Research Paper

The Effect of Kinesio Taping on the Feedforward Activity of the Lower Limb Muscles in Elite Volleyball Players With and Without Chronic Ankle Instability Performing Single-leg Jump-landing

Amin Farzami[1], Heydar Sadeghi[2, 3*], Ali Fatahi[1]

1. Department of Sport Biomechanics, Faculty of Physical Education and Sport Sciences, Central Tehran Branch, Islamic Azad University, Tehran, Iran.
2. Department of Sport Biomechanics and Injuries, Faculty of Physical Education & Sport Sciences, Kharazmi University, Tehran, Iran.
3. Department of Sport Biomechanics, Kinesiology Research Center, Kharazmi University, Tehran, Iran.

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ABSTRACT

Purpose: The current research aims to examine the effect of taping on the feedforward activity of the lower limb muscles in elite volleyball players with and without chronic ankle instability while performing single-leg jump-landing.

Methods: The electromyographic activities of the lateral gastrocnemius, tibialis anterior, peroneus longus, rectus femoris, gluteus medius, and vastus lateralis of the non-dominant leg were registered before and after taping in 26 volleyball players while performing the spike skill with single-leg landing. These volleyball players entered the research by purposive sampling. The root mean square (RMS) was employed to compute muscle activity before and after taping. The multivariate analysis of variance (MANOVA) test at $P \leq 0.05$ was utilized to analyze the data.

Results: The results of the multivariate analysis of variance (MANOVA) test demonstrated that the groups did not have a significant factor in any of the variables in the feedforward phase, except for the maximum root mean square (RMS) of the peroneus longus muscle ($P=0.01$).

Conclusion: The results showed that taping cannot improve the feedforward activity of the selected muscles during single-leg landing in people with chronic ankle instability. Therefore, it is recommended to use other methods and exercises to improve the muscle feedforward activity in these individuals during the rehabilitation phases.

Keywords:
Volleyball, Ankle injury, Muscle feedforward activity, Athletic tape, Jump-landing

*** Corresponding Author:**
Heydar Sadeghi, PhD.
***Address:** Department of Sport Biomechanics and Injuries, Faculty of Physical Education & Sport Sciences, Kharazmi University, Tehran, Iran.*
***Phone:** +98 (912) 2453175*
***E-mail:** h.sadeghi@khu.ac.ir*

Highlights

• Taping can decrease the maximum root mean square (RMS) of the peroneus longus muscle activity in people with chronic ankle instability performing single-leg landing.

• The increased feedforward activity of the gluteus medius muscle can be the reason for compensatory movements in the hip joint in people with chronic ankle instability.

Plain Language Summary

In this study, we have investigated the effect of taping on the feedforward activity of the lower limb muscles in elite volleyball players with and without chronic ankle instability while performing single-leg jump-landing. We used the MANOVA test to analyze the data acquired by measuring the mean and maximum root mean square (RMS) of selected muscles' feedforward activities among 26 selected volleyball players. Our findings indicate that the grouping was not a significant factor in any of the variables in the feedforward phase, except for the maximum RMS of the peroneus longus muscle by providing a compensative movement in the thigh's muscle in players with chronic ankle instability. Overall, The results show that taping cannot improve the feedforward activity of the selected muscles during single-leg landing in people who have chronic ankle instability. Therefore, it is recommended that other methods and exercises be practised to improve the muscle feedforward activity in these individuals during the rehabilitation phases.

1. Introduction

Volleyball is not a contact sport. Nevertheless, a high number of injuries are witnessed in its competitions and practices [1]. A large number of jumps are done during volleyball training. Hence, it is not surprising that jumping and landing cause a high percentage (63%) of injuries in volleyball [2].

Ankle sprains are one of the most common causes of injury in sports [3], especially sports that involve a lot of jumping and landing tasks [4, 5]. In 25% of cases, ankle injuries prevent athletes from participating in competitions [6]. It has been reported that approximately 40% to 75% of people with lateral ankle sprains will eventually develop chronic ankle instability [7]. In 1965, for the first time, the functional instability of the ankle was defined by Freeman as a sensation of displacement of the foot following the initial external ankle sprain [8]. Ankle instability may be mechanical and functional or a combination of both. Mechanical instability results from improper joint mechanics and is related to measurable joint laxity, joint kinematic limitations, and synovial changes [9]. In contrast, functional instability is defined as a feeling of instability without joint laxity [10]. Damage related to the mechanical factors of the ankle joint (damage to ligament tissues, the arthrokinematic disorder, and the degenerative changes of the joint) occurs after severe or repeated twisting of the foot and results in the mechanical instability of the ankle joint [11]. On the other hand, ankle functional instability is associated with changes in proprioception, neuromuscular control, postural control, and strength [9].

Muscle weakness and dysfunction, changes in the feedback (reflexive) and feedforward (predictive) movement control mechanisms, changes in the sensitivity of muscle spindles around the ankle joint in response to environmental disturbances, and disturbance in the stimulation of alpha motoneurons in the peroneal and soleus muscles are among the sensory-motor disorders identified in patients with ankle instability. They have been proposed as the main factors for the chronic nature of ankle instability in these people [12, 13]. One of the possible hypotheses to explain the functional instability of the ankle is a change in the response of the muscles or their time-space patterns [14]. Previous studies have suggested that the dynamic stability control of the ankle joint is established through the feedforward mechanism rather than the feedback mechanism. Moreover, it seems that in people with functional instability of the ankle, the control of dynamic stability is mainly under the influence of the feedforward movement patterns rather than the feedback movement patterns [15].

The nervous system is responsible to control body movement through the feedforward and feedback mechanisms [15]. In the feedforward mechanism, the nervous system controls movement and posture by using different senses according to previous experiences and internal models [15]. A delay in the onset of the activity of lower limb muscles in individuals with functional instability of the ankle has been shown in several studies. In addition, this delay decreases the amount of activity. Various studies have reported this delay in the muscles close to the ankle joint and especially in the shank muscles, such as peroneus longus, tibialis anterior, and medial gastrocnemius in people with functional instability of the ankle [16, 17]. The muscular activity that starts before the foot hits the ground represents a central or feedforward motor control strategy that prepares the muscles to absorb the contact force. The starting time and magnitude of this muscle response are predicted by the central nervous system based on the sensory-motion memory of the ground reaction force during landing [18]. To prepare for the absorption of contact forces during landing, the activity of lower limb muscles takes place before the foot touches the ground. Such an activity, which is pre-planned and controlled by supraspinal centers, is recorded through electromyography and is called pre-activity. The timing of this muscular pre-activity is vital to control the stiffness of the lower limb at the moment the foot makes contact with the ground [18].

The taping technique has a crucial effect on the stimulation of the mechanical receptors of the skin and the accuracy of the proprioception of the ankle [19]. It seems that the use of ankle Kinesio tape does not limit the movement of the ankle. It increases its accuracy and reduces its instability only by stimulating the skin receptors of proprioception [20]. It is believed that proprioception plays a vital role in preventing acute injuries. It is said that the stretching and compressive effects of Kinesio tape on the skin lead to the stimulation of skin mechanoreceptors. This, in turn, increases the transmission of information about the position and movement of the joint and, therefore, can increase proprioception [21]. This research was conducted to assess the effect of taping on the feedforward activity of lower limb muscles in elite volleyball players with and without chronic ankle instability performing single-leg jump-landing.

2. Materials and Methods

The statistical population of this quasi-laboratory, comparative, and applied research included 300 volleyball players (18 to 25 years old) in Arak City, Iran. They had three training sessions per week and also had the experience of playing in the national championships, university competitions, and provincial/national leagues. Using the G-power 3.0.10 for each of the groups and by considering the power of 0.80, the significance level of 0.05, and the size effect of 0.60, 17 people were considered as the statistical sample. By considering the conditions and the statistical population available for this research, for each group, 13 individuals who were similar in terms of age, height, and weight were selected as a purposeful and accessible sample (Table 1).

Due to the small number of individuals with chronic ankle instability, all of them were selected. The inclusion criteria in the group with functional instability included experiencing at least two apparent sprains in one of the legs in the last year, at least two counts of ankle displacement during physical activity [11, 22], the absence of mechanical instability in the affected ankle confirmed by the anterior drawer and talar tilt test, the absence of ankle injury, pain, and swelling during the last three months (an injury that causes a person to be unable to put his body weight on the affected side and disturbs his performance), a score of <80% in sports activities and <90% in daily activities using the foot and ankle ability measurement (FAAM) (Appendix 1) in measuring the disability levels (the reliability and validity of this questionnaire were 3.13 and 0.97, respectively (intra-class correlation coefficient [ICC]=0.97, standard error of measurement [SEM]=3.13) [11, 23], and the absence of physiotherapy treatment at the time of assessment [23]. The inclusion criterion for the individuals without chronic ankle instability included the absence of an ankle sprain.

The exclusion criteria included feeling any pain and discomfort in the body during the test [23], balance dis-

Table 1. The Mean±SD of the subjects

Variables	Mean±SD		P
	Without Chronic Ankle Instability	With Chronic Ankle Instability	
Age (y)	21.69±2.86	21.76±2.48	0.258
Height (cm)	191.07±4.09	190.15±3.60	0.607
Weight (kg)	81.92±6.73	82.33±6.11	0.608

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orders caused by problems other than chronic ankle instability, history of any injury in the lower extremities (except for lateral ankle sprain), participation in an ankle rehabilitation program in the past six months, and reluctance to continue participating in the study. It should be noted that the subjects who did not succeed in performing the tests at the specified times were excluded from the study.

The tools used in this research were the high-tech scale (model: HI-721, Canada) with a measurement accuracy of 0.001 kg, a tape measure for height measurement, an 8-channel wireless electromyography device (Biometric, England) (Figure 1), a personal information questionnaire, and the FAAM questionnaire.

The data were collected in four parts, system setup, subject preparation, test execution, and data processing.

System setup: To register the muscle electrical activity, an eight-channel biometric electromyography device was used. The electrodes were connected to the selected muscles during the jumping and landing phases. The sampling frequency in this system was chosen at 1000 Hz based on our pilot study.

Subject preparation: Before the test, we explained the purpose of the study and the test procedure to the subjects. In addition, they were allowed to withdraw from the study at any moment and for any reason. After grouping the subjects, it was explained to them that the test would have two stages (with and without taping). In the first stage, the hair at the electrode placement site is shaved to install the electrodes on the skin. Then, the electrode placement site is cleaned using alcohol. The surface electrodes were installed parallel to the muscle fibers in the desired locations according to the SENIAM[1] protocol (Table 2) using anti-allergic double-sided nano-adhesives. To reduce the noise or unwanted signals caused by the electrode movement, the electrodes were fixed using a non-woven adhesive bandage. In this study, the surface electromyography activity of the gluteus medius, lateral gastrocnemius, tibialis anterior, peroneus longus, rectus femoris, and vastus lateralis of the non-dominant limb in the healthy group (left leg) and the group with functional instability of the left ankle was recorded and studied in single-leg landings following a volleyball spike.

In the second stage, the test was performed with taping. The taping procedure was done by a trained and experienced physiotherapist [24]. For taping, the foot of each subject was put in a relaxed position as he sat on the taping table with his ankle in a slight plantar flexion. Stretched almost to 115-120% of its maximum length, the first strip of tape was put on the anterior midfoot and attached right below the anterior tibial tuberosity over the tibialis anterior muscle. The second strip of tape was placed right above the medial malleolus, wrapped around the heel like a stirrup, and attached just lateral to the first strip of tape. The third strip of tape extended across the anterior ankle and covered the lateral and medial malleolus. Lastly, the fourth strip of tape began at the arch and extended slightly 4-6 inches above the lateral and medial malleolus (Figure 2). The first three layers were placed with a tension of 75% and the last layer was placed with a tension of 50%. In the end, to activate its adhesive properties, the Kinesio tape (SPORT & THERAPY Sports tape) strip was rubbed by hand for two minutes.

1. Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM)

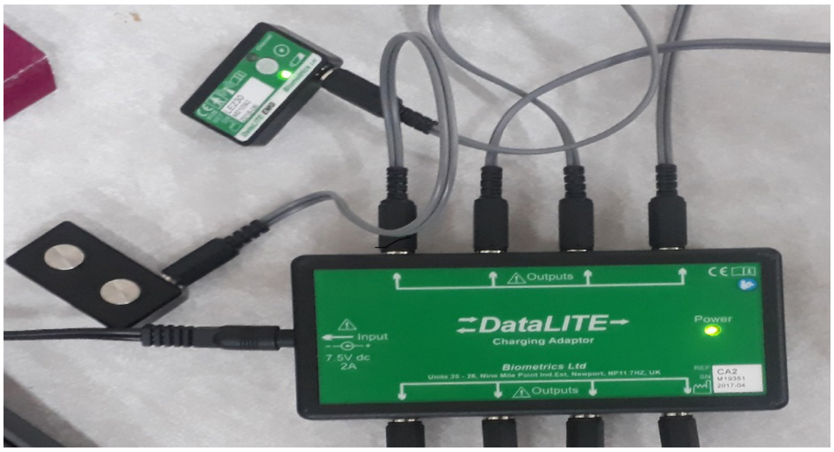

Figure 1. The biometric electromyography and the electrodes used in the present study

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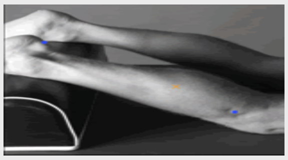
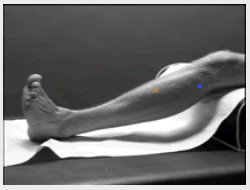
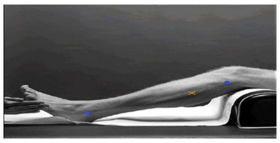
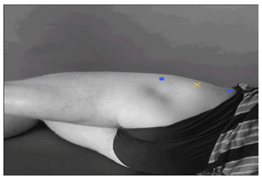
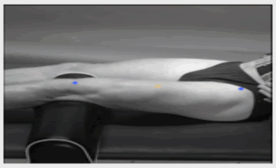
Table 2. Placing electrodes in selected muscles (The location of the electrode is marked with a yellow cross in the pictures)

	Gastrocnemius muscle (lateral) Main action: Ankle plantarflexion and helping flexion in the knee joint Electrode location: The upper 3rd of the line connecting the heel to the head of the fibula bone Distance of electrodes from each other: 20 mm		Tibialis anterior muscle Main action: Dorsiflexion Electrode location: The upper third of the line connecting the inner ankle to the head of the fibula bone Distance of electrodes from each other: 20 mm
	Peroneus longus muscle Main action: Plantar flexion and eversion Electrode location: 25% of the line connecting the head of the fibula to the external ankle Distance of electrodes from each other: 20 mm		Gluteus medius muscle Main action: Hip abduction Electrode location: 50% of the line connecting the spinal cord to the greater trochanter Distance of electrodes from each other: 20 mm
	Quadriceps femoris muscle (vastus lateralis) Main action: Knee extension Electrode location: Two-thirds of the line connecting the front part of the upper spine to the outer edge of the patella bone Distance of electrodes from each other: 20 mm		Quadriceps femoris muscle (rectus femoris) Main action: Knee extension and hip flexion Electrode location: 50% of the line connecting the front part of the upper spine to the upper edge of the patella. Distance of electrodes from each other: 20 mm

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Data collection: In both stages, the participants were tested individually and they did not see the performance of the other participants. The warm-up consisted of 15 minutes of shoulder and lower extremity exercises. The participants became familiar with the test environment and the method of procedure by performing two single-leg landings following a volleyball spike.

The subjects performed all the jumps and landings while hitting the ball held by the trainer at one point.

Data processing: In the first step, to guarantee the accuracy of the data, the examiner stood behind the system and his colleague stood behind the subject. If a problem occurred during the test (such as the separation of the electrodes from the skin or inappropriate landing), the test would be repeated. The accuracy of the data was checked by plotting and visualizing them in MATLAB software (2014a). In the second step (filtering), a fourth-order band-pass Butterworth filter with a cut-off frequency of 10-500 Hz was employed. In the third step

Figure 2. The applied kinesio tape strips the numbers indicate the order of application.

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(data normalization), the EMG data were normalized to the average of the EMG signal in dynamic activity [25]. After recording the data from the software of the electromyography device, they were entered into the custom-written MATLAB (2014a) Script software (MathWorks, Massachusetts, USA 2014a). Then, data processing was carried out. Finally, the data were analyzed. At this stage, the electromyographic data were calculated by the second root of the mean square in 50-millisecond windows. Then, the electromyographic activity of each muscle in the feedforward phase was calculated. The feedforward phase was considered within the 200 millisecond time range (160 and 40 milliseconds before and after ground contact, respectively) [26].

In the statistical analysis, the Mean±SD, and variance were utilized for data description. Moreover, to assess data distribution normality, the Shapiro-Wilk test was employed. The MANOVA[2] test was used to compare the effect of taping.

3. Results

The descriptive information of the variables of the current research demonstrated that except for the maximum Root Mean Square (RMS) of the gluteus medius of both groups and the maximum RMS of the peroneus longus of the healthy group, both groups had a higher mean RMS in all variables in the feedforward phase before taping. Similarly, except for the mean RMS of the gluteus medius in the group with ankle instability and the peroneus longus in the healthy group, all the variables in both groups had a higher mean before taping (Figures 4 and 5).

2. Multivariate Analysis of Variance

The Lambda test results in the multivariate analysis of variance indicated that the groups (with ankle instability and without ankle instability) did not have a significant factor in the maximum and mean RMS of the muscles in the feedforward phase (Table 3).

The descriptive information of the variables of the current research demonstrated that except for the maximum RMS of the tibialis anterior, gluteus medius, gastrocnemius, and peroneus and the mean RMS of the peroneus, tibialis anterior, and gastrocnemius in other variables, the mean difference in the group with ankle instability was lower than that in the healthy group. The results of the MANOVA test revealed that the groups (with ankle instability and without ankle instability) had no significant factors in the maximum and mean RMS of the muscles in the feedforward phase (P>0.05) except for the maximum RMS of the peroneus longus muscle (P=0.01) (Table 4).

4. Discussion

The current research was conducted to evaluate the effects of using and not using taping on the feedforward activity of the rectus femoris, tibialis anterior, peroneus longus, gluteus medius, lateral gastrocnemius, and vastus lateralis of the non-dominant extremity during single-leg jump-landing in professional volleyball players with and without chronic ankle instability. The results demonstrated that, except for the maximum RMS of the gluteus medius of both groups and the maximum RMS

Figure 3. Approaching for the spike, hitting the ball, and landing

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Table 3. The lambda test results in the multivariate analysis of variance

Group	Value	F	Sig	Effect size
Wilks Lambda	0.34	1.92	0.14	0.66

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Table 4. The results of the multivariate analysis of variance (MANOVA) test showing the effect of the groups (with ankle instability and without ankle instability) on the maximum and mean root mean square (RMS) of the muscles in the feedforward phase

Phase	Variables	Group	Mean±SD	d_f	F	P	Effect Size
Maximum RMS of the muscle in the feedforward phase (%)	Rectus femoris	With	-0.92±-6.12	1.00	0.02	0.88	0.00
		Without	-1.22±-3.91				
	Gluteus medius	With	1.74±-3.47	1.00	0.19	0.67	0.01
		Without	1.00±4.85				
	Vastus lateralis	With	-1.30±-3.47	1.00	1.36	0.26	0.06
		Without	-3.09±-4.14				
	Gastrocnemius	With	-2.19±-4.12	1.00	0.79	0.38	0.03
		Without	-0.43±-5.59				
	Tibialis anterior	With	-2.54±-5.78	1.00	1.73	0.20	0.07
		Without	0.00±3.75				
	Peroneus longus	With	-4.39±-4.49	1.00	7.13	0.01	0.24
		Without	1.25±5.91				
Mean RMS of the muscle in the feedforward phase (%)	Rectus femoris	With	-0.03±-2.83	1.00	0.31	0.59	0.01
		Without	-0.66±-2.83				
	Gluteus medius	With	0.31±1.76	1.00	0.38	0.54	0.02
		Without	-0.38±-3.48				
	Vastus lateralis	With	-1.35±-2.01	1.00	0.18	0.68	0.01
		Without	-1.64±-1.38				
	Gastrocnemius	With	-2.16±-2.11	1.00	2.50	0.13	0.10
		Without	-0.64±-2.64				
	Tibialis anterior	With	-1.02±-2.17	1.00	0.57	0.46	0.02
		Without	-0.20±-3.12				
	Peroneus longus	With	-1.82±-3.03	1.00	2.68	0.12	0.10
		Without	0.02±2.5				

RMS: Root mean square.

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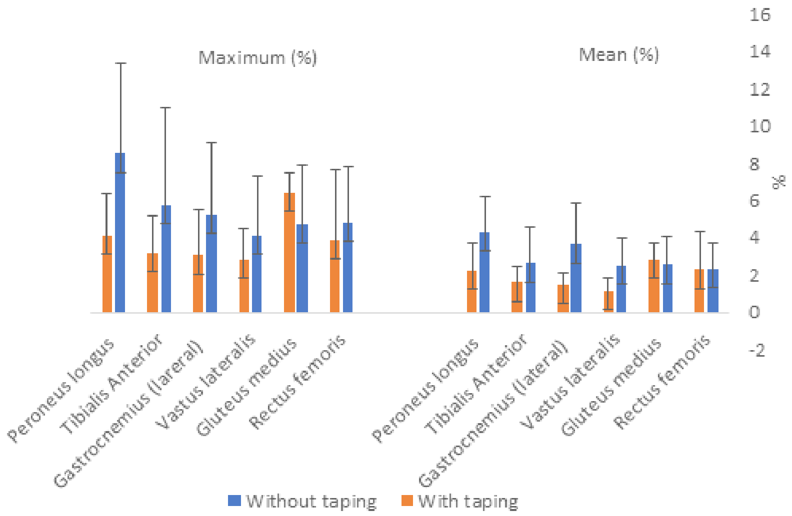

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Figure 4. The descriptive information in the feedforward phase about the function of the lower limb muscles with and without taping during single-leg landing in the ankle instability group

of the peroneus longus of the healthy group, both groups had a higher mean RMS in all variables in the feedforward phase. Similarly, both groups had a higher mean in all variables before taping, except for the mean RMS of the gluteus medius in the ankle instability group and the peroneus longus in the healthy group. Furthermore, the results of the MANOVA test showed that the groups (with ankle instability and without ankle instability) had no significant factors in the maximum and mean RMS of muscles in the feedforward phase (P>0.05) except for the maximum RMS of the peroneus longus muscle (P=0.01).

Steib et al. found that ankle sprains lead to changes in muscle strength, balance, and proprioception [27]. The peroneus longus is the first muscle to contract in reaction to sudden ankle inversion and plays a remarkable role in controlling dynamic ankle stability [28]. The tibialis anterior muscle, which acts as a dorsiflexor and invertor, also has a significant role in ankle stability. The activity of the peroneus longus and tibialis anterior muscles may be disturbed in athletes with chronic ankle instability. This disturbance may prevent an insufficient ankle inversion in the initial stages of landing, creating a higher inversion angular velocity in the descending phase [28].

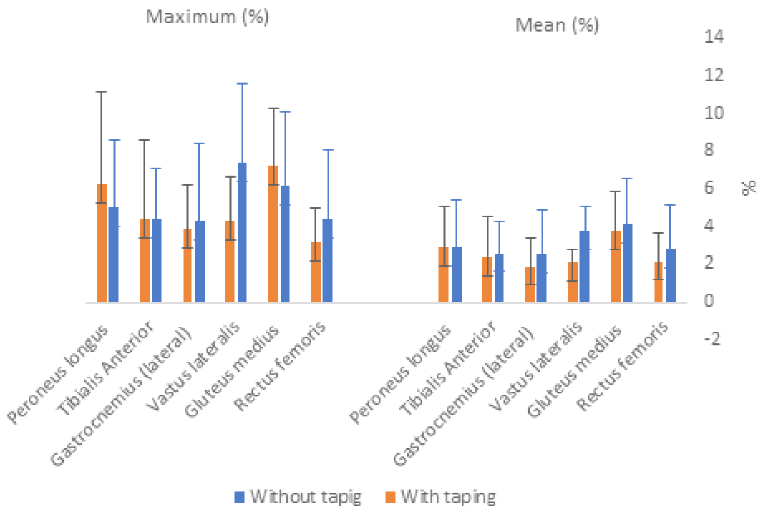

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Figure 5. The descriptive information in the feedforward phase about the function of the lower limb muscles with and without taping during single-leg landing in the healthy group

Soda and Sacco reported that the longus peroneus muscle in people with functional ankle instability had lower and higher levels of activity in the pre-landing and post-landing phases, respectively.

During a sideward lateral cutting movement, the peroneus longus and lateral gastrocnemius muscles are simultaneously activated and before the tibialis anterior muscle in healthy people. However, these three muscles are activated simultaneously in individuals with functional ankle instability [29]. The activation of the peroneus longus muscle prevents ankle sprains by increasing the stability, torque, and speed of the subtalar joint. Therefore, this muscle protects the joint against incoming forces and subsequent rotations [30]. Tashman et al. claimed that the stability of the frontal plane of the lower extremity strongly affects the landing phase [31]. This is due to the pre-stretching of the gluteus medius muscle in the initial phase which helps the hip joints to perform abduction during the landing phase and compensates for the shock and instability due to using one leg to support the body [31].

It was previously assumed that Kinesio taping increases muscle activity during exercise [32]. It was believed that similar to other taping techniques, Kinesio taping increases the stimulation of cutaneous mechanoreceptors which in turn increases motor activity and contributes to a stronger and faster activation of the muscles. These assumptions are not consistent with the present study.

The reduction in muscle activity may be due to several mechanisms. The stimulation of cutaneous mechanoreceptors helps increase the activity of the gamma motor neuron and subsequently increases the sensitivity of the muscle spindle [33]. The study of Yamashiro et al. (2011) showed that the repeated use of Kinesio tape in ankle balance taping during two months increased the range of motion of the ankle [34].

Landing requires whole body coordination because the motion control system must properly coordinate the muscles acting on different joints. Pre-landing muscle responses are responsible for acceleration control during voluntary landing [35]. Feedforward control and muscle timing are vital in controlling the lower extremity stiffness at the moment the foot makes contact with the ground [36]. The start time and duration of muscle activity before the foot contacts the ground are key variables that ensure the appropriate level of muscle force created during ground contact [37]. Therefore, any delay in muscle activity and stiffness can cause extra movements in the knee and ankle, leading to injury [38]. The reduction of muscle activity before ground contact (feedforward activity) can be ascribed to the changes in the pre-designed programs that are sent from the central nervous system to the muscles [39]. Before the foot makes contact with the ground in the landing phase, the lower extremity muscles are activated to absorb the applied forces during contact [39]. The results of the study of Samadi et al. showed that the pre-activity of the plantar, tibialis anterior, and peroneus longus muscles started earlier in the intervention group compared to the control group. It should be noted that the activity of the muscles (especially the peroneus longus) increases the stability of the subtalar joint during landing and before foot contact with the ground.

The peroneus muscles are the main ankle eversions. It is thought that the reaction time of these muscles and the magnitude of their response have a remarkable role in preventing the inversion torques of the ankle on the ground and producing an eversion torque [14]. A significant reduction in the activity of the peroneus longus muscle and a significant increase in ankle inversion before the contact of the foot with the ground have been observed in people with functional ankle instability compared with healthy people [17]. Researchers have emphasized the role of the peroneal muscles in preventing possible ankle inversion torque during landing [17, 40, 41]. It has also been stated that the plantar flexors also play a crucial role in preventing ankle sprains by using a proper extension torque to reduce the downward acceleration of the body during landing. Hong et al. [42] reported the EMG activation of shank muscles before and after using Kinesio tape. Nonetheless, they designed a specific taping technique in their study to support the gastrocnemius and soleus muscles. Rather than stabilizing the joint, their purpose was to determine its effect on the performance criterion (vertical jump height).

The reduction of muscle activity in the present research may be due to the mechanical characteristics of the Kinesio tape which has been recommended as a method to improve the motion range of the joint. It has been reported that the technique employed in the present research increases the stiffness without changing the full movement of the joint [43]. Thus, the nervous system may sense the enhanced mechanical support at the joint and later adapt muscle activation. This explains the reduced need for dynamic restraints. The landing forces are expected to increase with less muscle activation [20]. The correlation between ground reaction forces and muscle activation is unclear. It should be noted that the tape was applied only across the ankle joint and the hip and knee joints were not taped. It has been observed that traditional ankle taping changes the movement patterns in the knee and hip joints [44]. This may not be the case with the more flexible Kinesio tape. The kinetic and kinematic analyses to calculate the forces in the knee, ankle, and hip joints help to clarify the role of taping in absorbing force in the lower extremities.

5. Conclusion

The findings of the current research revealed that taping can reduce the maximum RMS of the peroneus longus muscle activity in people with chronic ankle instability performing single-leg landing. In addition, the results demonstrated a reduction in the activity of all studied muscles except for the gluteus medius muscle. The increased feedforward activity of this muscle can be the reason for compensatory movements in the hip joint in people with chronic ankle instability. Therefore, it is advisable to use other methods and exercises to improve the feedforward activity of the selected muscles in these people in the rehabilitation and exercise phases. It is also recommended to investigate the synergies of these muscles in future studies.

Ethical Considerations

Compliance with ethical guidelines

The ethical principles observed in the article, such as the informed consent of the participants, the confidentiality of information, the permission of the participants to cancel their participation in the research. Ethical approval was obtained from the Research Ethics Committee of the Research Institute of Movement Sience Research Center (Code: IR-KHU.KRC.1000.154).

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Authors' contributions

Conceptualization and supervision: Heydar Sadeghi; Methodology, investigation, writing original draft, and writing, review & editing, data analysis: Farzam Farzami; Heydar SadeghiI; Data collection: Amin Farzami; Review: Ali Fatahi.

Conflict of interest

The authors declared no conflict of interest.

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