested.**
Level of evidence: 3b.

KEY WORDS: chronic ankle instability, choice reaction time task, pre-motor time, motor time, reaction time, anticipation time, pre-landing muscle timing.

Introduction

Lateral ankle sprains are one of the most predominant sport injuries that have high rate of occurrence (about 1.34 per 1000 athletes) in American football and basketball players. In sports, ankle sprains can occur with contact or non-contact mechanisms and approximately 77% of non-contact sprains occurs during landing maneuver and following inversion force on a plantar flexed foot[1,2]. Although fundamental and clinical studies have done, the rate of recurrence is very high and the causes of this are still unknown[3]. Factors such as impairments in proprioception, range of motion, muscle strength, muscle reaction time, and postural sway deficits in neuro-muscular system have been identified as sources of possible causes of instability in literature[4-6].
The assessment of neuromuscular control strategies is important to improve our knowledge about injury occurrence and preliminary mechanisms of them. One of the ways to study neuromuscular control is investigating the muscle timing and anticipation in muscles around the ankle joint[7]. The tibial muscle and the triceps complex work as antagonist muscles which cause preparatory ankle positioning before heel contact and regulation of stiffness of tendomuscular system for absorption of high loading at touchdown moment[8]. On the other hand, it seems that peroneal muscles control the subtalar joint and with their eccentric contraction help to stabilize the ankle in mediolateral direction during standing[9]. Reports of studies suggest that the reflex activity after touchdown isn't fast enough to protect the ankle joint. So it concluded that the preparatory activity of peroneal muscles is necessary to support the ankle joint. These information are the results of studies which

applied the sudden inversion perturbation[9-11]. Preparation also increases the tendomuscular system stiffness. Neuromuscular reactions after initial contact can be studied in a time window of short, medium and long reflex responses[9].

Furthermore anticipatory postural adjustments produce in trunk and leg muscles according to the accurate prediction of the timing of the whole body perturbation without considering its internal or external source[12]. On the other hand primary evidences show that the adaptive motor changes in feed forward or anticipatory postural adjustment are feasible after training and these changes in APA depend on the type of motor task[13,14]. If the evidences will show the changes in anticipation time in athletes with chronic ankle instability, then clinicians could improve it by training and the rate of reoccurrence might be reduced as a possible consequence of it.

Besides investigating anticipation time in the present study, we use reaction time and its components to study muscle activity in time domain to compare the athletes with or without chronic ankle instability. In this study jumping protocol in response to visual 'go signal' was applied, because it is not only the most common mechanisms of non-contact ankle sprain but also it is more similar to the functional environment of the athletes.

Material and methods

Eight athletes with CAI (2 females, 6 males, age: mean value= 23.75, s= 2.05 years old, weight: mean value= 60.43, s= 9 Kg, height: mean value= 173.63, s= 10.91 Cm, BMI: mean value= 19.97, s= 1.78 $Kg.M^{-2}$) and eleven healthy athletes (2 females, 9 males, age: mean value= 24.73, s= 3.74 years old, weight: mean value= 66.68, s= 13.45 Kg, height: mean value= 175.27,s= 10.03 Cm, BMI: mean value= 21.53, s= 3.10 $Kg.M^{-2}$) participated in this study. All the participants were physical education students at Tehran University, who exercised regularly; three sessions a week and each session was at least for 2 h. The approval for performing the study was given by Ethics Committee of Tehran University of Medical Sciences (IR.TUMS. Rec.1394.1).

Inclusion criteria: (a) ages of participants ranged from 18 to 32 year old; (b) there should be no history of heart disease, cardiovascular disease, diabetes, visual disturbances, vestibular disorders, neurological disorders, dizziness, cognitive problems and musculoskeletal trauma in lower limb for any of the participants (a and b are criteria for both healthy and CAI groups); (c) a history of ankle sprain in one foot (6 months-1 year needed have be passed since the initial injury and repeated ankle sprain needed to have occurred at least once during this period and participants also needed to feel 'giving way' in their ankles) and (d) no pain and restriction in both ankles during the test and negative talar test (c and d are criteria for only CAI group).

Exclusion criteria: (a) 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, (b) inability to do the test, (c) improper record of EMG activity and (d) reluctance of participants to do the test.

The study was performed in the Biomechanic Laboratory of the School of Rehabilitation. Before doing the test, the examiner had explained the objectives and the procedure of the study to the participants. Then, the participants sighed an informed consent form. The initial assessment was consisted of the personal data questionnaire and measurements of their weight and height. In the first phase, the examiner asked the participants to do the stretching and warm-up exercises to prevent the possible injury during the test. In the second phase, participants were asked to do the forward jump-landing protocol 3 times on each leg and the forward jumping distances were measured by the examiner; 75% of the maximum jumping was considered for the final jumping distance. For jumping protocol, participant 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 the injured/non-injured leg for the athletes with CAI or dominant/non-dominant leg for the healthy athletes"[15] (Fig. 1).

Eight electrodes [SX230, Biometrics Ltd, Gwent, UK; Diameter: 10 mm, bipolar configuration, inter electrode distance: 20 mm, CMRR: 96 dB (typically 110 dB) at 60Hz, Impute Impedance > 10,000.000 M ohms, and Noise < 5 μV] 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 gastroc-soleus, peroneus longus, peroneus brevis, and tibialis anterior muscles in line with fiber direction, according to SENIAM guidelines (http://www.seniam.org), and 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. Contact switches (Force Sensing Resistor Sensors, Biometrics Ltd) were attached to the heels of both feet to show the feet contact. These indicators were connected to DataLink System, so they were synchronized with EMG recording.

In the final phase of the test, participants were asked to stand at the determined distance for jumping which was outside the force plate and they were instructed "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 was 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 no jump".

The test was repeated three times for each leg and the mean values of variables were calculated for final analysis. It was citable that the LED lamps (red and

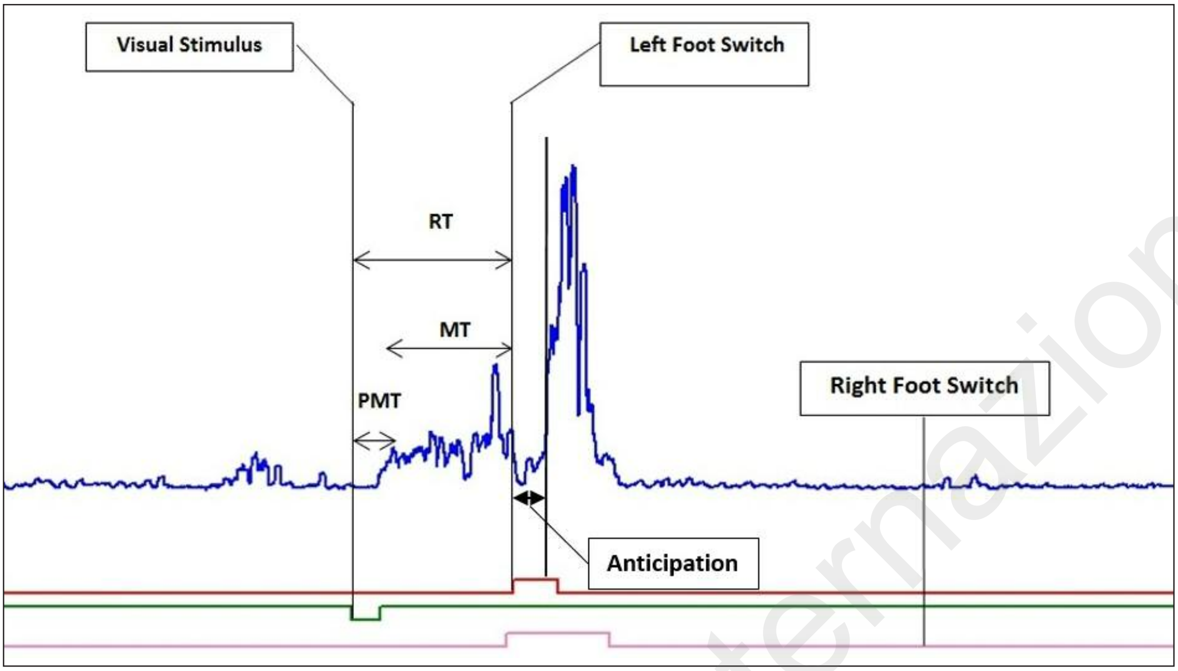

Figure 1. RMS of electromyography data of left leg's peroneus longus of a participant who were asked to land on his left leg after visual stimulus (green lamp) was shown; premotor time (PMT), motor time (MT), reaction time (RT) and anticipation are shown on diagram.

green visual trigger) were designed by the research team and they were lit up manually and selectively by the examiner.

Data reduction

Data Link software was used to analyze the EMG data. Root Mean Square (RMS) of the raw EMG signals was obtained and the time window of 50 ms (20 Hz) was used for smoothing signals so that frequencies below 20 Hz, mostly related to movement noises, were excluded. The unit measure for each variable was millisecond (ms).

Pre-motor time (ms): Premotor time of the target muscles was defined as the time interval between activation of the visual stimulus and onset of the EMG activity (Mean + 3SD at resting).

Motor time (ms): Motor time was defined as the time span between onset of the EMG activity and onset of the motion (Identified by contact switch when test heel was raised from the ground).

Reaction time (ms): Reaction time was also defined as the time interval between activation of the visual stimulus and onset of the motion.

Anticipation (ms): for defining anticipation we determine the minimum and maximum of the EMG activity of the off time of the contact switch and calculate it from the onset of off time to the moment when the EMG signal reach minimum + 10% maximum (Fig. 2).

Statistical analysis

SPSS software version 19 was used to analyze all the data. For determining normal distribution of all variables, a sample of Kolmogorov-Smirnov test was done (P>0.05). Independent t-test for the comparison of anthropometric data between both groups was used. Reliability analysis for all the data was performed by the ICC in each group separately and even in each leg. The sample size was analyzed for reliability and then the average ICC was reported. ICC values of variables were interpreted according to Munro's classification of reliability: 0.26 to 0.49 reflects a low correlation, 0.50 to 0.69 reflects a moderate correlation, 0.70 to 0.89 reflects a high correlation and 0.90 to1.00 indicates a very high correlation[16]. For final analysis and comparison, the mean value of all the three sets of jump-landing was used. Two-way repeated measurement ANOVA was used in comparing both groups of healthy athletes and athletes with CAI.

Results

Data were gathered from 11 healthy athletes and 8 athletes with chronic ankle instability during forward jump-landing protocol. Values of Kolmogorov-Smirnov showed that the distribution of all variables in both groups was normal. According to the results of Independent T- test for the comparison of anthropometric data between athletes with and without CAI, all participants were matched (P>0.05).

All the variables in healthy athletes had very high or high anticipation should be omitted correlation except for the motor time of peroneus longus (ICC=0.67) and

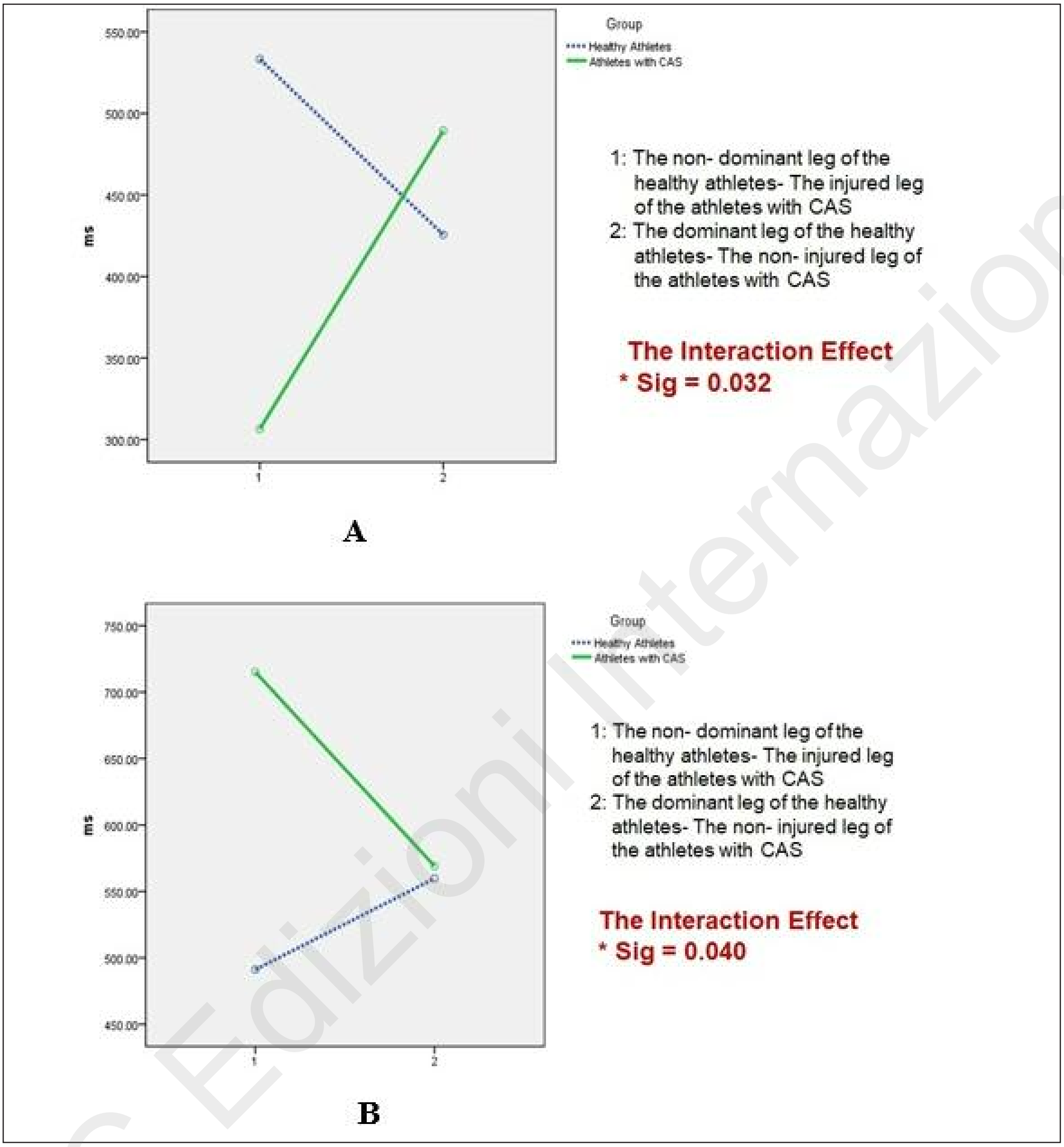

Figure 2. The results of the two-way repeated measurement ANOVA for comparing athletes with and without chronic ankle instability. A: the interaction effect of the tested leg and group for the pre- motor time of peroneus longus was significant (P=0.032, F=5.434); B: the interaction effect of the tested leg and group for the motor time of peroneus longus was significant (P=0.40, F=4.937).

anticipation time of tibialis anterior in non-dominant leg (ICC= 0.69). As well as, all variables had very high or high correlation except for pre-motor time of peroneus longus (ICC= 0.67) and anticipation time of all four muscles (GS: ICC=0.56, PL: ICC=0.41, PB: ICC=0.47 and TA: ICC=0.39) in the injured leg and anticipation time of tibialis anterior (ICC=0.53) in non-injured leg.

The mean value and standard deviation of the variables in the dominant and non-dominant leg of the healthy athletes and the injured and non-injured leg of the athletes with CAI are available on Table I.

The results of the two-way repeated measurement ANOVA for comparing both groups showed that only the interaction of the tested leg and group effects for pre- motor time (P=0.032, F=5.434) and motor time (P=0.40, F=4.937) of peroneus longus were significant (Tabs. II, III, Fig. 2).

Table I. Mean value and standard deviation of the pre-landing muscle timing variables in healthy athletes (n=11) and athletes with chronic ankle instability (n= 8).

Variables		Healthy athletes		Athletes with CAI	
	Muscles	Dominant leg	Non-dominant leg	Injured leg	Non-injured leg
Pre- motor Time (ms)	Gastroc-soleus	687.42 ± 207.14	724.94 ± 318.20	619.58 ± 352.41	338.37 ± 152.92
	Peroneus Longus	425.60 ± 240.37	533.30 ± 327.90	306.46 ± 142.92	489.37 ± 220.22
	Peroneus Brevis	455.27 ± 249.62	561 ± 408.09	497.29 ± 273.81	529.29 ± 198.52
	Tibialis Anterior	251 ± 78.82	317.64 ± 76.57	285.96 ± 233.67	363.83 ± 193.33
Motor time (ms)	Gastroc-soleus	295.24 ± 186.90	301.09 ± 178.28	401.58 ± 231.33	338.37 ± 152.39
	Peroneus Longus	559.76 ± 319.38	491.10 ± 214.83	715.12 ± 328.72	569.04 ± 318.62
	Peroneus Brevis	530.09 ± 82.65	467.97 ± 71.30	525.33 ± 272.87	528.54 ± 313.13
	Tibialis Anterior	734.36 ± 77.95	711.42 ± 93.19	735.21 ± 410.56	794.04 ± 401.5
Reaction time) (ms)		978.94 ± 74.69	1029.06 ± 90.19	1021.17 ± 315.68	1057.57 ± 348.99
Anticipation Time (ms)	Gastroc-soleus	151.15 ± 76.59	164.15 ± 72.55	160.17 ± 54.89	162 ± 57.18
	Peroneus Longus	145.09 ± 63.13	130.85 ± 57.68	126.04 ± 27.08	140.08 ± 75.97
	Peroneus Brevis	142.58 ± 51.58	133.82 ± 64.88	146.42 ± 34.96	148.54 ± 66.58
	Tibialis Anterior	105.15 ± 36.15	114.64 ± 43.40	113.96 ± 28.57	98.29 ± 24.13

Legend: ms, millisecond.

Discussion

The results of the present study showed no significant difference in most of the variables in athletes with and without CAI except for interaction effects of the tested leg and tested group in pre-motor time and motor time of peroneus longus which were significant.

Particular attention should be to choose the appropriate technique for analysis reaction time, unsuitable methods of analysis can increase reaction time up to 167%[17]. In this study, we defined reaction time from the initiation of the visual stimulus to the onset of heel off, so we considered it as a long latency response which is consist of stimulus processing, decision making, and movement programming and is different from short latency reflex responses of muscles followed by inversion/plantar flexion perturbation on the mechanical trapdoor[18-30].

Some studies showed the non-significant difference in muscle strength, muscle latency, joint position sense, kinesthesia and balance in dominant and non-dominant leg in healthy individuals with sedentary life style but others showed difference in these parameters in healthy athletes population which suggest that these differences in sensorimotor control are because of different demands which are placed on limbs. Different activities according to loading placed on dominant and non-dominant leg may produce changes in the muscle spindle activity. Changes in gamma motor sensitivity in dominant leg due to different demands on it, might reduce motor neuron recruitment and reflexive activity in the dominant leg. Yeung and Ekstrand et al. in their studies showed that the dominant ankle sprains 2.4 times more than the non-dominant ankle. Knight et al. reached to this conclusion that weaker balance or longer peroneus longus in dominant leg might be the risk factor for prevalence of sprains in it[31]. In our study only the pre-motor time and motor of peroneus longus were significant and this is in line with several studies which examined the reaction time as a reflex response. The main concern about lack of differences in other variables remains unclear, but Authors suggest that the high variability between trials in some of variables might be the source of these results and recommend studies with larger sample size. On the other hand, the most of the study population in the present study were men and only two women existed in each group and research showed that it seems that peroneal muscles activation strategies are sex-dependent[7], so we should speak carefully about the results.

Reports of Le Pellec et al. showed that central nervous system (CNS) not only predict the balance perturbation produced by initial movement, but also predict the whole sequence of movement. It is an acceptable fact that the reaction time increases by the difficulty of voluntary movements. In our study as theirs, participants should jump after the visual go signal and pay special attention to the considered distance of jumping, therefore the time between the go signal and onset of muscle activity cannot be considered as the actual reaction time. On the other hand we used the choice reaction time task which is more difficult than simple reaction time task and in this condition CNS needs more time for planning and it is likely that at least part of increased time of planning is due to the programming of APA[32].

It seems that several factors contribute in processing and producing APA, among them intensity and direction of expected perturbation, properties of the voluntary activity related to the perturbation, body posture before activity and properties of the postural task are notable[33]. The main concern about preparation for landing is reducing impact forces and this is provided

Table II. Within-subjects and between-subjects' effect for the study of the interaction of the tested leg and the tested group on reaction time 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**	9005.889	1	0.206	0.655	0.012	0.071
	Tested Group	12450.083	1	0.088	0.770	0.005	0.059
	Tested Leg * Group	43713.762	1	1.001	0.331	0.056	0.157
Motor Time of Gastroc-soleus	**Tested Leg**	11043.772	1	0.584	0.455	0.033	0.111
	Tested Group	47770.708	1	0.920	0.351	0.051	0148
	Tested Leg * Group	7619.411	1	0.403	0.534	0.023	0.092
Pre-motor Time of Peroneus Longus	**Tested Leg**	13103.469	1	0.364	0.554	0.021	0.088
	Tested Group	61585.102	1	0.687	0.419	0.039	0.123
	Tested Leg * Group	195585.781	1	5.434	0.032*	0.242	0.594
Motor Time of Peroneus Longus	**Tested Leg**	13890.331	1	0.642	0.434	0.036	0.118
	Tested Group	126029.602	1	0.830	0.375	0.047	0.138
	Tested Leg * Group	106768.842	1	4.937	0.040*	0.225	0.554
Pre-motor Time of Peroneus Brevis	**Tested Leg**	12619.024	1	0.326	0.575	0.019	0.084
	Tested Group	241.945	1	0.002	0.968	0.000	0.050
	Tested Leg * Group	43985.761	1	1.137	0.301	0.063	0.172
Motor Time of Peroneus Brevis	**Tested Leg**	9883.420	1	0.383	0.544	0.022	0.090
	Tested Group	7214.255	1	0.059	0.811	0.003	0.056
	Tested Leg * Group	8037.701	1	0.311	0.584	0.018	0.082
Pre-motor Time of Tibialis Anterior	**Tested Leg**	18244.618	1	2.116	0.164	0.111	0.279
	Tested Group	822.426	1	0.009	0.927	0.001	0.051
	Tested Leg * Group	4588.442	1	0.532	0.476	0030	0.106
Motor Time of Tibialis Anterior	**Tested Leg**	15484.383	1	1.034	0.324	0.057	0.279
	Tested Group	16131.134	1	0.075	0.788	0.004	0.051
	Tested Leg * Group	2983.259	1	0.199	0.611	0.012	0.106
Reaction Time	**Tested Leg**	416.675	1	0.032	0.860	0.002	0.053
	Tested Group	11687.052	1	0.070	0.795	0.004	0.058
	Tested Leg * Group	17459.258	1	1.338	0.263	0.073	0.194

by muscle activity. When the landing time is long, the first burst of reflexive activity mostly continued by the second burst of voluntary activity which occur 40-140 before heel contact. It is discussed that onset of second phase depends on the seeing the landing surface[34]. Evidences suggest the role of distal muscles, which control the ankle joint, are relatively minor and may be include fine tuning of APA patterns which are mostly provide by proximal muscles[33]. In the present study we did not examined the proximal muscles of lower limbs or trunk muscles and only considering distal muscles which have the minor role according to the literature.

Individuals who participated in this study knew that they should jump after seeing the green light, so the anticipation might affect the results and like reaction time, anticipation is sex-dependent because studies showed higher amplitudes of pre-activation in women which is to some extend due to the different neuromuscular control in prediction of touchdown[7].

Small sample size, and not checking knee, hip and trunk muscles are some of limitations that should be acknowledged in this study. Future studies should also consider the kinematics of ankle joint in order to provide the possible loading information related to the lateral ankle sprains and carry out with larger sample size to have results with higher power.

Design of this study may be used in other studies investigating lower limb timing in athletes with musculoskeletal injuries.

Table III. Within-subjects and between-subjects' effect for the study of the interaction of the tested leg and the tested group on muscle anticipation 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
Gastroc-soleus	**Tested Leg**	288.766	1	0.143	0.710	0.008	0.065
	Tested Group	109.096	1	0.015	0.903	0.001	0.052
	Tested Leg * Group	509.538	1	0.252	0.622	0.015	0.076
Peroneus Longus	**Tested Leg**	1852.608	1	1.124	0.304	0.062	0.170
	Tested Group	223.062	1	0.042	0.840	0.002	0.054
	Tested Leg * Group	0.093	1	0.000	0.994	0.000	0.050
Peroneus brevis	**Tested Leg**	274.260	1	0.146	0.707	0.009	0.065
	Tested Group	798.106	1	0.178	0.679	0.010	0.068
	Tested Leg * Group	101.874	1	0.054	0.819	0.003	0.056
Tibialis anterior	**Tested Leg**	1464.965	1	1.747	0.204	0.093	0.239
	Tested Group	131.582	1	0.082	0.779	0.005	0.058
	Tested Leg * Group	88.498	1	0.106	0.749	0.106	0.061

Conclusion

In this study premotor time, motor time, reaction time, and anticipation of the leg mucles of athletes with or without chronic ankle instability in response to a visual stimulus was investigated. Although a significant difference was reported in peroneus longus timing, no significant differences were reported regarding gastroc-soleus, peroneus brevis and tibialis anterior. It seems that some of the non-significant results might be related to neuromuscular adaptation that occurred in in-field athletes and some of them are related to small sample size.

Conflicts of interest

None.

Ethics

The Authors declare that this research was conducted following basic ethical aspects and international standards as required by the Journal and recently update in[35].

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