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Changes in the muscle reaction time of ankle periarticular muscles by balance training

Naruto Yoshida^{1,2*}, Naoyuki Kobayashi², Akihiko Masunari³, Shun Kunugi³, Toshikazu Miyamoto³,
Tomoo Ishii⁴ and Shumpei Miyakawa³

¹ Department of Acupuncture and Moxibustion, Faculty of Health Care, Teikyo Heisei University, 2-51-4 Higashiikebukuro, Toshima-ku, Tokyo 170-8445, Japan

² Graduate School of Health Science, Teikyo Heisei University, 2-51-4 Higashiikebukuro, Toshima-ku, Tokyo 170-8445, Japan

³ Division of Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi, Ibaraki 305-8577, Japan

⁴ Department of Orthopedic Surgery, Endowed Department of Human Resources Development for Community Medicine, Tokyo Medical University Ibaraki Medical Center, 3-20-1 Chuo, Ami-machi, Inashiki-gun, Ibaraki 300-0395, Japan

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Abstract Ankle inversion sprains are the most common football-related injuries. About 74% of patients with residual symptoms such as general ankle instability, the ankle suddenly giving way, or recurrent ankle sprains, may develop chronic ankle instability. Balance training is a common rehabilitation procedure used after an ankle sprain. However, the influence of balance training on the muscle reaction time and muscle chain reaction is still unclear. Accordingly, this study examines how balance training influences muscle reaction time and muscle chain reaction. This controlled laboratory study involved 33 male college football players assessed for existence/non-existence of ankle functional instability (FI). The subjects were then divided into a group of 12 players with FI who underwent balance training (FI group), 12 players without FI who underwent balance training (Con group), and 9 players without FI who did not undergo balance training (NTr group). Muscle reaction times during ankle varus simulation with Trapdoor were measured. The main effect was seen between the peroneus muscle group and anterior tibialis muscle in the Con and NTr groups. In the FI group, no significant main effect on the muscle was seen, but the main effect on intervention period was significant. Balance training reduced the muscle reaction time of the FI group. Results suggest that balance training may improve muscle reaction time. However, the absence of a significant difference between the peroneus muscle group and anterior tibialis muscle in the FI group after balance training indicates that the muscle chain reaction did not recover to the level of an uninjured leg.

Keywords : muscle reaction time, muscle chain reaction, ankle instability, ankle sprain

Introduction

Football (or soccer), a fascinating globally popular sport, is associated with many injuries, and ankle inversion sprains are the most common acute trauma experienced by players¹⁾. Previous research has shown that approximately 74% of patients with residual symptoms such as general ankle instability, the ankle suddenly giving way, or recurrent ankle sprains, may develop chronic ankle instability²⁾. Hence, clinicians require appropriate information in order to provide appropriate treatment.

Ankle functional instability is evoked by functional failure of the ankle proprioceptor and periarticular muscles after an ankle sprain, leading to the characteristic symptoms of increased postural sway and delayed peroneal

muscle reaction time³⁾. Peroneal muscle reaction time, in particular, has been reported to be influenced not only by the peroneal muscle, but also by muscle reflex movement and strength of the other muscles⁴⁾. However, these reports have focused only on muscle reaction time in the long peroneal, short peroneal, and anterior tibialis muscles. When considering the structural and functional aspects of the human body, execution of joint movement is considered to be effective when the prime mover acts on associated joints by suppressing the antagonistic muscle(s), a principle known as reciprocal innervation. Nichols reviewed how both reciprocal inhibition and co-contraction contribute to increased joint stiffness in response to mechanical perturbation⁵⁾. Thus, not only an absolute value of a given muscle's reaction time, but also its association with agonist and antagonist muscles should be investigated, especially focusing on the timing of the onset of contraction.

*Correspondence: naruto-y@kch.biglobe.ne.jp

Previous investigations have examined the muscle reaction times of the ankle periarticular muscles among college football players by subjecting their legs to ankle inversions and also examining the effects on related muscles. The results showed that, in healthy legs, the stimulated peroneal muscle group (long peroneal muscle or short peroneal muscle) began contracting earlier than the anterior tibialis muscle. In legs with instability, the results did not demonstrate a significant difference in muscle reaction time between the peroneal muscle group and the anterior tibialis muscle. Thus, contraction of the anterior tibialis muscle after contraction of the peroneal muscle group has been described as a normal muscle chain reaction⁶⁾.

Balance training is now often performed as a rehabilitative therapy following an ankle sprain. Many preceding studies have examined the influence of balance training on functional instability by reviewing postural sway as an index. Freeman⁷⁾ reported on ankle functional instability in 1965, and diagnosed the existence or non-existence of such instability using the Romberg test. Subsequently, he indicated that instability could be improved by muscular strength training and coordinated exercise. Bernier and Perrin⁸⁾ reported that postural sway improvement was observed following the execution of progressively complicated balance training conducted in 10-min sessions, 3 times per week for 6 weeks. Balance training was also reported to improve postural sway by Pintsaar et al.⁹⁾ and Tropp et al.¹⁰⁾. Postural sway was regarded as an index that was also influenced by something other than the ankle joint. Therefore, measurement of other factors, like muscle reaction time and muscle chain reaction, is also important. Although there is one report regarding the influence of balance training on muscle reaction time¹¹⁾, this report only examined the muscle reaction time of the long peroneal muscle. This report did not consider the relationship between agonist and antagonist muscles.

From the above descriptions, the impact of balance training on the relationship of certain muscles remains unclear. The relationship between agonist and antagonist muscles was defined as a muscle chain reaction, and it was evaluated whether or not the contraction of the anterior tibialis muscle occurred after the contraction of the peroneal muscle group in this study. The purpose of this study was to investigate the impact of balance training on muscle reaction time and muscle chain reactions. The hypothesis of this study is that balance training will decrease muscle reaction time; and after balance training, the peroneal muscle will contract earlier than the tibialis anterior muscle in inversion stimulation.

Materials and Methods

Subjects. The study involved 33 male, college football players (33 legs) who were assessed for the existence/non-existence of ankle functional instability (FI) using the Karlsson score¹²⁾ (Table 1). Players were classified

as having FI (less than 90 points on the Karlsson score) or not having FI. The subjects were then divided into a group of 12 players with FI who underwent balance training (FI group), 12 players without FI who underwent balance training (Con group), and 9 players without FI who did not undergo balance training (NTr group) (Table 2).

For the target legs in the examination, the leg that had the lowest Karlsson score was the leg that was studied in subjects with FI in both legs; the FI group thus had 7 right legs and 5 left legs. The legs in the other 2 groups were matched with those in the FI group, so that there were 7 right legs and 5 left legs in the Con group, and 7 right legs and 2 left legs in the NTr group.

This study was approved by the Ethical Committee of Comprehensive Human Sciences at our institution. The study subjects all provided written or oral consent to participate in the study after being provided with an explanation of the study's intent and methods. (No.21-354)

Measurement of muscle reaction time. The subjects were asked to assume a relaxed standing position over a Trap-door¹³⁾, with equal weight on both legs, prior to receiving a sudden, simulated stimulation of ankle inversion on one side of the target leg's ankle (Fig. 1). The subjects were asked to position their second toe in line with the tuberal region of the calcaneal bone. The 3 target muscles examined in the study were the long peroneal muscle, the short peroneal muscle, and the anterior tibialis muscle. After shaving the hair and cleaning the skin over the target muscle, electrodes (EMG amplifier; Biometrics Ltd, Cwmfelinfach, Gwent, UKC), separated by a 2-cm center-to-center distance, were attached to the area parallel to each muscle's fiber direction. The derived muscle electric potential was converted to A/D, with a sampling frequency of 1 kHz, and saved to a personal computer using a data importing/universal analysis program (TRIAS System, Biometrics Ltd, Cwmfelinfach, Gwent, UK). The EMG signals were pre-amplified over a bandwidth of 5Hz-450Hz. In addition, the signal from the Trap-door was recorded, using an A/D converter, in order to synchronize the slope starting point with the electromyogram (EMG).

The muscle reaction time was measured while tilting the Trap-door 25° from the relaxed standing position. The criterion for the starting point of muscle activity was defined as the maximum value of the rectified waveform during the relaxed condition or the point where the waveform of the electromyogram exceeded the maximum value¹³⁾. The muscle reaction time was determined as continuing from the starting point of the trap door tilt to the starting point of muscle activity.

In all cases, the examiner was positioned behind the study subject to prevent the subject from recognizing when the examiner activated the Trap-door. Each test was conducted 3 times with each study subject and averaged for statistical analysis. For each measurement, the muscle reaction time of the peroneus muscle group was defined

Table 1. Karlsson score

		Score
Pain	None	20
	During exercise (training, etc.)	15
	Walking on uneven surface	10
	Walking on even surface	5
	Constant (severe)	0
Swelling	None	10
	After exercise	5
	Constant	0
Instability (subjective)	None	25
	1-2 times during exercise in a year	20
	1-2 times during exercise in a month	15
	Walking on uneven surface	10
	Walking on even surface	5
	Constant (severe) using ankle support	0
Stiffness	None	5
	Moderate in the morning or after exercise	2
	Marked (constant, severe)	0
Stair climbing	No problem	10
	Impaired (instability)	5
	Impossible	0
Running	No problem	10
	Impaired	5
	Impossible	0
Work activities	Same as pre-injury	15
	Same work, less sports normal leisure activities	10
	Lighter work, less sports normal leisure activities	5
	Severely impaired work capacity, decreased leisure activities	0
Support	None	5
	Ankle support during exercise	2
	Ankle support during daily activities	0

as the muscle reaction time of the earlier contraction of either the long peroneal or short peroneal muscle (Fig. 2).

To minimize any influence of fatigue by regular exercise and training, measurements were not conducted immediately after regular team exercise or balance training. The study subjects were also asked to relax, as much as possible, for 2 hours prior to the measurements.

Balance training. In addition to regular team exercise, the study subjects (Con group and FI group) were required to undergo balance training for 6 weeks. Balance

Table 2. Physical characteristics of the study subjects

	Height (cm)	Weight (kg)	Age (years)
Con group	174.1 ± 6.2	65.2 ± 6.1	19.0 ± 0.0
FI group	173.7 ± 6.2	68.7 ± 10.6	19.1 ± 0.3
NTr group	172.3 ± 5.2	66.3 ± 5.2	20.4 ± 0.5

Values are represented as Mean ± SD.

Fig. 1 Study apparatus. The Trap-door device was tilted 25° from the starting position. The examiners were positioned behind the subjects to prevent them from recognizing when the examiner was about to activate the Trap-door.

Fig. 2 Calculation of peroneal muscle group's muscle reaction time. This is one example of EMG. Muscle reaction time of PL (between Tr and L) is 51ms, PB (between Tr and S) is 37ms, and TA (between Tr and A) is 60ms. In this case, the muscle reaction time of the peroneal muscle group (PM) is 37ms because PB is shorter than PL.

training consisted of various exercises conducted with a DYJOC BOARD (Sakai Medical, Tokyo, Japan) for 5 min per day, 5 days a week. In addition, the exercise content was designed to allow the subjects to progress through 6 stages of balance training from a beginning level (postural maintenance while standing on one leg) to a high level involving multiple actions (kicking or heading while maintaining posture with the subject standing on one leg) (Table 3, Fig. 3). Each subject progressed through the various stages incrementally as they developed additional skill under the guidance of the team trainer. All of the subjects participated in regular team exercises, but the NTr group was prohibited from participating in the balance training that the Con and FI groups underwent.

Experimental protocol. Muscle chain reaction, muscle reaction times, and Karlsson score were measured both before and after the intervention period.

Statistics. All of the measurement results were reported as means $\pm$ standard deviation (SD); statistical analyses

were conducted using SPSS ver. 19 (IBM, Armonk, NY, USA). To compare the reaction times of the peroneus muscle group and the anterior tibialis muscle, interactions were examined using two-way factorial analysis of variance (ANOVA), the two factors were “muscles” and “pre/post intervention period”. Post hoc tests between these muscles were also performed using the Student's *t*-test, including the comparison of each muscle pre/post intervention period. Statistical significance was set at less than 5%. In addition, the relevance of the statistical significance was measured using the effect size (ES) for the different indices according to the method of Cohen (1988); furthermore, post hoc power analysis was also done using the calculation G*Power 3¹⁴⁾.

Results

Two-way factorial ANOVA for each group. The main effect was significantly seen between the peroneus muscle group and anterior tibialis muscle in the Con and NTr groups. In the FI group, no significant main effect on

Table 3. Balance training

Level	Standing on one leg	Bending and stretching one leg	Hand-pass	Play skill
1	Cross arms over the chest	Knee bending and stretching at 90° while standing on one leg	Hand-pass with both hands	Inside-pass
2	Knee bending and stretching of idle leg	Cross arms over the chest Knee bending and stretching at 90° while standing on one leg	Knee bending for idle leg Hand-pass with both hands	Cross arms over the chest Inside-pass
3	Swinging of idle leg (Forward and back movement)	Picking up/Placing a soccer ball	Quick chest pass	Pass with changing ball locations
4	Swinging of idle leg (Right and left)	Picking up/Placing a soccer ball with location change	Knee bending of idle leg Quick chest pass	Pass with various ball locations at random
5	Movement on one-to-one basis	Picking up/Placing a tennis ball	One hand catch and pass	Heading
6	Look that way (Japanese game: Making an opponent's head to turn to a designated direction after "scissors-paper-rock")	Picking up/Placing a tennis ball with changing locations	Pass direction at random	Two-touch pass

Fig. 3 Balance training. A) Arms crossed over chest, B) picking up and placing a ball, C) an inside kick, D) heading the ball.

the muscle was seen, but the main effect on intervention period was significant. In addition, interactions were not significant in any of the groups (Table 4).

Comparisons between the muscles in the pre-intervention period using a post hoc test.

The muscle reaction time for the peroneus muscle group in the Con subjects (54.1 ± 14.7 ms) was significantly ($p < 0.05$) shorter than that for the anterior tibialis muscle (62.4 ± 13.5 ms, ES = 0.69, power = 0.58). Similarly, in the NTr group, the peroneus muscle group reaction time tended to be shorter (49.0 ± 11.9 ms) than the anterior tibialis muscle reaction time (57.7 ± 15.3 ms) ($p = 0.052$), but the difference was not statistically significant (ES = 0.76, power = 0.67). Also, there wasn't any significant difference in the reaction times between the two muscles in the FI group (peroneus muscle group, 62.7 ± 15.2 ms; anterior tibialis muscle, 68.4 ± 15.9 ms, ES = 0.43, power = 0.26) (Table 4).

Comparisons between the muscles in the post-intervention period using a post hoc test.

After the intervention period, a significant difference was observed in the muscle reaction times between the peroneus muscle group and the anterior tibialis muscle in the Con group (peroneus muscle group, 44.0 ± 13.1 ms; anterior tibialis muscle,

Table 4. Muscle reaction times in each group

FI group	pre	post
Karlsson score	77.7 ± 10.7	77.7 ± 10.7
Anterior tibialis muscle	68.4 ± 15.9	57.9 ± 10.8
Peroneus muscle group	62.7 ± 15.2	53.0 ± 15.4 †
Effect Size(ES)	0.43	0.33
Power(1- $\hat{\alpha}$)	0.26	0.18
ES, power: TA vs PM		†: pre- vs. post-intervention p < 0.05
NTr group	pre	post
Karlsson score	100 ± 0	100 ± 0
Anterior tibialis muscle	57.7 ± 15.3	62.0 ± 16.7 *
Peroneus muscle group	49.0 ± 11.9	44.9 ± 10.2
Effect Size(ES)	0.76	0.97
Power(1- $\hat{\alpha}$)	0.67	0.87
ES, power: TA vs PM		*: TA vs. PM p<0.05
Con group	pre	post
Karlsson score	99.2 ± 1.9	99.2 ± 1.9
Anterior tibialis muscle	62.4 ± 13.5 *	59.5 ± 15.1 *
Peroneus muscle group	54.1 ± 14.7	44.0 ± 13.1
Effect Size(ES)	0.69	1.23
Power(1- $\hat{\alpha}$)	0.58	0.97
ES, power: TA vs PM		*: TA vs. PM p<0.05

59.5 ± 15.1 ms, ES = 1.23, power = 0.97) and in the NTr group (peroneus muscle group, 44.9 ± 10.2 ms; anterior tibialis muscle, 62.0 ± 16.7 ms, ES = 0.97, power = 0.87). However, we did not see a significant difference in the muscle reaction times of muscles in the FI group (peroneus muscle group, 53.0 ± 15.4 ms; anterior tibialis muscle, 57.9 ± 10.8 ms, ES = 0.33, power = 0.18) (Table 4).

Comparisons between the pre-/post- intervention periods using a post hoc test. The muscle reaction time of the peroneus muscle group was significantly shortened after balance training intervention in the FI group (pre-intervention, 62.7 ± 15.2 ms; post-intervention, 53.0 ± 15.4 ms). There was also a marginally significant reduction in the anterior tibialis muscle (p = 0.13). No significant change in the reaction time for the peroneus muscle group in the Con and NTr groups was observed; and the reaction time of the anterior tibialis muscle did not change significantly in any of the groups as a result of the balance training (Table 4).

Karlsson score of each subject. There was no change in the Karlsson score of subjects after the intervention period (Table 4).

Discussion

For the FI group subjects, there was no significant difference in the muscle reaction times of the peroneus muscle group or the anterior tibialis muscle; but for both the Con and NTr groups, the peroneus muscle group reaction time was significantly shorter than that of the anterior tibialis muscle. In healthy legs, the peroneus muscles contracted earlier than did the anterior tibialis muscles in response to the stimulation of ankle inversion, indicating proper functioning of the muscle chain reaction. It was reported in another study that sedentary subjects, who underwent balance disc training for 8 weeks, had an inversion muscle (anterior tibialis muscle) stimulation response that was delayed compared to that of eversion muscles (long peroneal muscle, short peroneal muscle, and extensor digitorum longus muscle)¹⁵⁾; this result was

also observed in this study in healthy legs before undergoing balance training. Since the subjects in this study were athletes who practiced every day, their muscle chain reactions functioned well even before the balance training.

Muscle reaction times were significantly shortened in FI subjects as a result of 6 weeks of balance training. Previously, Osborne et al.¹⁶⁾ reported that the muscle reaction times of the anterior tibialis muscle in both legs were significantly shortened by a training regimen involving only one leg, conducted for over 8 weeks. Linford et al.¹¹⁾ also reported that muscle reaction times of the anterior tibialis muscle were shortened by a 6-week training program. Furthermore, another group¹⁷⁾ reported that the reaction time of the peroneus muscle was extended as a result of an underperforming reflex path in patients with acutely sprained ankles or with chronic functional instability. This same group also reported that an improvement in the instability and muscle reaction time of long peroneal muscle could be achieved through coordinated training. These reports suggested that balance training could improve muscle reaction times, as was confirmed by the present study. As with the previous study, it might be a mechanism for improving the muscle reaction time. The balance training might be re-educating the brain and other cerebral higher centers, and may enhance the coordination of the muscles in stabilizing the ankle joint. However, the present study failed to reveal a significant difference between the peroneus muscle group and the anterior tibialis muscle in the FI subjects, even after balance training. This result indicates that the muscle chain reaction in FI subjects did not fully recover function similar to that in healthy legs, in spite of the 6-week balance training protocol. The Karlsson score of this study's subjects did not improve after the balance training protocol. These results also suggest that a degree of functional instability remains in the ankle of the FI subjects. Furthermore, there is a possibility that FI subjects attempted to increase joint stiffness due to the co-contraction of the peroneal muscle group and the anterior tibialis muscle. In order to clarify this possibility, a future study should measure muscle activation and calculate the co-contraction index defined by Lin¹⁸⁾.

The muscle reaction time of the peroneus muscle group was significantly shorter than that of the anterior tibialis muscle, even after the intervention in both the Con and NTr groups. Regardless of the use of a 6-week balance training program, the results suggested that a functional muscle chain reaction, following ankle inversion, was maintained in the healthy legs. Further study is required to examine whether or not the functioning of the muscle chain reaction would change over the course of a football season in the presence or absence of a balance training program. Such a study may be designed as a prospective study to examine the rate of injury occurrences among players participating in such a training program, relative to those not participating.

Although this study examined the influence of a balance

training regimen on muscle reaction times, often used in rehabilitation programs after an ankle sprain, other studies have examined postural sway as an index of FI^{8,19)}. In addition, Tropp and his group^{10,20)} reported improvement in postural sway by coordinated training for 6 weeks. Furthermore, a comparison between rehabilitated subjects and uninjured subjects showed that there was no difference between the groups with regard to peroneus muscle latency, irrespective of whether the injured individuals were treated conservatively or surgically²¹⁾. The above results indicate that balance training not only shortens muscle reaction time but also improves postural sway. Future studies may need to include a coordinated examination of muscle reaction times, muscle chain reactions, and postural sway.

The current study has some limitations. Firstly, all of the ankle instability subjects underwent balance training. In order to reveal the effect of balance training on ankle instability in more detail, future studies need to include a control group that doesn't participate in balance training. Moreover, this work regarded ankle instability as the only functional instability. In future studies, mechanical instability should also be evaluated using X-ray stress tests. Another limitation was that the dominant and non-dominant legs of the subjects were not considered in this study. Also, we need to alter the quantitative period and/or qualitative contents and discuss whether balance training can affect the muscle chain reaction.

Conclusion

This study suggests that balance training may improve muscle reaction time. However, there was no significant difference between the peroneus muscle group and anterior tibialis muscle in the FI group after balance training. Therefore, the muscle chain reaction of the FI group may not recover to the level of an uninjured leg.

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