Title: The Effect of Neuromuscular and Traditional Training on Load Rating and Free Torque of 15–18-Year-Old Girls with a History of Ankle Ligament Sprain

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Abstract

Introduction: This study seeks to examine how neuromuscular training, in contrast to standard exercise routines, influences load perception and free torque among adolescent girls aged 15 to 18 with a history of ankle ligament sprains—an aspect that has not yet been thoroughly explored in prior research.

Method: This investigation adopted an applied, semi-experimental approach using a pre-test–post-test framework. Participants were divided into three groups: two experimental groups—one receiving neuromuscular training and the other traditional training—and a control group. The statistical sample of this research included 45 people (15 people in each group) with an age range of 15 to 18 years. A force plate was used to evaluate the load rating and free torque of while walking. To analyze the data, two-way analysis of variance and Bonferroni post hoc tests were performed at a significance level of $p \leq 0.05$.

Results: Evaluation over the six-week period indicated that the loading rate improved to a lesser extent in the group receiving conventional training relative to the group performing neuromuscular training ($P = 0.030$; $d = 0.148$).

Conclusion: The present results indicate that, relative to conventional exercise approaches, neuromuscular training yields more pronounced gains in both loading rate and free torque. Based on these outcomes, the inclusion of neuromuscular training protocols in the rehabilitation and conditioning plans of individuals with lateral ankle ligament injuries or chronic ankle instability is recommended, as such programs may enhance functional recovery and clinical results**.**

Keywords: Neuromuscular training, Biomechanics, Ankle ligament injury, Ankle sprain.

Highlights:

- Neuromuscular training demonstrates greater effectiveness than conventional training in enhancing loading rate.
- Neuromuscular training shows superior benefits over traditional methods in increasing free torque
- Neuromuscular training is essential for rehabilitation after lateral ankle injuries.

Plain Language Summary:

This study looked at how neuromuscular and traditional training affect girls aged 15–18 with ankle sprain history. The results show that neuromuscular training is better than traditional training for improving loading rate and free torque. Since these factors depend on muscle performance, we will also examine how training affects muscle activity. The findings suggest that neuromuscular training is more effective overall. Therefore, trainers and rehab professionals should use neuromuscular training during recovery from ankle injuries and for those with ongoing sprains to improve results.

Introduction

Ankle sprains are among the most common musculoskeletal injuries encountered in sports [1]. Following an initial sprain, persistent symptoms are frequently reported, with joint instability and recurrent "giving-way" episodes being the two most prevalent [2]. Such issues considerably elevate the risk of reinjury within the next 12–24 months. In 20–50% of cases, this reinjury progresses to chronic pain or lasting instability, which in turn imposes high healthcare expenditures, increases work absenteeism, and diminishes participation in athletic and physical activities [3]. Consequently, effective prevention of ankle sprains is essential not only for protecting individual athletes but also for reducing the broader social and economic burden.

A variety of preventive strategies have been introduced to either forestall initial ankle sprains (primary prevention), decrease the chance of subsequent sprains (secondary prevention), or address both simultaneously [4, 5]. Such strategies may include external supports—like ankle braces, taping, and bandaging—along with modified footwear or orthotics, neuromuscular and other exercise-based programs, or integrated combinations of these approaches [6, 7].

Neuromuscular training—often referred to as balance or proprioceptive training—generally involves exercises performed on ankle discs, balance platforms, or wobble boards [8]. This form of training enhances mechanoreceptor responsiveness and improves neuromuscular coordination, allowing the central nervous system to activate motor neurons in a more precise and synchronized way, thereby heightening joint position sense [9]. During stance tasks, it also promotes more accurate transmission of sensory input from joint receptors to the central nervous system, which contributes to improved postural control and stability [10]. Evidence from review studies has consistently shown that neuromuscular training exerts beneficial effects on balance and motor performance [11, 12].

Load rating denotes the level of mechanical stress or workload that an athlete can safely tolerate during training and competition [13]. A clear understanding of this threshold enables coaches and trainers to design programs that prevent excessive strain on muscles, joints, and tendons, thereby reducing the likelihood of injuries such as sprains and strains [14]. When athletes train within their optimal load rating, they can improve strength, endurance, and technical skills without increasing injury risk [15].

Free torque describes the rotational force that muscles and joints are capable of producing without jeopardizing stability or causing tissue damage. Appropriate regulation of this parameter helps preserve joint stability during dynamic activities, lowering the probability of dislocations or ligament injuries [16]. By learning to generate and control free torque effectively, athletes can maintain correct technique—a key factor in injury prevention during high-intensity movements.

In essence, both load rating and free torque are critical in reducing injury risk while enhancing athletic performance [17]. Careful management of these variables allows athletes to fine-tune their training, expand physical capacity, and minimize injuries in competitive contexts [18].

Currently, only limited data exist on how such exercises affect load rating and free torque. Furthermore, the specific mechanisms by which neuromuscular training alters these parameters—especially in comparison with other exercise modalities—remain poorly understood. It is still unclear whether neuromuscular training confers distinct advantages over alternative methods for improving these outcomes or whether no substantive differences occur. Moreover, little research has directly examined the comparative impact of neuromuscular and conventional training on load rating and free torque in adolescent girls aged 15–18 with ankle ligament sprains. Addressing this knowledge gap forms the basis of the present investigation, which seeks to clarify these factors in the context of rehabilitation and performance enhancement for this population. By exploring these effects, the study aims to generate practical recommendations to inform training and rehabilitation programs for young athletes recovering from ankle injuries.

Materials and Methods

Participants

This semi-experimental study employed an applied research approach, utilizing both neuromuscular and traditional exercise interventions. Participants were randomly selected from the target population to ensure unbiased representation. The study followed a pre-test and post-test design across three groups: two experimental groups—one receiving neuromuscular training and the other engaging in traditional exercises—and a control group. The study protocol was affirmed at Research Ethics Committees of Islamic Azad University- Sari Branch (IR.IAU.SARI.REC.1404.273).

All groups underwent assessments before and after the intervention period. The study population consisted of girls aged 15 to 18 years with a history of ankle sprains. Sample size determination relied on data from previous similar studies [19] and calculations performed with G*Power software. Using a confidence level of 95%, statistical power of 80%, and an estimated effect size of 0.5, the required number of participants for each group was calculated. Accounting for a possible 10% dropout, the final sample included 15 participants per group, totaling 45 individuals. The effect size used in this estimation was based on balance-related measures.

Participants were assigned to groups using computer-generated block randomization, ensuring equal distribution and minimizing potential biases. The allocation process was conducted by a research team member who remained blinded to participants' identities, preventing any influence on group assignment.

Randomization:

Participants were allocated to groups using a computer-generated block randomization method, designed to keep group sizes consistent throughout the study. This procedure reduces the risk of selection bias and ensures a balanced distribution across groups. The assignment was carried out by a research team member who was blinded to participant identities and had no role in recruitment or data collection, guaranteeing an unbiased allocation process.

Inclusion Criteria

Participants qualified for the study if they met all of the following conditions:

- Female
- Aged between 15 and 18 years
- No history of cardiovascular or neuromuscular disorders
- Not participating in high-intensity physical activities during the study period
- Free from postural abnormalities in the upper or lower limbs that could influence the study outcomes

Exclusion Criteria:

Participants were excluded from the study if they met any of the following conditions:

- Missing two consecutive or three non-consecutive training sessions
- Experiencing musculoskeletal pain caused by the exercises
- Using neurological medications that could influence function
- Having a history of upper or lower limb injuries within the past six months
- Diagnosed with muscular or neurological disorders (e.g., myopathy, myositis, peripheral neuropathy, muscular dystrophy)
- Undergoing surgery or sustaining a fracture within the year prior to the study

Procedure

Before securing consent and confirming the agreement of the subjects, the researcher thoroughly explained the following aspects: purpose of the study, research methodology confidentiality of collected information. After selecting the participants, a consent form was provided to those willing to take part in the research. Only individuals who agreed proceeded into the study. Following the random assignment of participants to the different study groups, they were required to fill out several forms, including: personal characteristics questionnaire, general health survey, health assessment questionnaire.

Participants in the experimental groups were instructed to refrain from engaging in any other exercise programs aside from their assigned regimen. They were also advised not to introduce any new medications into their daily routines. The experimental groups—one focusing on the neuromuscular training and the other on the traditional exercises —followed their designated exercise programs for a duration of 6 weeks. Each group participated in three sessions per week, with each session lasting between 45 to 60 minutes. Following the intervention, the same assessments conducted during the pre-test were repeated in the post-test, adhering to the same timing and sequence.

Measurement

Measurement

Participants' height was measured with a wall-mounted stadiometer (Seca 222, Terre Haute, IN) and recorded to the nearest 0.5 cm. Body mass was determined using a digital scale (Tanita, BC-418MA, Tokyo, Japan) with an accuracy of 0.1 kg [20].

Load rating and free torque were assessed using a Kistler force plate (model BA 9286, Switzerland) at a sampling rate of 1000 Hz. The device showed high intra-rater reliability, ranging from 0.93 to 0.97, and inter-rater reliability of 0.73 [21].

Data Acquisition and Analysis

Each participant completed three trials, and the mean values were used for subsequent analysis. Data processing and analysis were performed using MATLAB software. The evaluation of load rating and free torque followed a systematic procedure, including setting up the force plate and torque sensor, connecting them to the data acquisition system, and methodically collecting, processing, and analyzing the signals to extract the desired parameters.

In MATLAB, a data acquisition object was configured to include the relevant channels for both the force plate and torque sensor. The sampling rate and recording duration were set, and data collection was initiated to capture voltage signals from the sensors. These raw voltage signals were then converted into meaningful units—Newtons for load rating and Newton-meters for torque—using established calibration coefficients. Peak and average values were calculated for both load rating and free torque throughout the measurement period. The results were visualized with MATLAB's plotting functions to illustrate load and torque over time.

To minimize measurement noise, all signals were filtered using a 20th-order low-pass Butterworth filter. The force plate and torque sensor demonstrated high intra-rater reliability (0.93–0.97) and acceptable inter-rater reliability (0.73), ensuring consistent and reproducible measurements [22].

Intervention

Participants underwent a 6-week progressive dynamic neuromuscular training program, which included exercises targeting postural stability, strength, plyometrics, and speed/agility (see Table 1). Currently, research addressing ankle sprain rehabilitation through a comprehensive, impairment-based classification system is limited. To account for the multifactorial nature of ankle sprains, a multi-component program was implemented.

The exercises were structured to progress from simple to more complex tasks, drawing from previously published rehabilitation protocols to remain consistent with contemporary best practices while addressing the specific functional needs of each participant. Given the dynamic demands of athletic activities and the common feelings of instability during high-speed movements, incorporating speed and agility training into the program was considered essential (Table 1) [23].

Table 1: 6-Week Neuromuscular training Program						
Week	**1**	**2**	**3**	**4**	**5**	**6**
Postural Stability	Single leg stance on Airex® cushion: (3 minutes)	Single leg stance on tilt board: (3 minutes)	Single leg stance on BOSU® ball: (3 minutes)	Single leg stance on BOSU® ball with rebounding ball catches: (3 minutes)	Anterior jump lands from Reebox® step: (2 sets × 10 reps with 10 second stabilization)	Lateral jump lands from Reebox® step: (2 sets × 10 reps with 10 second stabilization)
Strength	Double leg heel raises: (3 sets × 12 reps)	Double leg bridge: (2 sets × 10 reps)	Clam-shell gluteus medius: (2 sets × 10 reps - each side)	Double leg heel raises: (3 sets × 12 reps)	Double leg bridge: (2 sets × 10 reps)	Clam-shell gluteus medius: (2 sets × 10 reps - each side)
	Single leg heel raises: (2 sets × 10 reps - each side)	Single leg bridge: (3 sets × 12 reps - each side)	Figure-4 gluteus medius: (2 sets × 10 reps - each side)	Single leg heel raises: (2 sets × 10 reps - each side)	Single leg bridge: (3 sets × 12 reps - each side)	Figure-4 gluteus medius: (2 sets × 10 reps - each side)
	Single leg heel raises with weight (15 kg): (3 sets × 12 reps - each side)	Double leg squats: (3 sets × 12 reps)	Resisted lateral side-steps: (3 sets × 12 reps/step - each side)	Single leg heel raises with weight (20 kg): (3 sets × 12 reps - each side)	Single leg squats: (3 sets × 10 reps - each side)	Resisted lateral side-steps: (3 sets × 12 reps/step - each side)
Plyometrics	Tuck jump: (3 sets × 10 reps)	Broad jumps: (3 sets × 10 reps)	180° tuck jumps: (3 sets × 5 reps in each direction)	90° hop turns: (10 reps - clockwise and anti-clockwise)	Double leg lateral jumps over mini-hurdle: (3 sets × 10 reps)	Single leg lateral jumps over mini-hurdle: (3 sets × 10 reps)
Speed/Agility	Figure of 8 runs: (10 m course, 5 reps in each direction)	Ladder: forward run through: (10 reps)	Ladder: lateral run through: (10 reps - each way)	Ladder: lateral hop through: (10 reps - each way)	Ladder: hopping slalom drill: (10 reps)	Lateral shuttle runs: (10 m course, 2 sets × 10 reps)

Traditional Training Program

The 6-week traditional training program for ankle sprains was designed to support recovery, restore function, and strengthen the ankle joint. The program began with gentle mobility and flexibility exercises during the first week, focusing on pain-free range of motion to relieve stiffness.

As participants progressed, strengthening exercises using resistance bands and body weight were introduced to enhance muscular support around the ankle. By the fourth week, balance and stability exercises were incorporated to improve proprioception and reduce the risk of reinjury.

In the final weeks, functional movements and agility drills were emphasized, gradually preparing participants for a safe return to their usual activities or sports. This structured program provides a comprehensive approach to rehabilitation while addressing the specific needs of individuals experiencing ankle instability (Table 2) [24].

Table 2. 6-Week traditional training

Week	Goals	Exercises
1	Initial Recovery and Mobility	- **Ankle Pumps:** 3 sets of 10 reps - **Towel Stretch:** Hold for 15-30 seconds, 3 times - **Gentle Range of Motion:** Flexion and extension (3 sets of 10) - **Isometric Exercises:** - Dorsiflexion: Press foot against a wall, hold for 5 seconds, 10 reps - Plantarflexion: Press foot against a wall, hold for 5 seconds, 10 reps
2	Increase Range of Motion	- **Heel Slides:** 3 sets of 10 reps - **Alphabet Writing:** Write the alphabet with toes, 1 session - **Towel Stretch:** Hold for 15-30 seconds, 3 times - **Resistance Band Dorsiflexion:** 3 sets of 10 reps
3	Strengthening	- **Heel Raises:** 3 sets of 10-15 reps - **Toe Raises:** 3 sets of 10-15 reps - **Resistance Band Plantarflexion:** 3 sets of 10 reps - **Resistance Band Eversion:** 3 sets of 10 reps
4	Enhanced Strength and Stability	- **Single-Leg Balance:** Hold for 30 seconds, 3 sets (progress to eyes open) - **Lateral Step-Ups:** 3 sets of 10 reps each leg - **Heel-to-Toe Walk:** 3 sets of 10 steps - **Wall Squats:** Hold for 15-30 seconds, 3 sets
5	Functional Movement	- **Forward Lunges:** 3 sets of 10 reps - **Side Lunges:** 3 sets of 10 reps - **Balance Board Exercises:** 5 minutes of various movements - **Step-Ups:** 3 sets of 10 reps each leg
6	Return to Activity	- **Agility Exercises:** Light cone drills (5-10 minutes) - **Continuous Heel Raises:** 3 sets of 15 reps - **Single-Leg Heel Raises:** 3 sets of 10 reps each leg

Statistical analysis

The normality of all data, both before and after the interventions, was assessed using the Shapiro–Wilk test. Data are presented as means ± standard deviations (SDs). A two-way repeated-measures analysis of variance (ANOVA) was conducted, with factors for group (2 levels) and time (pre- and post-intervention), using SPSS software (version 21.0 for Windows, SPSS Inc., Chicago, IL, USA) to evaluate changes in measured parameters.

When a significant F value was detected, Bonferroni post hoc tests were applied to determine specific differences between measures. Effect sizes were calculated using Cohen's d to quantify the impact of the training programs. Thresholds for interpreting effect sizes were defined as follows: <0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, 2.0–4.0 = very large, >4.0 = perfect. All effect sizes are reported with 95% confidence intervals (CIs). Statistical significance was set at $p \leq 0.05$, and the study maintained a statistical power of 0.80 ($1 - \beta$).

Results

The means and standard deviations of the participants' demographic characteristics, including age, height, and weight, are presented in Table 3. Analysis revealed no significant differences between the two groups in any of these demographic measures ($P > 0.05$) (Table 3).

Table 3: Demographic Characteristics of Participants (Mean and Standard Deviation)

Parameters	Muscular Training Group	Traditional Training Group	Control Group	Significance Level
Height (cm)	164.00 ± 5.42	163.35 ± 5.03	162.98 ± 4.23	0.729
Weight (kg)	61.86 ± 14.35	57.88 ± 9.94	58.12 ± 7.11	0.364
Age (years)	16.33 ± 0.48	16.47 ± 0.51	16.14 ± 1.05	0.447

***** The significance level was set at $p > 0.05$.

The results indicated that there were no significant differences in any of the loading rate or free torque components during walking between the pre-test and post-test measurements for either the neuromuscular or traditional training groups among girls aged 15–18 with ankle sprains (Table 4).

Table 4: Comparison of Pre-Test Values Between the Two Groups for Loading Rate and Free Torque Components During Walking

Variables	Non-Neuromuscular Training Group	Traditional Training Group	Control Group	Significance Level
Loading Rate	11.10 ± 1.09	10.22 ± 2.14	162.98 ± 4.23	0.165
Negative Free Torque	-0.45 ± 0.15	-0.40 ± 0.15	58.12 ± 7.11	0.351
Positive Free Torque	0.48 ± 0.18	0.49 ± 0.19	16.14 ± 1.05	0.961

***** The significance level was set at $p > 0.05$.

The results following the 6-week training program showed that the group effect on the loading rate was smaller in the traditional training group compared to the neuromuscular training group (P = 0.30; d = 0.148) (Table 4). Significant interaction effects between time and group (time × group) indicate that changes in load rating and free torque are not solely due to the passage of time but are also influenced by the specific type of training each group underwent.

This finding suggests that the pattern and magnitude of adaptation differ between neuromuscular and traditional training over the study period. In other words, the effectiveness of each exercise protocol depends on the timing of measurements, reflecting that improvements in these biomechanical variables occur at different rates across interventions. These time-dependent differences emphasize the need to consider both the training method and the temporal dynamics of adaptation when assessing rehabilitation or performance-enhancing programs.

Table 5: Effects of Time, Group, and Time × Group Interaction on Loading Rate and Free Torque During Walking

Variables	Neuromuscular Training		Traditional Training		Control Group		Significance Level		
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test	Time	Group	Time*Group
Loading Rate	11.10 ± 1.09	11.08 ± 0.05	10.22 ± 2.14	9.56 ± 2.36	11.56 ± 1.98	10.98 ± 1.16	0.365 (0.027)	0.030* (0.14)	0.385 (0.02)
Negative Free Torque	-0.45 ± 0.15	-0.52 ± 0.17	-0.40 ± 0.15	-0.41 ± 0.22	-0.39 ± 0.14	-0.38 ± 0.13	0.339 (0.030)	0.120 (0.07)	0.429 (0.021)
Positive Free Torque	0.48 ± 0.18	0.56 ± 0.15	0.49 ± 0.19	0.47 ± 0.17	0.47 ± 0.20	0.48 ± 0.11	0.424 (0.021)	0.405 (0.03)	0.271 (0.040)

***Significance level p>0.05

Discussion

This study explored the effects of neuromuscular versus traditional training on load rating and free torque in girls aged 15–18 with a history of ankle ligament sprains. The results showed that neuromuscular training produced greater improvements in both loading rate and free torque compared with conventional exercise programs.

Given the critical role of muscle function in these biomechanical measures, future research should focus on how different training protocols influence muscle activation patterns. Such investigations could help clarify the mechanisms underlying the observed enhancements in load rating and free torque, providing deeper insights into effective rehabilitation strategies for ankle instability.

The findings of this study are consistent with previous research investigating the effects of neuromuscular and proprioceptive training on muscle activity and overall neuromuscular function. This alignment supports the view that these training methods effectively enhance muscle performance and neuromuscular efficiency [25–28].

For example, Fallahi Farrash, Sheikhhoseini, and Babakhani (29) examined functional training on soft surfaces and reported significant improvements in the responsiveness of proprioceptive receptors in the lower limbs. Similarly, Oliveira and Rezende (30) found that neuromuscular training increases electromyographic activity in lower limb muscles, with greater effects observed when exercises were performed with eyes closed compared to eyes open. Additional studies by Cruz-Diaz and Lomas-Vega (31), Feger and Donovan (32), and De Ridder and Willems (33) also demonstrated that neuromuscular training enhances muscle activity in individuals with a history of ankle sprains.

These findings suggest that incorporating neuromuscular training into rehabilitation programs can be particularly effective for promoting functional recovery after ankle injuries. Such training improves neuromuscular control, allowing for more efficient activation of motor units and muscle fibers during physical tasks. This improvement is associated with increased neural drive to the lower-limb muscles, combined with heightened awareness of muscle positioning, trunk stability, and pelvic alignment, all of which contribute to greater force production [34].

Evidence indicates that the rapid changes in muscle length and tension during the eccentric phase of neuromuscular exercises trigger adaptations in muscle spindles and Golgi tendon organs. This increased spindle sensitivity enhances afferent signaling to the central nervous system [35]. Additionally, the unpredictable nature of these exercises requires anticipatory muscle activation, and repeated exposure further improves the responsiveness of muscle fiber recruitment, thereby enhancing overall muscle function [36].

Neuromuscular training primarily boosts force and power output by improving the efficiency and coordination of the neuromuscular system. A key mechanism involves modulating inhibitory signals that normally limit muscle force. Specifically, such training can reduce the sensitivity of inhibitory receptors that control muscle tension, allowing the muscles to produce greater force with fewer restrictions [37].

Furthermore, neuromuscular coordination is crucial for optimizing force production by influencing the speed and effectiveness of muscle contractions. Improved coordination facilitates more efficient recruitment of motor units and muscle fibers, leading to faster and stronger contractions. Through consistent neuromuscular training, individuals enhance muscle responsiveness and efficiency, ultimately resulting in significant improvements in overall strength and power [38].

Neuromuscular training includes a variety of techniques designed to stimulate peripheral sensory pathways, promote coordinated muscle activation, and enhance both reflexive and anticipatory motor control [39]. Exercises that challenge joint stability—particularly those performed in unbalanced positions—are especially effective for addressing multiple functional demands. With repeated practice and gradual increases in intensity, muscle activity, whether reactive or anticipatory, progressively shifts from conscious control to automatic motor responses [40].

From a motor control perspective, movements are organized around specific goals, with motor programs representing sequences of coordinated actions rather than isolated muscle contractions [41]. In practice, muscles rarely act independently; focusing on a single muscle during an activity may unintentionally draw attention to it. Muscles typically operate in coordinated groups, or synergies, adapting their roles according to the requirements of the task [42]. Therefore, training a single muscle in isolation may not fully prepare it for the diverse demands of real-world activities. This highlights the importance of a holistic training approach that considers the integrated and context-dependent nature of muscle function [43].

Limitations and Future Directions

This study investigated the effects of neuromuscular versus traditional training on load rating and free torque in girls aged 15–18 with a history of ankle ligament sprains. The results indicate that neuromuscular training is more effective than traditional methods in improving these biomechanical variables, which are closely linked to muscle function.

Future research should examine the direct relationship between different training protocols and muscle activity, given its critical role in influencing load rating and free torque. While the findings align with previous studies on neuromuscular training and proprioceptive enhancement, several limitations should be noted. First, the relatively small sample size may limit the generalizability of the results. Second, the study focused exclusively on female participants within a narrow age range, which may not reflect how these interventions affect other populations .Future studies should include larger and more diverse samples to enhance the applicability of the findings across different demographic groups. Additionally, while this study highlights the short-term benefits of neuromuscular training, it does not provide information on its long-term effects on muscle performance or injury prevention. Investigating the sustained impact of neuromuscular training beyond the rehabilitation period could provide valuable insights into its effectiveness in reducing the risk of future ankle sprains.

Conclusion

The findings of this study indicate that neuromuscular training is more effective than traditional exercise in enhancing load rating and free torque. Based on these results, it is recommended that coaches and rehabilitation specialists include neuromuscular training in recovery programs for individuals with lateral ankle ligament injuries or chronic ankle sprains. Incorporating this approach can improve both clinical outcomes and functional performance, supporting a more effective and comprehensive rehabilitation process

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Authors' Contributions

All authors contributed equally to the conception, design, and preparation of this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest related to this study.

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