Research Paper

Effects of Plyometric, Balance, PNF and Combined Trainings on Basketball Players Ankle Muscle Activation

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ABSTRACT

Purpose: Basketball, a popular sport, often leads to ankle injuries, prompting the need for effective preventive training. It has been illustrated that plyometric, balance and proprioceptive neuromuscular facilitation (PNF) trainings reduce the injury rate between basketball players; however, these trainings alone are not sufficient for fully enhancing ankle muscle electrical activity.

Objectives: This study aimed to compare the effects of plyometric, balance, PNF and combined trainings on ankle muscle electrical activity (tibialis anterior [TA], peroneus longus [PL], gastrocnemius medialis [GM], soleus [SL]) during single-leg jumps. Although previous studies have examined ankle muscle activation during jumping, a systematic analysis of electromyographic (EMG) patterns across all four biomechanical phases has not been comprehensively conducted. This study offers a comprehensive phase-by-phase assessment to identify precise neuromuscular deficits and optimize injury prevention strategies for basketball players.

Methods: The study participants consisted of 75 young basketball players (aged 12–16 years) with no history of ankle injuries and participants were randomly assigned to five equal groups (n=15 each). The single-leg box jump test was systematically analyzed across four biomechanically defined phases.

Results: The results indicated that combined training was most effective in reducing electrical ankle activity in specific ankle muscles. Plyometric training decreased activity in TA, PL, and SL (phase 1), GM and SL (phase 2), and GM and TA (phases 3–4). Balance training influenced TA and PL (phase 1), GM (phase 2), GM and SL (phase 3), and TA (phase 4), while PNF showed no significant impact.

Conclusion: The study concludes that while individual training methods improve specific aspects of ankle stability, combined training offers a comprehensive solution by enhancing strength and reducing injury risk across all jump phases, making it a suitable option for inclusion in warm-up protocols.

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Highlights

• Ankle injury prevention is crucial. Plyometric, balance, and PNF training each help but none are sufficient on their own. A combined approach works best.

• Training impacts muscle activity differently. Plyometrics reduce ankle muscle activation in jump phases. Balance training affects some muscles. PNF showed no significant effect.

• Combined training is most effective. It strengthens ankles and reduces injury risk better than single-method training, making it suitable for warm-up protocols.

Plain Language Summary

This study found that while plyometric, balance, and proprioceptive neuromuscular facilitation (PNF) training each help reduce ankle injury risks in basketball players, none are fully effective alone—plyometrics improve muscle control during jumps, balance training helps stability, and PNF does not have a significant impact. However, combining all three methods strengthens ankles more effectively, making it the best warm-up strategy to prevent injuries. The main takeaway is that basketball players should integrate jump, balance, and stretching exercises into their routines for optimal ankle protection.

Introduction

Basketball, a sport that has captivated millions around the world, has a rich and fascinating history [1]. Injuries are an inevitable aspect of sports, and basketball is no exception [2]. The physical demands and high-intensity nature of the game make basketball players susceptible to various types of injuries [3]. Ankle twists are a common occurrence in basketball, often resulting in significant pain and functional limitations for players [4]. Understanding the mechanism behind ankle twists is crucial for developing effective preventive measures and rehabilitation strategies [5]. Ankle injuries are common among basketball players and can lead to various problems for basketball players, affecting their performance, playing time, and long-term health [4]. Poor ankle stability is a significant risk factor for ankle injuries. Basketball players with weaker ankle muscles and ligaments are more prone to ankle sprains found that players with decreased ankle stability had a higher incidence of ankle injuries and players with a history of ankle sprains are more likely to experience recurrent ankle injuries [6]. Athletes have an increased risk of subsequent sprains [7]. Certain movement patterns, such as sudden changes in direction, jumping, and landing, can put stress on the ankle joint and increase the risk of injury [8]. Ankle injury prevention is crucial for basketball players to maintain their performance and reduce the risk of long-term complications and some trainings, such as plyometric and balance and proprioceptive neuromuscular facilitation (PNF), are effective [9]. Balance and proprioception exercises can improve ankle stability and reduce the risk of ankle injuries [10]. Board training program significantly reduced the incidence of ankle sprains among basketball players [11]. Strengthening the muscles around the ankle joint, including the calves, can provide better support and stability [12]. Strengthening exercises can be effective in reducing ankle injuries in basketball players [13]. PNF exercises include stretching exercises that are effective for improving range of motion, reducing spasms and accelerating recovery, designed based on natural patterns [14]. However, the same study indicated that PNF exercises do not have a significant effect on stimulus feedback time or ankle dorsiflexion strength [14]. A thorough warm-up routine that includes dynamic stretching exercises can help enhance flexibility and prepare the muscles for the demands of basketball [15]. Neglected or mismanaged ankle injuries can lead to long-term joint damage, such as osteoarthritis and continued stress, and instability in the ankle joint can accelerate joint degeneration, also ankle sprains were associated with an increased risk of developing ankle osteoarthritis in later life [16]. Ankle injuries can have psychological consequences, including fear of reinjury, decreased confidence, and psychological distress. Athletes may develop anxiety or apprehension related to returning to play after an ankle injury [17]. Given this, basketball is a sport with high risk of ankle injury, a com-parative training program is necessary to prevent ankle injury. This study aimed to investigate the electrical ac- tivity of the ankle muscles of basketball players between groups in the jumping test.

Objectives

This study evaluated the effectiveness of plyometric, balance, and PNF training protocols in preventing ankle injuries among 75 competitive basketball players, using electromyographic (EMG) analysis during single-leg jumps. The key findings demonstrated that plyometric training significantly reduced muscle activation in ankle stabilizers (particularly tibialis anterior (TA) and gastrocnemius) during critical jump phases. Balance training showed specific benefits, while PNF training exhibited no measurable effects. Crucially, the data revealed that a combined training protocol integrating all three methods produced superior outcomes in optimizing neuromuscular control and reducing injury-risk activation patterns across all jump phases. These results suggest that multimodal training interventions may offer the most effective strategy for ankle injury prevention in basketball. However, further longitudinal research is needed to validate these findings and establish optimal implementation protocols.

Materials and Methods

This study included 75 young male basketball players (aged 16-18 years) with at least two years of competitive basketball experience and no history of ankle injury. The participants (mean age 17.26±0.24 years; mean height 182.38±11.7 cm; mean body mass 80.82±3.04 kg; mean BMI 24.38±1.36 kg/m²) were from Shahrekord City, southwest Iran. All participants were right-hand and dominant-foot. They were randomly assigned to one of five training groups (n=15 per group): Plyometric, balance, PNF, combined (plyometric, balance, and PNF), and a control group (Table 1). One-way analysis of variance (ANOVA) confirmed no significant baseline differences in demographic characteristics between the groups (P>0.05), ensuring group comparability at study initiation. The control group continued their standard basketball practice without any additional warm-up training. In contrast, the experimental groups incorporated their specific training protocols into their warm-up period before basketball training. These protocol trainings were applied consistently across the experimental groups and were optimized over the 8-week period [18] (Table 2). Before the study commenced, the aims and procedures

Table 1. Training protocol of the groups

Group	Variables	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Plyometric	Barrier height	30 cm	35 cm	40 cm	45 cm	60 cm	50cm	55 cm	65 cm
	Jump type	Pair foot	Pair foot	Pair foot	Pair foot	Single leg	Single leg	Single leg	Single leg
	Set and repeat	12×3	12×3	12×3	10×4	12×4	10×4	10×4	12×4
Balance	Balance type	Pair foot	Pair foot	Single leg	Single leg	Single leg	Pair foot	Pair foot	Single leg
	Platform type	Constant	Fluctuated	Constant	Fluctuated	Constant	Constant	Fluctuated	Fluctuated
	Eye type	Open	Open	Open	Open	Close	Close	Close	Close
	Set and repeat	3×20 S	3×20 S	3×20 S	3×20 S	3×10 S	3×10 S	3×10 S	3×10 S
PNF	Stretch type	Static	Static	Static	Static	Dynamic	Dynamic	Dynamic	Dynamic
	Pressure type	Non active	Non active	Active	Active	Active	Active	Non active	Active
	Set and repeat	3×20 S	3×20 S	3×20 S	3×20 S	3×20 S	3×20 S	3×20 S	3×20 S
Combined	Barrier height	30 cm	35 cm	40 cm	45 cm	60 cm	50 cm	55 cm	65 cm
	Jump and land on platform	Pair foot Constant	Pair foot Fluctuated	Single leg Fluctuated	Single leg Fluctuated	Pair foot Constant	Pair foot fluctuated	Single leg Constant	Single leg Constant
	Set and repeat	2×15	2×15	2×15	2×15	3×15	3×15	3×15	3×15
	Stretch pressure type (PNF)	Static active (20s)	Dynamic active (20s)	Dynamic non active (20s)	Dynamic active (20s)	Dynamic non active (20s)	Static non active (20s)	Dynamic active (20s)	Dynamic active (20s)

PNF: Proprioceptive neuromuscular facilitation.

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Table 2. Demographic data of the groups

Variables	Mean±SD (95% CI)					P
	Plyometric	Balance	PNF	Combined	Control	
Age (y)	17.3±0.2 (17.1–17.5)	17.2±0.3 (17.0–17.4)	17.3±0.2 (17.1–17.5)	17.2±0.2 (17.0–17.4)	17.3±0.3 (17.1–17.5)	0.985
Height (cm)	181.5±10.2 (178.3–184.5)	183.1±12.4 (178.5–187.7)	182.8±11.6 (178.4–187.2)	182.0±12.1 (178.1–185.9)	182.4±11.9 (178.3–186.5)	0.992
Body mass (kg)	81.2±2.9 (78.7–83.7)	80.5±3.1 (77.8–83.2)	80.8±3.2 (77.9–83.7)	80.7±3.0 (77.9–83.5)	80.9±3.3 (77.9–83.9)	0.998
BMI (kg/m²)	24.5±1.3 (23.3-25.7)	24.2±1.4 (22.9–25.5)	24.3±1.5 (23.0–25.6)	24.3±1.3 (23.1–25.5)	24.4±1.4 (23.1–25.7)	0.995

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Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; BMI: Body mass index.

were explained to the participants. All participants voluntarily signed informed consent forms. The participants were also assured they could withdraw from the study whenever they wished. Following anthropometric measurements (age, height, weight, BMI), the researcher measured functional factors, including strength, endurance, power and range of motion as pre-tests. The experimental groups then performed one of the four training methods (plyometric, balance, PNF, or combination) for 30-45 minutes per session, alongside their regular skill exercises. These sessions took place three times per week for eight weeks. The researcher directly supervised the groups. The exercise program for the experimental groups adhered to the principle of overload with gradual increases in the duration and repetition of each exercise. According to the training program, plyometric exercises included double-leg and single-leg jumping exercises in length and height, and balance exercises included exercises for maintaining balance in pair-leg and single-leg positions with stable and unstable surfaces and with open eyes and close eyes positions also PNF training included stretching and pressure exercises at different levels and also combination training included plyometric, balance and PNF exercises. Exercises are progressed from an easy level to a hard level of intensity over the eight weeks according to the principle of overload. The control group performed their usual training sessions concurrently. Following the training period, the researcher measured functional factors in experimental and control groups as post-tests. This research recorded the muscle electrical activity using an 8-channel biofeedback electromyography device (pro-comp infiniti, canada) with a sampling rate of 2000 Hz [19]. The targeted muscles encompassed the TA, peroneus longus (PL), gastrocnemius medialis (GM), and soleus (SL) [20]. Before measuring the electrical activity of muscles, the following actions were taken (according to the SENIAM protocol): To capture muscle activity accurately, surface EMG electrodes were strategically placed over the targeted muscles. Common electrode placement protocols were followed, aligning with established guidelines for each muscle group. The muscles assessed included: TA, PL, gastrocnemius (media land lateral) and SL. Prior to electrode application, the skin was prepared to minimize impedance. This typically involved gentle abrasion and cleansing to ensure optimal electrode-skin contact, as recommended in literature on EMG procedures. Before initiating the test protocols, the EMG system underwent calibration procedures to establish a baseline for muscle activity. This step is crucial for accurate interpretation of EMG signals and is aligned with the standard practices in electromyography research. Participants were familiarized with the testing environment, and anthropometric measurements were taken to guide electrode placement. Informed consent was obtained, and ethical considerations were upheld throughout the study, in accordance with ethical guidelines. After preparation and setup of the measurement equipment, maximal voluntary isometric contractions (MVIC) of the ankle muscles were measured. Subsequently, subjects performed the single jump test with their dominant (right) foot from a 30 cm box [21]. Following the After the pre-test assessment, the experimental groups performed plyometric, balance, PNF and combined exercises (plyometric and balance and PNF) in addition to basketball exercises. The control group continued with only basketball exercises [22]. For a more accurate assessment, the jump test was divided into four different phases. The activity of each muscle in each phase was examined between five training groups. These phases are defined as follows [23]: The first phase of jumping refers to the distance between maintaining balance and the command of the examinee until the first contraction of the target muscles before jumping; the second phase of jumping is the interval between the first contraction of the ankle muscles before jumping and the separation of the toe and heel from the ground; the third phase of jumping or the swing phase is the distance between the separation of the toe and heel from the ground to the first contact of the foot with the surface after jumping; and the fourth phase of jumping is the distance between the first contact of the foot with the surface and the complete landing and maintaining balance [24]. Following the jump tests, the root mean square (RMS) value for each muscle's activity during each phase was calculated for both pre-test and post-test. These RMS values were normalized to the MVIC of each respective muscle, expressed as a percentage. This allowed for the examination and measurement of muscle activation percentages across all four phases in both pre-test and post-test conditions [25]. Participants performed the single-leg jump-and-land task, replicating real-world scenarios and the EMG system recorded muscle activity throughout the task, capturing data on the targeted muscles during takeoff, flight, and landing phases [26]. The single-leg box jump test was systematically analyzed across four biomechanically defined phases: 1) Initial contact phase (0–100 ms after ground contact), characterized by rapid impact absorption with eccentric muscle activation; 2) Braking phase (from initial contact to peak knee flexion, typically 100–300 ms), where muscles decelerate downward momentum; 3) Propulsion phase (from peak knee flexion to toe-off, 300–500 ms), dominated by concentric activation for upward acceleration; and 4) Stabilization phase (first 200 ms after landing on the box), requiring dynamic control to maintain balance. EMG signals were segmented into these phases using kinematic (motion capture) and kinetic (force plate) triggers, with RMS amplitude calculated for each phase to quantify phase-specific neuromuscular adaptations [26]. EMG signals were continuously recorded during the entire test using a synchronized data acquisition system. Signal processing techniques, such as filtering and normalization, were applied to enhance the accuracy of the recorded [27]. Collected data underwent rigorous analysis using established algorithms. Muscle activation patterns, onset, and offset times were extracted for each targeted muscle, allowing for a detailed examination of neuromuscular responses [28]. Statistical methods, including paired t-tests or ANOVA, were employed to assess significant differences in muscle activation patterns between pre-test and post-test conditions [29]. This analytical approach aligns with recommended statistical practices in EMG research.

Results

In this part, research hypotheses were tested using statistics and SPSS software, version 21. A paired t-test was used to compare the pre-test and post-test scores of each group, and the ANOVA statistical test was used to compare the changes across the five training groups over the intervention period. Differences in muscle electrical activity in the jumping phases were analyzed based on the absolute value of the normalized differences (Figures 1, 2, 3, 4 and 5). Paired t-test results indicated that combined training significantly affected the activity of TA, PL, medial and lateral GM, and SL muscles during the first jumping phase, demonstrating a more pronounced effect compared to other interventions. Exercise showed more and better effect in the first phase of jumping. In addition, plyometric training significantly affected TA muscle activity, and PNF training had a significant effect on PL muscle activity (Table 3) ($P<0.05$). The results of ANOVA test showed significant differences in TA muscle activity during the first jumping phase between the plyometric, balance, and combined groups compared to the control group. In addition, significant differences were observed between combined training group with the plyometric, balance, and PNF groups. In the PL muscle, signifi-

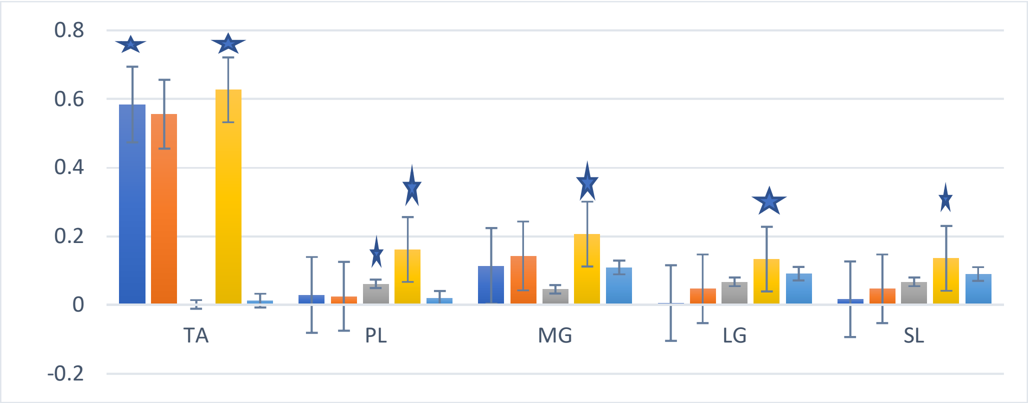

Figure 1. Electrical activity of muscles in first phase according to paired t-test between groups PHYSICAL TREATMENTS

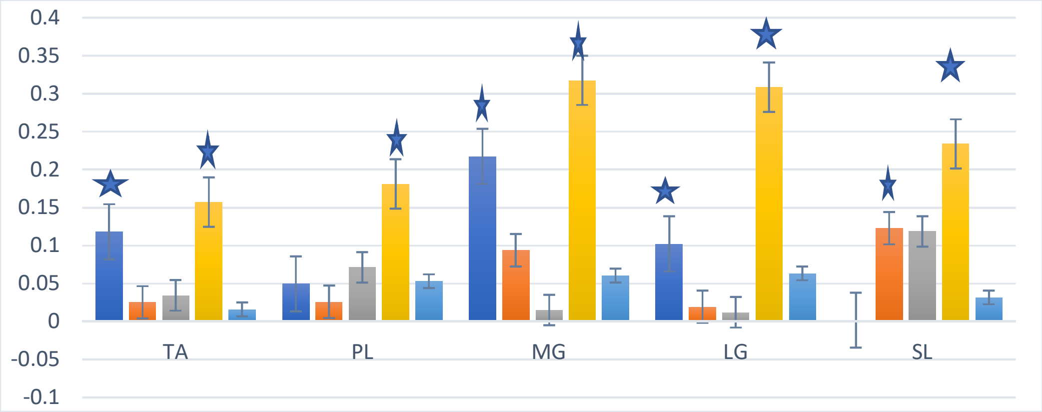

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Figure 2. Electrical activity of muscles in second phase according to paired t-test between groups

cant differences were observed between the plyometric and control group, and between the combined training group and both the balance and control groups. In the medial GM muscle, a significant difference was found between the combined with balance and control groups. No significant difference was observed in the lateral GM muscle between groups. In the SL muscle, significant differences were observed between balance with control and PNF groups. Additionally, differences were found between the plyometric group and both the balance and control group. Finally, a significant difference was observed between combined with balance and control groups (Table 4) (P<0.05).

Paired t-test results indicated that combined exercises significantly affected all five ankle muscles during the second jumping phase. Furthermore, plyometric training significantly affected the TA and both medial and lateral GM muscles. Balance training significantly affected the SL muscle, whereas PNF training showed no significant effect on any of the studied muscles (Table 5) (P<0.05). According to the ANOVA test, in the TA, differences were observed between the combined group and the balance, PNF, and control groups. No significant differences were observed in the PL muscle between any groups. In the medial GM muscle, significant differences were observed between the combined group and both the balance and control groups. Additionally, differences were observed between the plyometrics group and the balance, PNF, and control groups. In the lateral GM muscle, a difference was observed between the balance group and both the PNF and control groups. In the SL muscle, differences were observed between the combined group and the balance, PNF, and control groups. Furthermore, differences were observed between plyometrics training group and balance, PNF, and control groups (Table 6) (P<0.05).

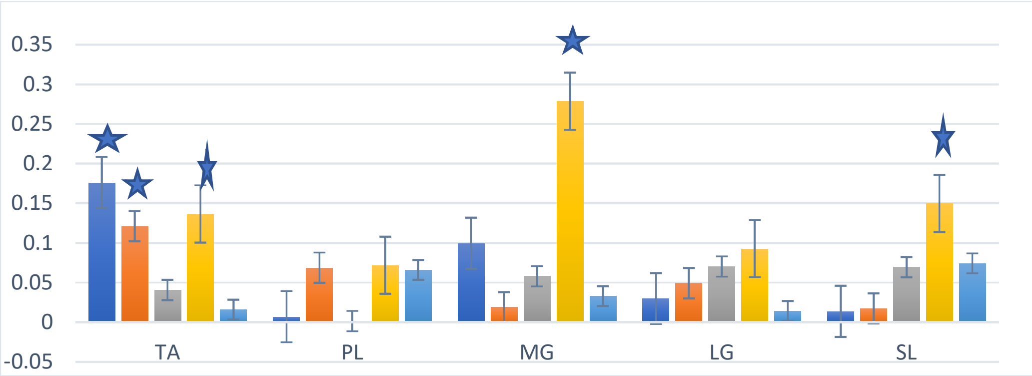

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Figure 3. Electrical activity of muscles in third phase according to paired t-test between groups

Table 3. The comparison of electrical activity of groups according to paired t-test in first phase

Muscle	Group	Mean±SD (95% CI)		95% CI of Difference	P
		Pre-test	Post-test		
TA	Plyometric	0.1261±0.0011 (0.125-0127)	0.0677±0.08 (0.038-0.098)	(-0.058) (-0.098-0.018)	0.004*
	Balance	0.1056±0.002 (0.105-0.107)	0.1612±0.078 (0.131-0.191)	(0.055) (0.015-0.095)	1.145
	PNF	0.1892±0.0034 (0.188-0.190)	0.191±0.0022 (0.190-0.192)	(0.002) (-0.038-0.042)	0.985
	Combined	(.2562±0.0054 (0.254-0.258)	0.129±0.0027 (0.127-0.131)	(-0.127) (-0.167-0.087)	0.001*
	Control	0.1892±0.0012 (0.188-0.190)	0.2022±0.0023 (0.201-0.203)	(0.013) (-0.027-0.053)	1.011
PL	Plyometric	0.3138±0.0056 (0.311-0.317)	0.284±0.034 (0.270-0.298)	(-0.030) (-0.070-0.010)	0.059
	Balance	0.3216±0.007 (0.318-0.326)	0.3473±0.0065 (0.343-0.351)	(0.025) (-0.015-0.065)	0.894
	PNF	0.2825±0.004 (0.281-0.285)	0.3442±0.0088 (0.339-0.349)	(0.061) (-0.021-0.101)	0.002*
	Combined	0.3949±0.0056 (0.392-0.398)	0.2331±0.0087 (0.228-0.238)	(-0.0162) (-0.202-0.122)	0.004*
	Control	0.3164±0.0078 (0.312-0.320)	0.3373±0.0067 (0.333-0.341)	(0.021) (-0.019-0.061)	0.998
Medial GM	Plyometric	0.425±0.0097 (0.420-0.430)	0.311±0.0065 (0.307-0.315)	(-0.114) (-0.154-0.074)	0.070
	Balance	0.3281±0.023 (0.317-0.339)	0.4712±0.0052 (0.469-0.473)	(0.143) (0.103-0.183)	0.655
	PNF	0.4239±0.0012 (0.423-0.425)	0.4699±0.0033 (0.468-0.472)	(0.046) (0.006-0.086)	1.656
	Combined	0.5102±0.0076 (0.506-0.514)	0.3033±0.006 (0.300-0.306)	(-0.207) (-0.247-0.167)	0.004*
	Control	0.3359±0.0054 (0.333-0.339)	0.4456±0.065 (0.413-0.479)	(0.110) (0.070-0.150)	0.996
Lateral GM	Plyometric	0.3514±0.0056 (0.348-0.354)	0.3455±0.025 (0.334-0.358)	(-0.005) (-0.045-0.035)	0.997
	Balance	0.2198±0.0087 (0.216-0.224)	0.3673±0.0033 (0.366-0.368)	(0.147) (0.107-0.187)	1.885
	PNF	0.3236±0.004 (0.322-0.326)	0.3913±0.0032 (0.390-0.392)	(0.067) (0.027-0.107)	1.465
	Combined	0.4202±0.056 (0.392-0.448)	0.2862±0.0054 (0.284-0.288)	(-0.134) (-0.174-0.094)	0.002*
	Control	0.2566±0.0087 (0.253-0.261)	0.3471±0.0087 (0.343-0.351)	(0.090) (0.050-0.130)	1.626
SL	Plyometric	0.3289±0.0098 (0.325-0.333)	0.3455±0.0066 (0.342-0.350)	(0.017) (-0.023-0.057)	1.223
	Balance	0.2198±0.0043 (0.218-0.222)	0.3673±0.0087 (0.363-0.371)	(0.147) (0.107-0.187)	0.704
	PNF	0.3236±0.0074 (0.320-0.328)	0.3913±0.0056 (0.388-0.394)	(0.067) (0.027-0.107)	0.884
	Combined	0.4202±0.0064 (0.417-0.423)	0.2862±0.0075 (0.282-0.290)	(-0.134) (-0.174-0.094)	0.001*
	Control	0.2566±0.0068 (0.253-0.261)	0.3471±0.0065 (0.343-0.351)	(0.090) (0.050-0.130)	0.696

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.Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.

*P<0.05

Table 4. The comparison of electrical activity of groups according to ANOVA test in first phase

Muscle	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P
TA	Combined-plyometric	(0.130) (0.085-0.175)	0.001*	Plyometric- balance	(-0.021) (-0.006-0.024)	0.839	Balance-control	(0,084) (0.039-0.129)	. 001*
	Combined-balance	(0.151) (0.106-0.196)	0.002*	Plyometric- PNF	(0.063) (0.018-0.108)	0.638	PNF- control	(0.001) (-0.045-0.045)	. 406
	Combined-PNF	(0.067) (0.022-0.112)	0.001*	Plyometric-control	(0.063) (0.018-0.108)	0.021*			
	Combined- control	(0.127) (0.082-0,172)	0.012*	Balance- PNF	(0.084) (0.039-0.129)	0.122			
PL	Combined- plyometric	(0.081) (-0.004-0.166)	0.067	Plyometric- balance	(0.008) (-0.047-0.063)	0.999	Balance-control	(0.089) (0.034-0.144)	. 375
	Combined- balance	(0.073) (0.018-0.128)	0.001*	Plyometric- PNF	(0.031) (-0.024-0.086)	0.837	PNF-control	(0.066) (0.011-0.121)	. 983
	Combined- PNF	(0.112) (0.057-0.167)	0.004*	Plyometric-control	(0.081) (0.026-0.136)	0.021*			
	Combined- control	(0.162) (0.107-0.217)	0.001*	Balance- PNF	(0.023) (-0.032-0.078)	0.696			
Medial GM	Combined- plyometric	(0.085) (-0.030-0.200)	0.179	Plyometric- balance	(0.097) (0.012-0.182)	0.092	Balance-control	(0.008) (-0.077-0.093)	1. 000
	Combined- balance	(0.182) (0.097-0.267)	0.003*	Plyometric- PNF	(0.001) (-0.084-0.086)	1.000	PNF-control	(0.088) (0.003-0.173)	. 166
	Combined- PNF	(0.086) (0.001-0.171)	0.168	Plyometric-control	(0.089) (0.004-0.174)	0.157			
	Combined- control	(0.174) (0.089-0.259)	0*	Balance- PNF	(0.0960 (0.011-0.181)	0.099			
Lateral GM	Combined- plyometric	(0.069) (-0.216-0.354)	0.691	Plyometric- balance	(0.131) (-0.154-0.416)	0.445	Balance-control	(0.036) (-0.249-0.321)	. 237
	Combined- balance	(0.200) (-0.085-0.485)	0.995	Plyometric- PNF	(0.028) (-0.257-0.313)	0.978	PNF-control	(0.067) (-0.218-0.352)	1. 000
	Combined- PNF	(0.097) (-0.188-0.382)	0.340	Plyometric-control	(0.095) (-0.190-0.380)	0.993			
	Combined- control	(0.164) (-0.121-0.449)	0.439	Balance- PNF	(0.103) (-0.182-0.388)	0.168			
SL	Combined- plyometric	(0.091) (-0.004-0.186)	0.090	Plyometric- balance	(0.109) (0.024-0.194)	0.026*	Balance-control	(0.164) (0.079-0.249)	. 004*
	Combined- balance	(0.200) (0.115-0.285)	0.001*	Plyometric- PNF	(0.006) (-0.079-0.091)	1.000	PNF-control	(0.061) (-0.024-0.146)	. 357
	Combined- PNF	(0.097) (0.012-0.182)	0.064	Plyometric-control	(0.073) (-0.012-0.158)	0.283			
	Combined- control	(0.164) (0.079-0.249)	0*	Balance- PNF	(0.103) (0.018-0.188)	0.038*			

*P<0.05.

PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.

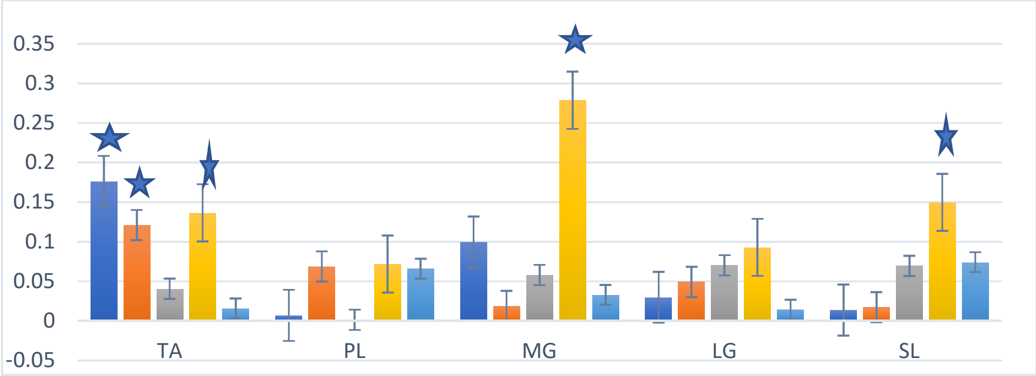
According to the results of the paired t-test for intragroup comparisons, it can be concluded that in the third phase of jumping, combined training had an effect on the TA, medial GM and SL muscles, as well as plyometric and balance trainings had significant effect on the TA muscle (Table 7) (P<0.05). The results of ANOVA test showed a difference in the medial GM muscle between the plyometric with balance, PNF and control groups. Furthermore, a difference was observed between the combined group and the control group. The lateral GM muscle demonstrated a significant difference between the combined group and the plyometric, PNF, and control groups. A significant difference was observed between the balance group and the control group, as well as between the plyometric group and the control group. A significant difference was observed in the SL muscle between the combined group and all other groups (Table 8) (P<0.05).

Table 5. The comparison of electrical activity of groups according to paired t-test in second phase

Muscle	Group	Mean±SD (95% CI)		M Difference (95% CI)	P
		Pre-test	Post-test		
TA	Plyometric	0.2603±0.021 (0.252-0.268)	0.1421±0.08 (0.111-0.173)	(-0.118) -(0.158-0.078)	0. 004*
	Balance	0.1803±0.041 (0.164-0.196)	0.3055±0.04 (0.286-0.326)	(0.126) (0.086-0.166)	1. 145
	PNF	0.2295±0.053 (0.210-0.250)	0.2639±0.05 (0.239-0.289)	(0.034) (-0.006-0.074)	0. 985
	Combined	0.3176±0.064 (0.291-0.345)	0.1604±0.06 (0.130-0.190)	(-0.158) (-0.198-0.118)	0. 001*
	Control	0.247±0.033 (0.233-0.261)	0.2629±0.03 (0.247-0.279)	(0.016) (-0.024-0.056)	1. 011
PL	Plyometric	0.4267±0.047 (0.410-0.444)	0.3771±0.043 (0.358-0.396)	(-0.050) (-0.090-0.010)	0. 554
	Balance	0.4326±0.058 (0.410-0.456)	0.4458±0.04 (0.426-0.466)	(0.013) (-0.027-0.053)	0. 449
	PNF	0.3393±0.06 (0.316-0.362)	0.4112±0.05 (0.386-0.436)	(0.072) (0.032-0.112)	1. 002
	Combined	0.7778±0.04 (0.763-0.793)	0.2511±0.07 (0.221-0.281)	(-0.527) (-0.567-0.487)	0. 002*
	Control	0.5248±0.03 (0.513-0.537)	0.7778±0.04 (0.763-0.793)	(0.253) (0.212-0.293)	0. 998
Medial GM	Plyometric	0.7975±0.05 (0.781-0.815)	0.5801±0.05 (0.555-0.605)	(-0.218) (-0.258-0.178)	0. 003*
	Balance	0.6831±0.06 (0.660-0.706)	0.7769±0.07 (0.742-0.812)	(0.094) (0.054-0.134)	0. 655
	PNF	0.5847±0.07 (0.558-0.612)	0.6997±0.06 (0.670-0.730)	(0.115) (0.075-0.155)	1. 656
	Combined	0.6753±0.05 (0.660-0.690)	0.3577±0.04 (0.338-0.378)	(-0.317) (-0.357-0.277)	0. 004*
	Control	0.5251±0.04 (0.510-0.540)	0.6854±0.075 (0.647-0.723)	(0.160) (0.120-0.200)	0. 996
Lateral GM	Plyometric	0.4998±0.07 (0.473-0.527)	0.3976±0.09 (0.353-0.443)	(-0.102) (-0.142-0.062)	0. 002*
	Balance	0.5991±0.07 (0.572-0.626)	0.4797±0.043 (0.459-0.501)	(-0.119) (-0.159-0.079)	1. 885
	PNF	0.3826±0.05 (0.366-0.400)	0.5032±0.04 (0.217-0.287)	(0.120) (0.080-0.160)	1. 465
	Combined	0.5201±0.04 (0.505-0.535)	0.3268±0.06 (0.297-0.357)	(-0.193) (-0.233-0.153)	0. 002*
	Control	0.3862±0.03 (0.376-0.396)	0.4496±0.03 (0.435-0.465)	(0.064) (0.024-0.104)	1. 626
SL	Plyometric	0.5645±0.06 (0.543-0.587)	0.5663±0.04 (0.546-0.586)	(0.001) (-0.039-0.041)	1. 223
	Balance	0.3423±0.08 (0.310-0.374)	0.5625±0.06 (0.533-0.593)	(0.221) (0.181-0.261)	0. 031*
	PNF	0.4198±0.08 (0.388-0.452)	0.5384±0.05 (0.513-0.563)	(0.118) (0.078-0.158)	0. 884
	Combined	0.5546±0.07 (0.528-0.582)	0.3208±0.04 (0.301-0.341)	(-0.234) (-0.274-0.194)	0. 001*
	Control	0.3728±0.008 (0.369-0.377)	0.5045±0.011 (0.485-0.525)	(0.132) (0.092-0.172)	0. 696

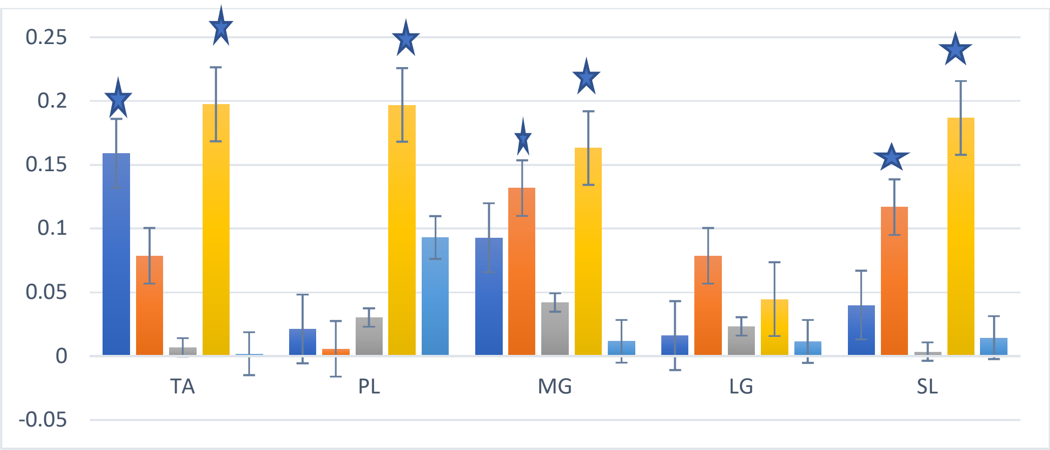
PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.
*P<0.05.



PHYSICAL TREATMENTS

Figure 4. Electrical activity of muscles in third phase according to paired t-test between groups



PHYSICAL TREATMENTS

Figure 5. Electrical activity of muscles in fourth phase according to paired t-test between groups

According to the results of the paired t-test for intra-group comparisons, combined training significantly affected the TA, PL, medial GM, and SL muscles during the fourth jumping phase. Additionally, plyometric training affected the TA muscle, and balance training impacted the medial GM and SL muscle (Table 9) (P<0.05). The results of ANOVA test showed a difference in the anterior large muscle between the combined group, and the PNF and control groups. Also, a significant difference was observed between plyometric group with control group. Differences were also found between the balance group and both the combined and control groups. In the SL muscle, a difference was observed between the combined group and the balance and control groups (Table 10) (P<0.05).

Discussion

This study showed that plyometric, balance and PNF trainings each had a positive impact on electromyography function of ankle muscles and reduced the rate of ankle injury. However, combined training (plyometric, balance and PNF) exhibited a greater impact on function muscles across four phases of jumping test. Plyometric training demonstrated considerable effectiveness in preventing ankle injuries among basketball players [30]. Studies have demonstrated that incorporating plyometric exercises into the training regimen of basketball players enhances ankle stability, muscular strength, and proprioception. These adaptations contribute to a reduced risk of ankle injuries during the dynamic movements involved in basketball [31]. Also, a targeted plyometric program significantly decreased the incidence of ankle sprains in basketball players, and plyometric interventions posi-

Table 6. The Comparison of electrical activity of groups according to ANOVA test in second phase

Muscle	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P
TA	Combined-plyometric	(0.058) (-0.052-0.168)	0.301	Plyometric-balance	(-0.080 (-0.165-0.005)	0.061	Balance-control	(0.043) (-0.042-0.128)	0.180
	Combined-balance	(0.138) (0.053-0.223)	0.001*	Plyometric-PNF	(0.030) (-0.055-0.115)	0.832	PNF-control	(-0.007) (-0.092-0.078)	0.977
	Combined-PNF	(0.088) (0.003-0.173)	0.030*	Plyometric-control	(0.013) (-0.072-0.098)	0.992			
	Combined- control	(0.108) (0.023-0.193)	0.004*	Balance-PNF	(0.050) (-0.035-0.135)	0.455			
PL	Combined-plyometric	(-0.002) (-0.112-0.108)	1.000	Plyometric-balance	(-0.006) (-0.091-0.079)	0.617	Balance-control	(0.008) (-0.081-0.097)	0.377
	Combined-balance	(0.004) (-0.081-0.089)	0.632	Plyometric-PNF	(0.087) (-0.002-0.176)	0.996	PNF-control	(-0.085) (-0.174-0.004)	1.000
	Combined-PNF	(0.085) (-0.004-0.174)	0.995	Plyometric-control	(0.002) (-0.087-0.091)	0.994			
	Combined-control	(0.001) (-0.089-0.089)	0.992	Balance-PNF	(0.093) (0.004-0.182)	0.393			
Medial GM	Combined-plyometric	(-0.122) (-0.232-0.012)	0.155	Plyometric-balance	(0.114) (0.029-0.199)	0.002*	Balance-control	(0.159) (0.074-0.244)	0.933
	Combined-balance	(-0.008) (-0.093-0.077)	0.004*	Plyometric-PNF	(0.213) (0.128-0.298)	0.001*	PNF-control	(0.060) (-0.025-0.145)	0.794
	Combined-PNF	(0.091) (0.006-0.176)	0.420	Plyometric-control	(0.273) (0.188-0.358)	0.001*			
	Combined-control	(0.151) (0.066-0.236)	0.047*	Balance-PNF	(0.099) (0.014-0.184)	0.303			
Lateral GM	Combined- plyometric	(0.020) (-0.090-0.130)	0.994	Plyometric-balance	(-0.099) (-0.184-0.014)	0.305	Balance-control	(0.213) (0.128-0.298)	0.001*
	Combined-balance	(-0.079) (-0.164-0.006)	0.539	Plyometric-PNF	(0.117) (0.032-0.202)	0.159	PNF- control	(-0.003) (-0.088-0.082)	0.901
	Combined-PNF	(0.137) (0.052-0.222)	0.065	Plyometric-control	(0.114) (0.029-0.199)	0.197			
	Combined-control	(0.134) (0.049-0.219)	0.085	Balance-PNF	(0.216) (0.131-0.301)	0.001*			
SL	Combined-plyometric	(-0.011) (-0.121-0.099)	1.000	Plyometric-balance	(0.222) (0.137-0.307)	0.001*	Balance-control	(0.052) (-0.033-0.137)	0.969
	Combined-balance	(-0.233) (-0.318-0.148)	0*	Plyometric-PNF	(0.145) (0.060-0.230)	0.025*	PNF- control	(0.129) (0.044-0.214)	0.865
	Combined-PNF	(-0.134) (-0.219-0.049)	0.044*	Plyometric-control	(0.192) (0.107-0.277)	0.002*			
	Combined-control	(-0.181) (-0.266-0.096)	0.003*	Balance-PNF	(-0.077) (-0.162-0.008)	0.478			

PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.

*P<0.05

tively impacted neuromuscular control. The influence of plyometric training on neuromuscular performance and injury risk in young athletes has been investigated, highlighting it as a crucial factor in preventing ankle injuries [32]. Balance training has proven to be a valuable component in preventing ankle injuries among basketball players [33]. In addition, a significant reduction in the incidence of ankle sprains was observed among basketball players who underwent a targeted balance training program. These findings support the role of balance training in enhancing proprioception and reducing the risk of ankle injuries in sports, including basketball [34]. Also, a study incorporated balance training into the regimen of basketball players evaluated its effects using functional assessments, including the Jump on Step Test. The findings revealed improvements in ankle muscle function, enhanced proprioception, and a decreased risk of ankle injuries among those who underwent balance training [35]. PNF training has demonstrated positive effects on preventing ankle injuries among basketball

Table 7. The comparison of electrical activity of groups according to paired t-test in third phase

Muscle	Group	Mean±SD (95% CI)		Mean Differences (95% CI)	P
		Pre-test	Post-test		
TA	Plyometric	0.3411±0.04 (0.326-0.356)	0.1651±0.022 (0.156-0.174)	(-0.176) (-0.196-0.156)	0.004*
	Balance	0.2211±0.05 (0.203-0.239)	0.3421±0.043 (0.325-0.359)	(0.121) (0.101-0.141)	0.032*
	PNF	0.2333±0.07 (0.206-0.260)	0.2937±0.03 (0.282-0.306)	(0.061) (0.041-0.081)	0.985
	Combined	0.3285±0.03 (0.318-0.340)	0.1919±0.088 (0.158-0.226)	(-0.137) (-0.157-0.117)	0.001*
	Control	0.3146±0.02 (0.307-0.323)	0.2986±0.053 (0.276-0.322)	(-0.016) (-0.036-0.004)	1.011
PL	Plyometric	0.2701±0.06 (0.248-0.292)	0.2631±0.023 (0.254-0.272)	(-0.007) (-0.027-0.013)	1.311
	Balance	0.347±0.08 (0.317-0.377)	0.4166±0.054 (0.394-0.440)	(0.070) (0.050-0.090)	0.894
	PNF	0.2571±0.06 (0.235-0.279)	0.4071±0.03 (0.395-0.419)	(0.150) (0.130-0.170)	1.002
	Combined	0.3311±0.043 (0.316-0.346)	0.2592±0.076 (0.229-0.289)	(0.072) (0.092-0.052)	0.906
	Control	0.2709±0.06 (0.249-0.293)	0.3368±0.084 (0.299-0.375)	(0.066) (0.046-0.086)	0.998
Medial GM	Plyometric	0.6183±0.043 (0.603-0.633)	0.4188±0.066 (0.393-0.445)	(-0.199) (-0.219-0.179)	0.088
	Balance	0.4116±0.03 (0.400-0.424)	0.6306±0.076 (0.600-0.662)	(0.219) (0.199-0.239)	0.655
	PNF	0.4391±0.011 (0.434-0.444)	0.5971±0.064 (0.571-0.623)	(0.158) (0.138-0.178)	1.656
	Combined	0.5728±0.087 (0.541-0.605)	0.2969±0.007 (0.294-0.300)	(-0.276) (-0.296-0.256)	0.004*
	Control	0.4016±0.07 (0.375-0.429)	0.5345±0.039 (0.518-0.552)	(0.133) (0.113-0.153)	0.996
Lateral GM	Plyometric	0.1513±0.066 (0.127-0.175)	0.1214±0.043 (0.105-0.137)	(-0.030) (-0.050-0.010)	0.661
	Balance	0.2689±0.054 (0.248-0.290)	0.1761±0.04 (0.161-0.191)	(-0.093) (-0.113-0.073)	1.885
	PNF	0.1813±0.047 (0.164-0.198)	0.2516±0.07 (0.221-0.283)	(0.071) (0.051-0.091)	1.465
	Combined	0.2705±0.04 (0.256-0.286)	0.1776±0.064 (0.151-0.205)	(-0.093) (-0.113-0.073)	0.741
	Control	0.1876±0.044 (0.170-0.206)	0.2017±0.061 (0.175-0.229)	(0.014) (-0.006-0.034)	1.626
SL	Plyometric	0.2559±0.03 (0.245-0.267)	0.2696±0.068 (0.241-0.299)	(0.074) (0.055-0.093)	1.223
	Balance	0.1909±0.05 (0.169-0.213)	0.3082±0.05 (0.286-0.330)	(0.117) (0.097-0.137)	0.663
	PNF	0.2732±0.06 (0.251-0.295)	0.3428±0.044 (0.324-0.362)	(0.070) (0.050-0.090)	0.884
	Combined	0.3792±0.066 (0.353-0.405)	0.2296±0.043 (0.211-0.249)	(-0.149) (-0.169-0.129)	0.001*
	Control	0.2209±0.009 (0.217-0.225)	0.2951±0.04 (0.278-0.312)	(0.014) (-0.006-0.034)	0.696

PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.

*P<0.05

Table 8. The comparison of electrical activity of groups according to ANOVA test in third phase

Muscle	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P
TA	Combined-plyometric	(0.012) (-0.098-0.122)	0.999	Plyometric- balance	(-0.120) (-0.205-0.035)	0.099	Balance-control	(0.060) (-0.025-0.145)	0.313
	Combined-balance	(0.107) (0.022-0.192)	0.174	Plyometric- PNF	(-0.108) (-0.193-0.023)	0.172	PNF-control	(0.035) (-0.050-0.120)	0.457
	Combined-PNF	(0.095) (0.010-0.180)	0.281	Plyometric-control	(-0.027) (-0.112-0.058)	0.982			
	Combined- control	(0.015) (-0.070-0.100)	0.999	Balance- PNF	(0.012) (-0.073-0.097)	0.999			
PL	Combined- plyometric	(0.061) (-0.101-0.069)	0.694	Plyometric- balance	(-0.077) (-0.162-0.008)	0.470	Balance-control	(0.164) (0.079-0.249)	0.605
	Combined- balance	(0.074) (-0.011-0.159)	0.996	Plyometric- PNF	(0.013) (-0.072-0.098)	0.999	PNF- control	(0.061) (-0.024-0.146)	0.991
	Combined- PNF	(0.060) (-0.025-0.145)	0.518	Plyometric-control	(-0.001) (-0.086-0.084)	0.996			
	Combined- control	(-0.045) (-0.155-0.065)	0.812	Balance- PNF	(0.090) (0.005-0.175)	0.311			
Medial GM	Combined- plyometric	(0.161) (0.076-0.246)	0.941	Plyometric- balance	(0.206) (0.121-0.291)	0.008*	Balance-control	(0.013) (-0.072-0.098)	1.000
	Combined- balance	(0.134) (0.049-0.219)	0.066	Plyometric- PNF	(0.179) (0.094-0.264)	0.031*	PNF- control	(0.012) (-0.098-0.122)	0.972
	Combined- PNF	(0.171) (0.086-0.256)	0.181	Plyometric-control	(0.216) (0.131-0.301)	0.006*			
	Combined- control	(0.120) (0.035-0.205)	0.049*	Balance- PNF	(-0.027) (-0.112-0.058)	0.991			
Lateral GM	Combined- plyometric	(0.002) (-0.083-0.087)	0.002*	Plyometric- balance	(-0.118) (-0.203-0.033)	0.003*	Balance-control	(0.030) (-0.055-0.115)	0.046*
	Combined- balance	(0.090) (0.005-0.175)	1.000	Plyometric- PNF	(-0.070) (-0.155-0.015)	0.866	PNF- control	(0.013) (-0.072-0.098)	0.084
	Combined- PNF	(0.084) (0.002-0.169)	0.040*	Plyometric-control	(-0.036) (-0.121-0.049)	0.002*			
	Combined- control	(0.122) (0.037-0.207)	0.006*	Balance- PNF	(0.048) (-0.037-0.133)	0.982			
SL	Combined- plyometric	(0.187) (0.102-0.272)	0.001*	Plyometric- balance	(0.065) (-0.020-0.150)	0.133	Balance-control	(0.008) (-0.081-0.097)	0.029*
	Combined- balance	(0.106) (0.021-0.191)	0.001*	Plyometric- PNF	(-0.017) (-0.102-0.068)	0.969	PNF- control	(-0.085) (-0.174-0.004)	0.816
	Combined- PNF	(0.061) (-0.049-0.171)	0.002*	Plyometric-control	(0.035) (-0.050-0.120)	0.717			
	Combined- control	(0.158) (0.073-0.243)	0.999	Balance- PNF	(-0.082) (-0.167-0.003)	0.311			

*P<0.05.

PHYSICAL TREATMENTS

Abbreviations: PNF, proprioceptive neuromuscular facilitation; CI, confidence interval; GM, gastrocnemius medialis.

players. Significant studies emphasize the efficacy of PNF techniques in enhancing proprioception and reducing the risk of ankle sprains [36]. Incorporating PNF exercises of basketball players has been shown to improve joint position sense and reduce the incidence of ankle injuries, emphasizing the role of PNF in enhancing neuromuscular control and decreasing the likelihood of ankle sprains in athletes [37]. Combined training, integrating plyometric and balance exercises, has been shown to be effective in reducing the rate of ankle injuries. Plyometric exercises focus on explosive movements, while balance training enhances proprioception and stability [38]. On the other hand, plyometric exercises focus on explosive movements that improve power and speed, while balance training helps improve proprioception and stability around the ankle joint. In addition, athletes who performed plyometric and balance exercises had better overall ankle stability and lower rates of injury

Table 9. The comparison of electrical activity of groups according to paired t-test in forth phase

Muscle	Group	Mean±SD (95% CI)		Mean Differences (95% CI)	P
		Pre-test	Post-test		
TA	Plyometric	0.2536±0.08 (0.224-0.284)	0.0945±0.065 (0.069-0.121)	(-0.159) (-0.199-0.119)	0.004*
	Balance	0.1142±0.06 (0.093-0.135)	0.1929±0.078 (0.162-0.224)	(0.079) (0.039-0.119)	0.799
	PNF	0.2068±0.054 (0.188-0.226)	0.2137±0.065 (0.187-0.241)	(0.007) (-0.033-0.047)	0.985
	Combined	0.3603±0.0788 (0.330-0.390)	0.1629±0.08 (0.133-0.193)	(-0.197) (-0.237-0.157)	0.001*
	Control	0.2167±0.055 (0.197-0.237)	0.2148±0.05 (0.195-0.235)	(-0.002) (-0.042-0.038)	1.011
PL	Plyometric	0.3007±0.043 (0.286-0.316)	0.2795±0.087 (0.246-0.314)	(-0.021) (-0.061-0.019)	1.311
	Balance	0.3248±0.05 (0.308.0.342)	0.3191±0.065 (0.291-0.347)	(-0.006) (-0.046-0.034)	0.894
	PNF	0.3338±0.06 (0.312-0.356)	0.3641±0.07 (0.336-0.392)	(0.030) (-0.010-0.070)	1.002
	Combined	0.4375±0.077 (0.409-0.467)	0.2406±0.044 (0.222-0.260)	(-0.197) (-0.237-0.157)	0.009*
	Control	0.2525±0.06 (0.231-0.275)	0.3618±0.05 (0.340-0.384)	(0.109) (0.069-0.149)	0.998
Medial GM	Plyometric	0.4234±0.05 (0.405-0.441)	0.3306±0.077 (0.299-0.363)	(-0.092) (-0.132-0.052)	0.088
	Balance	0.2708±0.04 (0.256-0.286)	0.4025±0.04 (0.388-0.418)	(0.132) (0.092-0.172)	0.002*
	PNF	0.4387±0.076 (0.410-0.468)	0.4807±0.065 (0.453-0.509)	(0.042) (0.002-0.082)	1.656
	Combined	0.4606±0.06 (0.440-0.482)	0.2975±0.087 (0.261-0.335)	(-0.163) (-0.203-0.123)	0.004*
	Control	0.3602±0.05 (0.342-0.378)	0.3718±0.05 (0.354-0.390)	(0.012) (-0.028-0.052)	0.996
Lateral GM	Plyometric	0.1346±0.044 (0.119-0.151)	0.1185±0.06 (0.097-0.141)	(-0.016) (-0.056-0.024)	0.661
	Balance	0.1151±.0.07 (0.084-0.146)	0.1364±0.05 (0.114-0.158)	(0.021) (-0.019-0.061)	1.885
	PNF	0.1881±0.066 (0.162-0.214)	0.2113±0.06 (0.185-0.237)	(0.023) (-0.017-0.063)	1.465
	Combined	0.2466±0.087 (0.215-0.279)	0.2019±0.07 (0.173-0.231)	(-0.045) (-0.085-0.005)	0.741
	Control	0.1788±0.06 (0.157-0.201)	0.1903±0.091 (0.151-0.229)	(0.011) (-0.029-0.051)	1.626
SL	Plyometric	0.2704±0.05 (0.253-0.287)	0.3104±0.055 (0.286-0.334)	(0.040) (0.001-0.080)	1.223
	Balance	0.1925±0.07 (0.070-0.165)	0.3093±0.065 (0.281-0.337)	(0.116) (0.076-0.156)	0.041*
	PNF	0.3355±0.0434 (0.321-0.351)	0.3391±0.07 (0.308-0.370)	(0.003) (-0.037-0.043)	0.884
	Combined	0.4674±0.03 (0.455-0.479)	0.2807±0.06 (0.255-0.307)	(-0.186) (-0.226-0.146)	0.001*
	Control	0.2459±0.065 (0.222-0.270)	0.2314±0.06 (0.206-0.256)	(-0.015) (-0.055-0.025)	0.696

PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.
*P<0.05

Table 10. The comparison of electrical activity of groups according to ANOVA test in fourth phase

Muscle	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P	Group	Mean Difference (95% CI)	P
TA	Combined-plyometric	(0.106) (-0.026-0.238)	0.116	Plyometric-balance	(0.140) (-0.042-0.322)	0.385	Balance-control	(0.078) (-0.144-0.300)	0.001*
	Combined-balance	(0.246) (0.124-0.368)	0.299	Plyometric-PNF	(0.047) (-0.075-0.169)	0.120	PNF- control	(-0.065) (-0287-0.157)	0.992
	Combined-PNF	(0.153) (0.031-0.257)	0.001*	Plyometric-control	(0.037) (-0.085-0.159)	0.046*			
	Combined- control	(0.144) (0.022-0.266)	0.001*	Balance- PNF	(-0.099) (-0.221-0.023)	0.001*			
PL	Combined- plyometric	(0.137) (-0.085-0.359)	0.968	Plyometric-balance	(-0.024) (0.246-0.198)	0.994	Balance- control	(0.047) (-0.075-0.169)	1.000
	Combined- balance	(0.133) (-0.109-0.355)	0.999	Plyometric-PNF	(-0.033) (-0.255-0.189)	0.978	PNF- control	(0.037) (-0.085-0.159)	0.739
	Combined- PNF	(0.104) (-0.118-0.326)	1.000	Plyometric-control	(0.185) (-0.037-0.407)	0.923			
	Combined- control	(-0.048) (-0.270-0.174)	0.596	Balance- PNF	(-0.009) (-0.231-0.213)	0.992			
Medial GM	Combined- plyometric	(0.038) (-0.184-0.260)	0.970	Plyometric-balance	(0.152) (-0.070-0.374)	0.086	Balance- control	(0.275) (0.053-0.497)	0.577
	Combined- balance	(-0.190) (-0.412-0.032)	0.994	Plyometric-PNF	(-0.016) (-0.238-0.206)	0.999	PNF- control	(0.132) (-0.090-0.354)	0.996
	Combined- PNF	(-0.022) (-0.244-.200)	0.996	Plyometric-control	(0.063) (-0.159-0.285)	0.831			
	Combined- control	(0.101) (-0.121-0.321)	0.461	Balance- PNF	(-0.168) (-0.390-0.054)	0.577			
Lateral GM	Combined- plyometric	(0.112) (-0.110-0.334)	0.673	Plyometric-balance	(0.020) (-0.202-0.242)	0.110	Balance- control	(-0.016) (-0.238-0.206)	0.810
	Combined- balance	(0.132) (-0.090-0.354)	0.868	Plyometric-PNF	(-0.053) (-0.275-0.169)	0.478	PNF- control	(0.063) (-0.159-0.285)	0.831
	Combined- PNF	(0.059) (-0.163-0.281)	0.110	Plyometric-control	(0.068) (-0.154-0.290)	0.673			
	Combined- control	(-0.004) (-0.226-0.218)	0.921	Balance- PNF	(-0.073) (-0.295-0.149)	0.921			
SL	Combined- plyometric	(0.197) (-0.025-0.419)	0.101	Plyometric-balance	(0.078) (-0.144-0.300)	0.273	Balance- control	(0.153) (0.031-0.257)	0.596
	Combined- balance	(0.275) (0.053-0.497)	0.001*	Plyometric-PNF	(-0.065) (-0287-0.157)	0.453	PNF- control	(0.144) (0.022-0.266)	0.970
	Combined- PNF	(0.132) (-0.090-0.354)	0.922	Plyometric-control	(0.024) (-0.198-0.246)	0.971			
	Combined- control	(0.221) (-0.001-0.443)	0.024*	Balance- PNF	(-0.143) (-0.365-0.079)	0.478			

*P<0.05.

PHYSICAL TREATMENTS

Abbreviations: PNF: Proprioceptive neuromuscular facilitation; CI: Confidence interval; GM: Gastrocnemius medialis.

compared to those who did not perform these combined interventions [39]. On the other hand, combined training, including plyometric and balance, improves ankle power and stability but showed no effect on the range of motion and coordination. Therefore, it is crucial to note that individual factors, such as range of motion, can influence the risk factors for ankle sprain in youth sports [40]. By combining plyometric and PNF exercises in a structured training program, athletes can benefit from the synergistic effects of both modalities. Plyometric training improves power and explosive strength, while PNF techniques enhance proprioception, coordination, and neuromuscular control. Together, these components can help athletes develop better ankle stability and reduce the risk of injuries [41]. While combined training with plyometric and PNF exercises can be beneficial, it is important to consider potential drawbacks and limitations. Several studies suggests that integrating these two training modalities can lead to improvements in muscle activation patterns, and functional performance, potentially contributing to a reduced risk of ankle injuries in athletes. However, this combined practice did not have a significant impact on balance and coordination [41]. Research supports the effectiveness of combined training involving balance and PNF exercises in reducing the rate of ankle injuries. These practices are also effective in neuromuscular and proprioceptive training program in preventing ankle ligament injuries in athletes. Furthermore, the positive impact of neuromuscular and proprioceptive training on injury prevention emphasizes the importance of balance exercises [42]. Balance training and PNF exercises improve proprioception, which is the body's ability to sense its position, movement, and balance. By enhancing proprioception through targeted exercises, athletes can better control their movements and respond to lateral forces, reducing the risk of ankle injuries caused by instability or poor coordination. While combined training with balance and PNF exercises can be beneficial for reducing the rate of ankle injuries, it is crucial to consider potential drawbacks and limitations. It has been demonstrated that combined (balance and PNF) training improves the stability, coordination and range of motion, but it has insufficient impact on enhancing the strength and power [43]. This research showed that plyometric, balance exercises, and PNF individually affect ankle muscles during different phases of a box jump test. However, combined exercises demonstrated a superior and greater effect across all four jump phases in basketball players' ankle muscles. In addition, combined exercises can be used to improve the electrical ankle muscle activity among basketball players or even to prevent ankle injuries. Since most ankle injuries occur during forward movement, the phasing of the test has significantly contributed to a more accurate examination of the ankle muscle activity. Moreover, in each examined phase, muscles undergo concentric and eccentric contractions. Weakness in each of the phases and muscles involved causes ankle injury under certain conditions [44]. Thus, it is concluded that a series of injury prevention exercises to strengthen and improve each of the muscles involved in different phases is necessary. The integration of plyometric, balance, and PNF training demonstrates a collective positive impact on preventing ankle injuries. Research consistently supports the individual efficacy of these methods, with studies highlighting improved strength, stability, and proprioception. However, the combining approach appears to yield a more comprehensive and heightened preventative effect. This amalgamation enhances neuromuscular control, addresses multiple facets of ankle stability, and fosters a more robust injury prevention strategy. The novel findings of this study provide a significant advancement in ankle injury prevention by offering the first detailed analysis of muscle activation patterns across all four critical phases of single-leg jumps in basketball players. Unlike previous research that examined general muscle activity, our phase-specific EMG data precisely identifies neuromuscular deficits during preparation, takeoff, flight, and landing phases. This granular understanding allows for targeted rehabilitation protocols that address phase-specific weaknesses, fundamentally changing how ankle stability training is approached in sports medicine. The demonstrated greater effectiveness of combined training underscores its potential as an evidence-based intervention, providing coaches and clinicians with actionable insights to reduce ankle injury rates among athletes. By connecting biomechanical evidence with practical training applications, this work establishes a new standard for injury prevention strategies in basketball and similar jumping sports.

Conclusion

The findings of this study demonstrate that while isolated plyometric, balance, and PNF training protocols each induce specific neuromuscular adaptations in the ankle stabilizers of young basketball players, their efficacy is limited to particular muscles and phases of a single-leg jump. The combined training protocol, integrating all three modalities, proved to be the most comprehensive and effective intervention. It elicited significant improvements in EMG activity across all four biomechanically defined phases of the jump (preparation, takeoff, flight, and landing), impacting the TA, PL, medial and lateral gastrocnemius, and SL muscles. This superior effect is likely due to the synergistic nature of combined training, which simultaneously enhances muscular strength, power, proprioceptive acuity, and dynamic neuromuscular control. Therefore, for clinicians and strength coaches aiming to optimize ankle stability and mitigate injury risk in basketball players, a multimodal training approach is strongly recommended over single-focus protocols. Implementing such a combined program as part of a regular warm-up or conditioning routine could provide a more robust defense against the high incidence of ankle sprains in this athletic population. Future research should investigate the long-term effects of this combined training on actual ankle injury rates and its applicability to other sports and demographic groups.

Research limitations

This research has several limitations. The study sample was limited to young male players (12–16 years old) with no history of ankle injury, which restricts the generalizability of the findings. The short, 8-week training duration may be insufficient to reveal long-term effects. The focus was also narrow, as EMG activity was measured only during single-leg jumps and not during more complex, game-like movements. Furthermore, the study design was unblinded, introducing potential bias since both participants and researchers were aware of group assignments. While muscle activity was measured, the actual incidence of injuries was not tracked. Consequently, these results may not be applicable to females, older athletes, or other sports.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Institute of Physical Education and Sport Sciences (Code: IR.SKU.REC.1400.075).

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Authors' contributions

Study design, training implementation data analysis, manuscript writing: Nayeb Ahmadpour; Supervision, data collection, manuscript review: Banafsheh Mohammadi; Methodology support, statistical analysis, manuscript editing: Mohammad Rabiei.

Conflict of interest

The authors declared no conflicts of interest.

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