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ORIGINAL RESEARCH

Comparative effectiveness of neutral and plantarflexion position training in male adolescent soccer players with lateral ankle sprain

Xiangxiang Dou[1], Yonghwan Kim[2], Munku Song[3,*]

[1]Public Subject Teaching Department, Shangqiu Medical College, 476000 Shangqiu, Henan, China
[2]Department of Physical Education, Gangneung-Wonju National University, 25457 Gangneung, Republic of Korea
[3]College of Sport Science, Sungkyunkwan University, 16419 Suwon, Republic of Korea

***Correspondence**
somogo@skku.edu
(Munku Song)

Abstract

Background: Lateral ankle sprain (LAS) is a common recurring injury among soccer players, often associated with weakness in the peroneus longus and peroneus brevis muscles and impaired balance. However, research on the effects of different training interventions on these muscles is limited. This study aimed to compare the effects of two distinct training interventions on the peroneus longus and peroneus brevis muscles, focusing on ankle positioning during the training. **Methods**: Fifty-six male high school soccer players (age: 16.3 ± 1.1 years; playing career: 6.1 ± 1.4 years) with recurrent LAS were recruited from 15 first-division soccer clubs. They were randomly assigned to either a neutral position training (NPT) with 0° group (n = 28) or a plantarflexion position training (PPT) with 40–50° group (n = 28). Both groups underwent an 8-week home-based training program with mobile monitoring. Pre- and post-intervention assessments included Foot and Ankle Outcome Scores (FAOS), ankle strength, dynamic balance and hop tests. **Results**: it showed significant improvements in FAOS, ankle strength, balance and hop tests for both groups ($p < 0.05$). Notably, the PPT group demonstrated significantly greater improvements in dynamic balance and hop test performance compared to the NPT group. Specifically, the distance in the dynamic balance test increased from 68.9 ± 4.2 to 73.6 ± 3.8 cm in the NPT group and from 69.5 ± 3.6 to 79.4 ± 3.5 cm in the PPT group ($p < 0.001$). The single hop distance improved from 132.4 ± 20.3 to 152.0 ± 13.1 cm in the NPT group and from 129.3 ± 17.0 to 172.9 ± 11.0 cm in the PPT group ($p < 0.001$). **Conclusions**: while both PPT and NPT interventions were effective in enhancing outcomes for adolescent soccer players with LAS, PPT led to more pronounced improvements in dynamic balance and hop test performance.

Keywords

Plantarflexion; Soccer; Dynamic balance; Eversion; Hop; Strength

1. Introduction

The ankle is a weight-bearing joint located at the distal end of the human body that plays a crucial role in dynamic movements such as running and jumping and is essential for maintaining balance [1]. Effective coordination of the ankle is vital for stability, and a reduction in this coordination can lead to injuries, with lateral ankle sprain (LAS) being one of the most common [2].

LAS accounts for 66.8% of all youth soccer-related injuries and approximately half of all sports injuries, resulting in an estimated annual medical cost of $4 billion in the United States [2, 3]. A study of high school athletes in the United States reported an incidence of LAS at 2.95 per 10,000 athlete exposures, with basketball and soccer having the highest rates. The average time lost from soccer play and training due to ankle sprains was 15.9 days [4, 5]. Furthermore, up to 75% of players experience recurrence, and 40% return to play without proper diagnosis and treatment [2]. LAS is particularly prevalent in athletes engaged in sports involving running, jumping and frequent changes in direction. Inversion, the most common cause of LAS, is a critical issue in soccer players, with 40% of LAS cases progressing to chronic ankle instability, which negatively impacts performance [6].

Biomechanical changes are the primary contributors to LAS. Anatomically, the lateral malleolus descends lower than the medial malleolus, functioning as a block during ankle eversion. Excessive inversion due to the shorter medial malleolus can lead to injury [7]. Additionally, the axis of motion of the ankle joint is slightly tilted in the coronal plane, leading to adduction when the ankle plantarflexes, making the ankle prone to inversion on uneven surfaces [8]. Reduced proprioception, resulting from ligament laxity following sprains, can further increase the likelihood of recurrent injuries by diminishing positional awareness [9]. Inversion ankle sprains typically involve the lateral anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL), with isolated ATFL damage being the most common, accounting for 85–90% of cases [10]. Injuries involving both ATFL and CFL occur in 20–30% of cases [11].

Generally, conservative management is preferred over surgical intervention for incomplete ruptures or isolated ATFL injuries [12, 13]. Rehabilitation and injury prevention programs often include exercises to strengthen the evertors to compensate for damaged lateral ligaments and to restore ankle balance. Thus, Attar *et al.* [14] reported that a prevention program including strength and balance training reduced ankle injuries in soccer players by 36%. Additionally, a study of young men with LAS demonstrated improvements in hop distance and subjective assessment after 6 weeks of strength and balance training [15].

The primary goals of such training are to enhance the strength and proprioception of the muscles responsible for ankle eversion, notably the peroneus brevis (PB) and peroneus longus (PL) [16]. These muscles contribute approximately 70% of ankle eversion actions [16] and play a compensatory role in maintaining ankle stability when lateral ligaments, such as the ATFL and CFL, are compromised [17]. Although both PB and PL function as evertors, electromyography and ultrasonography studies have shown that their activation can be selectively influenced by varying ankle positions and training methods. Specifically, the PB is more engaged during eversion when the ankle is in a nearly neutral position, while the PL is involved in both plantarflexion and eversion [18–20]. This is due to the anatomical fact that the PB and PL descend behind the lateral malleolus, but the PB is attached to the 5th metatarsal, while the PL is attached to the 1st metatarsal [21]. Despite differences in muscle recruitment between PB and PL, few studies have comprehensively investigated these differences in detail, especially in athletes.

Therefore, the present study aims to evaluate the effects of eversion and balance training, focusing on the PB in a neutral posture versus the PL in a plantarflexion posture in adolescent athletes. We hypothesized that which of these two training methods would be superior with respect to subjective assessment, strength and muscle function.

2. Materials and methods

2.1 Participants

The study sample size was determined using G*power version 3.1.9.4 (G*power, University of Düsseldorf, Düsseldorf, NRW, Germany), and the analysis incorporated a repeated measures design with a within-between interaction, setting the α error probability at 0.05, the power ($1 - \beta$ error probability) at 0.95, and the effect size (f) at 0.25. Based on these parameters, the required sample size was calculated to be 56.

Participants were recruited through convenience sampling from new soccer clubs until the desired sample size was reached. Researchers visited 18 first-division soccer clubs, recruiting eligible and consenting players from 15 of these clubs. The study's purpose, the intervention program, and its potential benefits were explained to both coaches and players. Players' injury histories were reviewed, and those who had experienced a LAS within the previous month and had been diagnosed and treated for LAS more than twice in the same period were selected. Furthermore, these players had recently been excluded from training and matches due to LAS. An orthopedic specialist diagnosed and examined the LAS, evaluating the severity and determining participant eligibility for inclusion in the study. Exclusion criteria included a history of lower-extremity surgery or significant pain and inflammation that would impede the examination and training program implementation. Of the eligible players, 28 were assigned to the plantarflexion position training (PPT) group, while the remaining 28 were assigned to the neutral position training (NPT) group. The study ultimately included 56 athletes with a mean age of 16.3 $\pm$ 1.1 years and a mean body weight of 65.3 $\pm$ 8.1 kg.

Given that the participants were minors, written informed consent was obtained from both the participants and their legal guardians. The researcher provided a detailed explanation of the potential benefits of participating in the study, including access to support for training programs and coverage of testing expenses. It was also emphasized that there would be no penalties for choosing not to participate. Additionally, participants were assured that they could withdraw from the study at any time without facing any negative consequences.

2.2 Study procedures

A total of 56 participants were included in the study, with 28 players assigned to the PPT group and 28 to the NPT group with recurrent LAS. To minimize researcher bias, the participants were assigned to groups using a registration number system: odd numbers were allocated to the NPT group, and even numbers to the PPT group. This study employed a double-blind procedure; investigators were not involved in intervention allocation or the order and method of testing, which were managed by an assistant blinded to the study design and participant characteristics. The professional tester conducting the evaluation was also blinded to the study design and participants.

Training sessions were conducted by five research assistants who provided educational materials and feedback to the participants. The intervention program was designed to be accessible either at home or at a training facility and was delivered through mobile device-compatible programs. Participants also had access to mobile question-and-answer support. The eight-week intervention required participants to engage in training sessions twice daily, in the morning and evening. They were instructed to maintain self-training within a tolerable pain threshold on the 10-point visual analog scale (VAS), targeting a range of 3–4. If discomfort exceeded a VAS of 5 or if LAS recurred, participants were advised to reduce training intensity and inform the researcher via mobile phone. Before and after the intervention, participants visited a rehabilitation clinic for a series of assessments, including the Foot and Ankle Outcome Score (FAOS), ankle isokinetic inversion and eversion tests, and the Y-balance test.

2.3 Self-assessment questionnaire

The participants were advised to rate the severity of their symptoms using FAOS across five domains: pain, symptoms, daily activities, sports and recreational physical activities, and quality of life [22]. This questionnaire has been validated for reliability, with an intraclass correlation coefficient (ICC) of 0.85, and it demonstrated a correlation with the pain scale of $r = 0.675$ ($p < 0.001$) [23]. The FAOS consists of 42 questions designed for participants to subjectively assess the severity of their symptoms in the aforementioned domains. Each item within the domains is rated on a scale from 0 to 4 points. These ratings are then converted to a scale of 0–100 points for each domain, where higher scores represent better conditions and lower scores indicate greater discomfort.

2.4 Ankle strength test with isokinetic device

Ankle strength was assessed using a CSMi isokinetic dynamometer, a clinical tool designed for measuring isokinetic muscle strength. This device quantifies muscle strength within a specified range of motion by employing computer-controlled equipment to regulate speed, with results reported in Nm [24]. This device was confirmed to have reliability (ICC: 0.71–0.95%), specificity (50.7–86.8%), and sensitivity (60.4–81.1%) for measuring muscle strength [25]. In this study, ankle inversion and eversion dynamics were evaluated using the concentric contraction mode at angular velocities of 30°/s and 120°/s. The testing protocol involved a range from 40° of inversion to 30° of eversion relative to the neutral position of the ankle. Before testing, participants underwent preparation, practice and demonstration sessions with the assessor to become familiar with the equipment and procedures. Each test session included four repetitions with appropriate rest intervals between angular speeds. Testing was performed bilaterally, starting with the healthy ankle to assess stability, followed by the evaluation of the injured ankle, with the maximum value recorded. To account for differences in body weight, muscle strength and power measurements were normalized by dividing the values by the participant's body weight.

2.5 Dynamic balance and hop tests

Dynamic balance was assessed using the Y-balance test (YBT) device (FMS Inc., Chatham, VA, USA), which evaluates balance in three directions: anterior, posteromedial and posterolateral. These directions were selected due to their high reliability in assessing dynamic ankle balance and proprioception, with ICC ranging from 0.80 to 0.91 [26]. Prior to testing, each participant received guidelines from the examiner and underwent three practice sessions, each lasting 10 minutes [27]. Participants removed their shoes and socks and positioned the test foot on the central test plate. From this position, the opposite foot was extended as far forward as possible in each of the three directions, maintaining the posture for over 2 seconds. While movement of the arms and lifting of the heels were permitted to help maintain balance, any part of the foot touching the ground was considered a test error. The maximum distance achieved was recorded, and the test was repeated three times in each direction. Testing began with the healthy ankle, followed by the injured ankle, with a 2-minute rest between sets. The highest value from the two tests was used for analysis [28].

Hop tests, used to evaluate leg muscle power, demonstrated ICC values ranging from 0.84 to 0.98 [29]. The participants were allowed a 10-minute practice period before the actual test, with a 2-minute rest interval between test sets [30]. Each test was performed twice, with the highest value used for analysis. In the single hop test, participants started with one foot behind the starting line, ensuring that the heel did not cross the line. At the signal, they jumped forward as far as possible. For the crossover hop test, a line was drawn perpendicular to the starting line. Participants hopped alternately to the left and right of the line three times consecutively from the starting line, aiming to cover the maximum distance. The distance from the starting line to the heel at landing was recorded in centimeters [31].

2.6 Intervention training

The NPT and PPT were designed based on electromyography, ultrasonography experiments, and intervention studies with similar designs [18–20]. Both interventions were conducted offline and face-to-face, focusing primarily on strength training with elastic exercise tubing (Theraband®; Hygenic Corp., Akron, OH, USA) and balance training with BOSU (BOSU®; HEDSTROM Fitness, Ashland, OH, USA). The BOSU device has been validated against traditional unstable exercise equipment, such as the wobble board, with an ICC ranging from 0.88 to 0.96 [32, 33]. Participants engaged in training twice daily for 8 weeks, with each session lasting approximately 20–30 minutes. During each session, participants performed concentric contractions for approximately 5 seconds while the ankle everted, followed by eccentric contractions to return to the starting position. Each set consisted of 20 repetitions, and participants completed five sets. The intensity of strength training was increased by changing the color of the elastic tube band from red to green. For balance training, participants maintained their center of gravity on the BOSU, standing for 2 minutes across a total of five sets. The intensity of balance training was increased by progressing to more challenging green and blue BOSU tools. The training intensity was maintained for the first four weeks and subsequently increased during the second four weeks. Athletes opting for home-based training were supervised through real-time video app monitoring at least once a week. Alternatively, participants were asked to film their training sessions and send the footage to researchers via a messaging app for feedback, ensuring adherence and accuracy of movement.

NPT: In this position, strength training involved ankle eversion using the tube band. Balance training required maintaining the ankle in a neutral position on an unstable tool inclined at 30°. Participants grounded the entire sole of the foot on the tool and performed balance exercises to maintain the center of gravity in this position (Fig. 1) [18, 19]. The athlete was asked to perform tube exercises while lying face down on a 50 cm high bed. The hip and knee joints were bent at approximately 45°. A tube band was installed on the forefoot, and the ankle

FIGURE 1. Ankle training at a neutral position.

was kept in a neutral position (0°) based on the anatomical position. One repetition was performed after performing the eversion movement, and the return was performed at a training speed of 1 time/2 s were repeated. Balance training was performed on the hard surface of the BOSU, and the center of gravity was maintained in a slightly inclined state so that an approximately 30° incline was generated.

PPT: The participants maintained plantarflexion of the ankle while performing eversion exercises using the tube band. Balance training involved lifting the heel, sustaining plantarflexion, and maintaining posture by counteracting the loss of the center of gravity (Fig. 2) [18, 19]. The athlete was instructed to sit with his knees extended and a tube band was placed around his forefoot. The exercise speed was 1 time/2 s. The ankle was instructed to maintain 40–50° of plantarflexion and then eversion and return. Balance training was performed by lifting the heel in the center of the BOSU and maintaining plantar flexion to maintain maximum balance.

2.7 Statistical analysis

Data analyses were conducted using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Paired t-tests were used for intra-group comparisons of pre- and post-intervention data, while independent t-tests were applied for inter-group comparisons. Categorical variables, including playing position, sprain grade, and injury frequency, were analyzed using the chi-square test. Repeated two-way analysis of variance (ANOVA) was utilized to examine main effects and interactions by time and group. Effect sizes were determined using Cohen's d (d) and phi (φ), with effect sizes classified as small (<0.3), medium (0.3–0.5), and large (>0.5). Statistical significance was set at $p < 0.05$.

$$d = \frac{(M1 - M2)}{\sqrt{\frac{[S1^2 + S2^2]}{2}}}$$

$$\varphi = \sqrt{(X^2 / n)}$$

FIGURE 2. Ankle training at a plantarflexion position.

3. Results

3.1 Comparison of information profiling of participants

Table 1 presents a comparison of the general characteristics between the NPT and PPT groups. The average ages of the NPT and PPT groups were 16.0 ± 1.1 years and 16.5 ± 1.0 years, respectively, with no significant difference between the groups. No significant differences were found in height, weight, body mass index, or athletic experience between the groups ($p > 0.05$). Additionally, there were no significant differences in the VAS scores, which reflect self-assessed subjective pain related to the injury, injury side, position or injury grade.

3.2 Changes in self-assessment score

Over the 8-week intervention period, both groups demonstrated significant improvements in their self-assessment scores. There were no significant differences between the groups before or after the intervention (Table 2). Pain improved by 19.9% in the NPT group and 15.1% in the PPT group. Sports and recreation scores improved by 8.8% in the NPT group and 14.2% in the PPT group ($p < 0.05$). No significant interaction effects between time and group were observed for any domain ($p > 0.05$).

3.3 Changes in ankle strength

Post-intervention isokinetic strength testing indicated significant improvements in both inversion and eversion at angular velocities of 30°/s and 120°/s for both the NPT and PPT groups ($p < 0.05$). However, no significant differences were observed between the groups for inversion and eversion at either velocity following the intervention ($p > 0.05$). Specifically, eversion strength improved from 39.8 ± 5.8 Nm/kg to 47.7 ± 4.8 Nm/kg (19.8%) in the NPT group, and from 37.8 ± 4.0 Nm/kg to 46.1 ± 2.5 Nm/kg (22.0%) in the PPT group at an angular velocity of 30°/s. Although the main effect of time was significant, there were no significant effects attributable to the group or interactions between time and group (Table 3).

3.4 Changes in dynamic balance and hop tests

Table 4 presents the results of the dynamic balance and hop tests. Data analysis showed that both the NPT and PPT interventions resulted in significant improvements from baseline. Notably, the PPT group demonstrated greater improvements in dynamic balance and hop tests compared to the NPT group. Interaction effects were observed in the posteromedial and posterolateral aspects of dynamic balance and in the single and crossover hop tests ($p < 0.05$). Specifically, the PPT group showed a 14.2% improvement in the posteromedial direction (from 68.9 ± 4.2 to 73.6 ± 3.8) compared to a 6.8% improvement in the NPT group (from 69.5 ± 3.6 to 79.4 ± 3.5). Similarly, the single hop distance increased by 33.7% in the PPT group (from 132.4 ± 20.3 to 152.0 ± 13.1) compared to a 14.8% increase in the NPT group (from 129.3 ± 17.0 to 172.9 ± 11.0) ($p < 0.05$).

4. Discussion

LAS is a common injury among adolescent soccer players. Current research indicates that exercise-based rehabilitation, particularly targeting evertor muscles, is beneficial for recovery [15, 34]. Our present study aimed to compare the effects of NPT and PPT by dividing them into positions based on their relation to eversion (PB and PL). Our findings indicate that PPT was more effective than NPT both before and after the intervention. Specifically, PPT demonstrated slightly greater improvements compared to NPT in the posteromedial and posterolateral directions of dynamic balance as well as in hop tests.

In this study, the FAOS demonstrated significant improvement after the intervention in both groups. However, the comparison between the groups revealed no significant differences post-intervention, and these results were consistent with previous studies. For instance, a study evaluating 27 patients with recurrent acute ankle sprains reported significant im-

TABLE 1. Characteristics of participants in the NPT and PPT groups.

Variables	NPT (n = 28)	PPT (n = 28)	E.S	*p*
Age (yr)	16.0 ± 1.1	16.5 ± 1.0	0.475	0.089
Height (cm)	175.2 ± 6.4	173.6 ± 5.9	0.259	0.353
Weight (kg)	66.4 ± 8.7	64.2 ± 7.4	0.272	0.325
Body mass index (kg/m^2)	21.6 ± 1.7	21.2 ± 1.5	0.249	0.453
Player career (yr)	6.1 ± 1.1	6.0 ± 1.7	0.069	0.873
VAS	5.0 ± 1.8	4.7 ± 1.9	0.162	0.601
Injury side, left/right (n)	16/12	17/11	0.036	0.786
Play position, MF/FW/DF/GK, (n)	13/8/6/1	14/7/7/0	0.145	0.758
Sprain grade, I/II/III, (n)	10/14/4	9/13/6	0.094	0.783
Injury frequency for 1 yr, ≤2/3–4/>5, (n)	20/6/2	19/8/1	0.107	0.724

NPT, neutral position training; PPT, plantarflexion position training; VAS, visual analog scale; MF, midfielder; FW, forward; DF, defender; GK, goalkeeper; E.S, effect size.

TABLE 2. Changes in self-assessment scores.

Test	Variables	Group	Baseline	8 weeks	Difference, %	E.S	*p*	*p*
FAOS								
	Pain	NPT	69.7 ± 10.8	83.6 ± 9.3	19.9	1.379	<0.001	Time: <0.001
		PPT	71.6 ± 8.9	82.4 ± 9.6	15.1	0.734	<0.001	Group: 0.883
		p	0.493	0.645				T × G: 0.129
	Symptoms	NPT	75.2 ± 10.9	83.4 ± 8.7	10.9	0.831	0.002	Time: <0.001
		PPT	73.9 ± 7.9	85.9 ± 8.4	16.2	1.471	<0.001	Group: 0.692
		p	0.631	0.292				T × G: 0.120
	Daily activities	NPT	76.5 ± 8.4	85.5 ± 9.2	11.8	1.021	<0.001	Time: <0.001
		PPT	73.6 ± 6.4	86.5 ± 8.6	17.5	1.701	<0.001	Group: 0.588
		p	0.154	0.677				T × G: 0.098
	Sport and recreation	NPT	72.4 ± 9.8	84.5 ± 7.2	16.7	1.407	<0.001	Time: <0.001
		PPT	74.8 ± 7.5	85.4 ± 8.1	14.2	1.357	<0.001	Group: 0.357
		p	0.314	0.632				T × G: 0.556
	Quality of life	NPT	77.4 ± 10.4	84.2 ± 9.3	8.8	0.689	<0.001	Time: <0.001
		PPT	79.5 ± 10.3	85.7 ± 8.9	7.8	0.640	0.006	Group: 0.412
		p	0.447	0.538				T × G: 0.827

$p < 0.05$; Values are presented as mean ± standard deviation; NPT, neutral position training; PPT, plantarflexion position training; E.S, effect size; T × G, time × group interaction effect; FAOS, Foot and Ankle Outcome Scores.

TABLE 3. Changes in ankle strength.

Test	Variables	Group	Baseline	8 weeks	Difference, %	E.S	*p*	*p*
30°/s								
	Inversion, Nm/kg	NPT	36.3 ± 3.3	44.2 ± 5.3	21.8	1.789	<0.001	Time: <0.001
		PPT	36.6 ± 4.0	45.3 ± 6.9	23.8	1.542	<0.001	Group: 0.458
		p	0.801	0.502				T × G: 0.671
	Eversion, Nm/kg	NPT	39.8 ± 5.8	47.7 ± 4.8	19.8	1.483	<0.001	Time: <0.001
		PPT	37.8 ± 4.0	46.1 ± 2.5	22.0	0.302	<0.001	Group: 0.090
		p	0.071	0.265				T × G: 0.459
120°/s								
	Inversion, Nm/kg	NPT	22.2 ± 0.9	26.9 ± 1.9	21.2	3.272	<0.001	Time: <0.001
		PPT	22.0 ± 1.2	27.7 ± 1.3	25.9	3.111	<0.001	Group: 0.570
		p	0.495	0.395				T × G: 0.134
	Eversion, Nm/kg	NPT	26.2 ± 9.4	29.2 ± 8.8	11.5	0.329	0.003	Time: <0.001
		PPT	25.3 ± 5.1	28.9 ± 4.5	14.2	0.748	<0.001	Group: 0.728
		p	0.659	0.875				T × G: 0.560

$p < 0.05$; Values are presented as mean ± standard deviation; NPT, neutral position training; PPT, plantarflexion position training; E.S, effect size; T × G, time × group interaction effect.

provements in pain, daily activities, and sports and recreation sections after one month of physical therapy. However, no improvements were noted in symptoms and quality of life [35]. This study's broad inclusion criteria, encompassing grades I, II and III, limit direct comparisons. Another study focusing on grade I–II sprains observed that 43% of patients receiving physical therapy and 37% receiving standard care showed satisfactory FAOS score improvements. Despite significant progress in both groups, no differences were found between them [36]. These results suggest that exercise-based rehabilitation might not offer a significant advantage over standard care, contrary to other studies indicating its effectiveness in reducing recurrence rates. For instance, Wagemans *et al.* [37] reported that exercise-based rehabilitation reduced recurrence by 40% compared to conventional treatments like medication and bracing.

In our present study, significant increases in ankle strength at 30°/s and power at 120°/s were observed in both the NPT and

TABLE 4. Changes in Y-balance test and hop tests according to training.

Test	Variables	Group	Baseline	8 weeks	Difference, %	E.S	*p*	*p*
YBT								
	Anterior	NPT	60.4 ± 7.2	65.6 ± 7.3	8.6	0.717	<0.001	Time: <0.001
		PPT	59.4 ± 8.3	64.4 ± 8.1	8.4	0.609	<0.001	Group: 0.597
		p	0.601	0.517				T × G: 0.752
	Posteromedial	NPT	68.9 ± 4.2	73.6 ± 3.8	6.8	1.173	<0.001	Time: <0.001
		PPT	69.5 ± 3.6	79.4 ± 3.5	14.2	2.788	<0.001	Group: 0.002
		p	0.6	<0.001				T × G: <0.001
	Posterolateral	NPT	74.5 ± 4.1	78.8 ± 3.7	5.8	1.101	<0.001	Time: <0.001
		PPT	73.8 ± 3.8	81.8 ± 4.5	10.8	1.920	<0.001	Group: 0.031
		p	0.522	0.011				T × G: <0.001
Hop								
	Single hop	NPT	132.4 ± 20.3	152.0 ± 13.1	14.8	0.963	<0.001	Time: <0.001
		PPT	129.3 ± 17.0	172.9 ± 11.0	33.7	2.266	<0.001	Group: 0.044
		p	0.548	<0.001				T × G: <0.001
	Crossover hop	NPT	314.3 ± 33.0	404.0 ± 53.5	28.5	1.039	<0.001	Time: <0.001
		PPT	322.7 ± 37.2	443.3 ± 61.0	37.4	1.516	<0.001	Group: 0.028
		p	0.404	0.014				T × G: 0.036

$p < 0.05$; Values are presented as mean ± standard deviation; NPT, neutral position training; PPT, plantarflexion position training; E.S, effect size; T × G, time × group interaction effect; YBT: Y-balance test.

PPT groups. However, the inter-group comparison revealed no significant difference between PPT and NPT, suggesting that both training programs effectively improved muscle strength. These findings diverge from those of a previous study, which reported different outcomes. Specifically, a 12-week intervention targeting the PB and PL positions showed significant muscle strength improvements in both groups, with PL-focused training demonstrating superior results compared to PB-focused training at both 30°/s and 120°/s [38]. These differing results may be attributed to variations in movements and postures between the studies. Additionally, the participant demographics could play a role: our study involved young athletes, while the previous study included non-athletic adults. Muscle weakness is commonly observed in patients with ankle injuries. For instance, Lee *et al.* [39] assessed the muscle strength characteristics of 91 men with ankle sprains and reported that 73.6% exhibited eversion strengths below normal, with similar findings for women, underscoring the importance of emphasizing eversion strengthening in LAS rehabilitation, as it plays an essential role in injury prevention [14, 15].

Dynamic balance is a fundamental component of soccer, requiring frequent rapid and precise movements. In the present study, both training groups demonstrated improvements in dynamic balance. Notably, the posteromedial and posterolateral balance scores were higher in the proprioceptive training (PL) group compared to the neuromuscular training (PB) group following the intervention. This discrepancy may be attributed to the wider balance tool and contact area in the PB position, while the PL position involved a heel-raise, which could have made the tasks more challenging. This fact is supported by experimental study of soleus muscles, which showed that improved strength through heel-raise training had a positive effect on postural control [40]. Greater improvements with PL training have been observed in other studies as well [38]. For instance, in a study involving non-athlete adults with chronic ankle instability, the PL-focused training group showed significant improvements in the YBT-anterior direction compared to the PB training group. However, no differences were found between the groups in the posterolateral and posteromedial directions [38]. The use of an unstable balance instrument in our study might have contributed to these differing results compared to studies that did not incorporate balance training. The PL training may have had a more pronounced effect due to its role in maintaining ankle stability, particularly when the medial arch is lowered during posteromedial training. Further context is provided by a previous YBT study, which reported reductions in dynamic balance of 30.7%, 24.2% and 17.6% in one-, two- and three-directional tests, respectively, in men with LAS. Only 27.5% of these patients achieved normal dynamic balance on the YBT [39], thereby highlighting the importance of investigating dynamic balance in relation to the severity of LAS, rather than relying solely on average comparisons.

The hop test results mirrored those of the balance tests, with the PPT group achieving a longer hop distance compared to the NPT group. The heel-raise posture in the PPT group likely stimulated the soleus, gastrocnemius and other plantar flexor muscles, contributing to the increased hop distance. In this regard, electromyography studies have demonstrated that plantarflexion strength is positively correlated with hopping ability [41]. These predictable biomechanical mechanisms may be due to anatomical features. The PL is a larger and longer muscle overall than the PB. The PB and PL pass together behind the lateral malleolus, but the PB attaches to the tubercle on the 5th metatarsal, while the PL attaches across the metatarsal to the first metatarsal and cuneiform bone [21]. Therefore, it may have performed better in the hop test because it is better able to perform the plantarflexion function.

This study had several limitations that should be acknowledged. The most significant limitation is the absence of a control group, which complicates the assessment of the relative effectiveness of the two interventions. Additionally, as the study was conducted exclusively with male youth soccer players, the findings may not be generalizable to females, adults, or participants in other sports. The study also did not control for other exercises outside of the intervention training, which could affect the results. Future studies should address this issue to ensure that observed improvements are attributable only to the intervention programs, rather than other exercise regimens. Furthermore, given the acute nature of the injury and the study duration of 8 weeks, natural improvement in pain and symptoms due to the progression of the inflammatory and subacute stages could have influenced the results. Although efforts were made to standardize the intensity and volume of exercises, differences in intensity due to positional variations and movement differences between the two training sessions may have impacted the outcomes. Another limitation was the reduced ability to monitor athletes who performed home-based training compared to those who participated in center-based training.

Future research should explore which training modality—PB or PL—has a greater effect on strength and balance and assess the long-term impacts of these interventions. Testing at the 4th week of the intervention could reveal changes in variable values over time. In addition, if we further diversify the variables related to muscle function to measure force, power and sensory motor, it could be expanded into a valuable study. Finally, further analysis of the biomechanics of PB and PL muscles, particularly in relation to movements commonly used in soccer, could provide valuable insights for preventing LAS.

5. Conclusions

After an 8-week training program, participants from both the NPT and PPT groups demonstrated significant improvements in self-assessment, ankle strength, dynamic balance, and hop test performance compared to baseline measurements ($p < 0.05$). Notably, PPT led to significant greater improvements than NPT in medial-lateral balance as well as in single- and crossover-hop tests ($p < 0.05$). These results suggest that while both PPT and NPT are effective in enhancing ankle function, PPT may offer additional benefits for adolescent male soccer players with recurrent LAS.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on request from the corresponding author.

AUTHOR CONTRIBUTIONS

XXD and YK—conceptualization, formal analysis, original draft writing; XXD and MS—methodology; YK—investigation; YK and MS—review and editing, supervision. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Informed consent was obtained from all subjects participating in the study and their legal guardians. Ethics approval for this study was obtained from the Research Ethics Committee of the Institutional Review Board of Gangneung-Wonju National University (No. 202113). This study was registered in the Korean clinical trial registration system (https://cris.nih.go.kr; Number: KCT0009828).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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