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Original Article

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Effects of Whole Body Vibration Exercise on Lower Extremity Muscle Activity and Balance Ability in Football Player with Chronic Ankle Instability

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Purpose: The purpose of this study was to determine the effects of whole body vibration exercise (WBVE) on lower extremity muscle activity and balance ability according to different methods of exercises in football player and use it as basic data for the rehabilitation training of chronic ankle instability.

Methods: Thirty subjects were randomly divided into two groups: the two groups, which each group have 15 members, are WBVE group and neuromuscular training (NMT) group according to training method. The exercise program was conducted for six weeks. Subjects were measured on lower extremity muscle activity and balance ability.

Results: The muscle activity increasement of the WBVE group was significantly higher than that of the NMT group ($p < 0.05$) and the balance ability decreasement of the WBVE group was significantly higher than that of the NMT group ($p < 0.05$).

Conclusion: These findings of this study suggest that WBVE may have a beneficial effect on improvement of lower extremity muscle activity and balance ability in football player with chronic ankle instability.

Keywords: Chronic ankle instability, Whole body vibration exercise, Muscle activity, Balance

INTRODUCTION

The ankle joint plays an important role in stability and shock absorption, and is one of the most frequently injured joints in athletes and non-athletes.[1] The lateral collateral ligament of the ankle is composed of tissues with a relatively weak structure; upon landing during sports activities or when walking on an uneven surface, sudden plantar flexion and adduction can cause injury to the lateral collateral ligament, resulting in joint instability.[2] Ankle sprain causes reduced dorsiflexion range of motion (ROM), and especially affects the gait pattern during walking and running, which increases the risk of re-injury.[3,4] In addition to the ankle ligaments, ankle sprain also causes injury to neural tissue in the ankle, including mechanoreceptors. This leads to deficits in kinetic sense and position sense, and 31–40% of subjects who experience ankle sprain show chronic ankle instability (CAI).[5,6]

CAI is defined as recurrent ligament injury and reinjury after ankle sprain. CAI is classified as mechanical ankle instability, characterized by reduced ligament stiffness and arthrokinematic changes, and functional ankle instability, characterized by recurrent ankle instability resulting from injury to the proprioception and neuromuscular systems.[7] CAI presents with symptoms of recurrent ankle sprain, pain, edema, instability, and giving way, and can persist for 6–18 months after the initial ankle injury.[8] Patients with CAI show activation of the peroneus longus muscle at initial contact during walking, whereas healthy individuals show activation after initial contact.[9] CAI patients also show less anticipatory muscle activity than healthy individuals upon landing from a jump,[10] reduced balance ability because of inaccurate proprioception after the initial injury, and impaired postural control as an adaptive response of the

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central nervous system.[11]

Individuals with CAI have shown improved ankle stability, balance, and ankle muscle activity using various interventions, including spiral taping, Mulligan technique, and neuromuscular training (NMT).[12-14] Each intervention method should include sensory-motor and balance training.[15] However, high intensity sensory-motor training, such as plyometric training, consists of various jumping and change-of-direction movements and requires sufficient musculoskeletal body condition; if the individual's condition is deficient, this type of training can cause ligament, tendon, and joint injury.[16] Whole body vibration exercise (WBVE) has been receiving attention as a safe exercise method that was recently developed to overcome these limitations.[17]

WBVE acts by application of mechanical vibration to muscles, which stimulates the primary motor endings of the muscle spindles, increasing the sensory input of Ia afferent neurons, generating stronger alpha motor neuron output, and thereby increasing the recruitment rate of motor units to enhance muscle activity.[18,19] In addition, WBVE is effective at improving balance ability in the elderly, athletes, and individuals with neurological injury, via an increase in somatosensory input.[20-22] Thus, the effectiveness of WBVE has been documented, but few studies have demonstrated an objective effect of WBVE in individuals with CAI.

Therefore, the present study aimed to implement a WBVE intervention in soccer players with CAI, to investigate the effects on balance and ankle muscle activity, and to provide basic data for rehabilitative exercise in individuals with CAI.

METHODS

1. Subjects

The subjects received a thorough explanation of the study content and aims and gave written consent before commencing the study. Among 50 university soccer players from Jeollanam-do, 30 subjects were selected who had complained of physical discomfort in one ankle with associated apprehension for at least 6 months, and had a score of less than 25 points on the Cumberland ankle instability tool,[23] with no ankle edema, and were able to support their body weight on the unstable ankle. The CAIT consists of 9 questions that answered separately for the right and left ankle. It is scored on a 30 point scale, with lower scores indicating decreased stability. The CAIT has excellent test-retest reliability. Initially, a cutoff score of ≤ 27 was reported for discriminating between in individuals with and without CAI. However, more recent research challenged the initial value and provide evidence that a lower score (≤ 25) should be used to indicate the presence of CAI. We excluded individuals with a history of ankle surgery or fracture within the prior 6 months, or with balance impairment due to vestibular system or other neurological disorders. The selected subjects were randomly allocated into a WBVE group and an NMT group, with 15 in each group (Table 1).

2. Experimental methods

1) Methods of exercises

(1) WBVE

For the WBVE intervention, a Wellengang START (Wellengang GmbH, Bayern, Germany) was used. Whole body vibration is programmed exercise which use randomly mixed a frequency of 5 to

Table 1. General characteristics of subject

	WBVE (n = 15)	NMT (n = 15)	p-value
Age (year)	22.51 ± 2.62	21.94 ± 2.54	0.643
Height (cm)	173.65 ± 8.34	172.74 ± 9.48	0.541
Weight (kg)	69.89 ± 7.49	70.57 ± 8.39	0.574
CAIT (score)	19.93 ± 4.29	19.86 ± 3.94	0.687
Dominance side (Lt/Rt)	3/12	2/13	

Values are group mean ± SD.
WBVE: whole body vibration exercise, NMT: neuromuscualr training, CAIT: Cumberland ankle instability tool.

Table 2. Exercise scheme of 6 weeks whole body vibration

	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week
Frequency	5-25 Hz (mix)			5-25 Hz (mix)		
Amplitude	3-6 mm (mix)			3-6 mm (mix)		
	One-legged stance			One-legged stance with eyes shut		
	Cross legged sway			Cross legged sway with resistance elastic band attached to the ankle		
Exercise	Runner's pose			Runner's pose with single leg heel raises		
	Catching and throwing a volley ball against wall			Catching and throwing a tennis ball against wall		

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25 Hz and amplitude of 3 to 6 mm. Alternating vertical and horizontal vibration modes were used. The intervention protocol presented by Sierra-Guzman et al.[24] was applied 30 min per day, 3 times per week, for 6 weeks (Table 2, Figure 1). The WBVE consist of total 30 minute including 5 minute exercise and 1 minute rest of a session.

(2) NMT

The NMT intervention was applied for 30 min per day, 3 times per week, for 6 weeks. The protocol consisted of 5 min of warm-up exercise, 20 min of the main exercises, and 5 min of cool-down exercise. Based on a study by Myer et al.,[25] the exercises performed were agility training, one-leg sideways jumps, vertical jumps, and one-leg figure-eight jumps.

2) Measurements

(1) Surface electromyography (sEMG)

An MP100 surface EMG system (Biopac System Inc., Santa Barbara, CA, USA) was used to measure leg muscle activity. The collected data were processed using Acqknowledge 3.91 software on a personal computer (Figure 2A). In order to minimize skin resistance during surface EMG, the skin at the electrode sites was shaved, rubbed 3-4 times with a thin piece of sandpaper, and washed with antiseptic alcohol. EMG data were collected from the tibialis anterior (TA), gastrocnemius (GCM), and peroneus longus (PL). A bipolar electrode was attached parallel to the muscle fibers, over the middle of each muscle belly. The sampling rate was 1,024 Hz; a 60 Hz notch filter and a 30-450 Hz band pass filter were used to minimize noise, and the signals were converted into root mean squares (RMS). In order to normalize the collected data, the maximum voluntary isometric contraction (MVIC) was used to convert measurements to %MVIC. For each muscle, MVIC was maintained for 5 seconds in the manual muscle testing position; three measurements were taken for each muscle, the first and the last 1 second of the signal was excluded, and the mean value for the middle 3 seconds was converted to %MVIC.[26]

Figure 1. Exercise program of whole body vibration

(2) Balance measuring system

A Biorescue (RM Ingenierie, France) was used to measure balance ability. The whole path length (WPL) and surface area (SA) of the center of pressure (COP) were measured as subjects stood on one leg for 60 seconds with their eyes open or closed (Figure 2B). Three measurements were taken, and the mean value was used.

3. Statistical analysis

IBM SPSS Statistics 19.0 (IBM Co., Armonk, NY, USA) was used for statistical analysis in this study. The Shapiro-Wilk test was used to test normality of general characteristics for the two groups. Analysis of covariance (ANCOVA) was performed to test differences between the two groups in lower extremity muscle activity and bal-

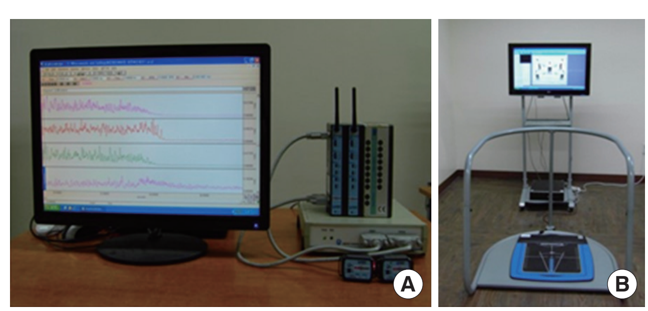

Figure 2. (A) sEMG, (B) Biorescue.

Table 3. Comparison of muscle activity (%MVIC) between groups (unit: %)

	WBVE (n=15)		NMT(n=15)		F	p-value
	Pre	Post	Pre	Post		
TA	23.65±3.29	30.15±5.52	24.15±3.67	27.74±5.11	5.382	0.041*
PL	21.31±5.24	28.74±6.13	22.15±4.95	25.14±7.81	5.383	0.041*
GCM	18.27±4.02	25.55±4.99	17.79±3.86	21.23±6.51	6.284	0.032*

Values are group mean±SD.
TA: tibialis anterior, PL: peroneus longus, GCM: gastronemius.
*p<0.05.

Table 4. Comparison of balance ability between groups

	WBVE (n=15)		NMT(n=15)		F	p-value
	Pre	Post	Pre	Post		
WPL (mm)	73.54±8.35	68.67±7.47	72.89±7.95	70.26±8.33	6.486	0.027*
SA (cm^2)	27.51±3.12	23.23±2.62	26.98±2.92	25.12±3.64	6.151	0.034*

Values are group mean±SD.
WPL: whole path length, SA: surface area.
*p<0.05.

ance ability. A statistical significance level of $\alpha = 0.05$ was used.

RESULTS

1. Comparison of changes in lower extremity muscle activity

The result of comparing the changes in lower extremity muscle activity between the two groups are as follows. The muscle acivity increasement of the TA, GCM and PL in the WBVE group was significantly higher than that of the NMT group ($p < 0.05$)(Table 3).

2. Comparison of changes in balance ability

The result of comparing the changes in balance ability between the two groups are as follows. The balance ability decreasement of the WPL and SA in the WBVE group was significantly higher than that of the NMT group ($p < 0.05$)(Table 4).

DISCUSSION

For football players, lower extremity muscle activity and balance ability are important factors in athletic performance. Various training methods have been suggested to improve lower extremity muscle activity and balance ability, and WBVE is a safe and comfortable method that improves exercise function, including muscle strength and reaction speed.[27] In the present study, WBVE was applied to football players with CAI, and the effects on ankle muscle activity and balance ability were analyzed. The results showed significant differences for the WBVE group compared to the NMT group in balance ability and activation of the TA, GCM, and PL.

In a study of 26 female subjects aged 20-29 years, Karatrantou[28] used a frequency of 25 Hz and an amplitude of 6 mm for 16 sessions of 25-minute sets per session, and examined post intervention changes in the strength of knee flexors and extensors. The WBVE group in that study showed significant differences in the isometric peak torque of the knee flexors and extensors compared to a control group. In a study of 33 soccer players, Kim[29] used frequencies of 20 Hz and 30 Hz in a semi-squat position for 20 minute per day, 5 days per week, for 6 weeks, and examined changes in the muscle activity of the quadriceps muscle. In that study, the WBVE group showed a significant difference in quadriceps muscle activity compared to the control group, and a post-hoc analysis revealed that the 30-Hz frequency was more effective at improving muscle activity. In the present study, we also found significant differences in TA, GCM, and PL activity when the WBVE group was compared to an NMT group, which was consistent with previous studies. In WBVE, mechanical vibrations are applied to the muscles; this stimulates the primary motor endings of the muscle spindles, increasing activity of Ia afferent neurons and increasing the excitation threshold of golgi tendon organs (GTOs).[30] This results in stronger alpha motor neuron output to the agonists and increases the recruitment of motor units, thereby improving muscle activity in the ankle muscles. Although previous studies have used a fixed frequency, we used a random-mixed frequency in the range 5-25 Hz. Torvinen et al.[31] implement-

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ed vibration exercise with fixed frequency and amplitude over a long period of time and found a reduction of its effect on muscle strength because of adaptation of the neuromuscular system. Hence, we believe that appropriate variation in the frequency, as in the present study, will be more effective at improving muscle activity.

Balance is controlled by the motor response to vestibular, visual, and somatosensory input. The balance ability of individuals with CAI shows a significant correlation with ankle muscle activity and changes in mobilization order.[32,33] In a study of 48 adults aged 20-29 years who had undergone anterior cruciate ligament reconstruction, Fu et al.[34] used a frequency of 20-60 Hz and amplitude of 2-4 mm in a standing position for 2 sessions per week, for a total of 16 sessions, and examined the change in balance ability following the intervention. The WBVE group was significantly different from a control group in balance ability. In a study of 44 elite or amateur soccer players, Cloak et al.[35] used a frequency of 40 Hz in a semi-squat position 3 times, for 60 seconds at a time, and examined the acute effects in terms of changes in balance ability. The WBVE group showed a significant difference in balance ability from the control group. The present study compared a WBVE group with an NMT group and found a significant difference in balance ability, which is consistent with previous studies. The agreement of the findings with those of previous studies supports the need for WBVE to improve balance ability. Somatosensory input from mechanical vibration is thought to improve balance ability via increased neuromuscular activity as a response of the sensory-motor system.

The present study applied a WBVE intervention for 6 weeks to football players with CAI, and examined its effects on ankle muscle activity and balance ability. The change in WPL and SA of the COP during one-leg standing with closed eyes and the change in ankle muscle activity demonstrated a significantly greater effect of WBVE compared to that of NMT. This provides basic data for the rehabilitation of individuals with CAI. This study had some limitations in the selection of subjects. As subjects were restricted to a specific sport and region, it is difficult to generalize the results to all athletes. In the future, further studies will be required to evaluate the effects of WBVE in combination with transcranial direct current stimulation on balance and jump ability in soccer players with CAI.

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