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Title: Comparative Effects of Plyometric, Balance, PNF, and Combined Training on Ankle Muscle Activation in Basket-ball Players

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Abstract:

Background: Basketball, a popular sport, often leads to ankle injuries, prompting the need for effective preventive training. Has been illustrated that plyometric, balance and PNF trainings effect to reduce the injury rate between basketball players but they are not enough to enhance the electrical activities of ankle muscles.

Objectives: This study aimed to compared the effects of plyometric, balance, PNF (proprioceptive neuromuscular facilitation) and combined trainings on ankle muscle electrical activity (TA, PL, GM, SL) during single-leg jumps. While previous studies have examined ankle muscle activation during jumping, none have systematically analyzed electromyographic patterns across all four biomechanical phases; our study provides the first comprehensive phase-by-phase assessment to identify precise neuromuscular deficits and optimize injury prevention strategies for basketball players.

Method: 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.

Result: Results indicated that combined training was most effective in reducing electrical ankle activity. 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 ideal for warm-up protocols.

Keywords: Ankle muscle activation, jump phase analysis, basketball injury prevention, combined training

Highlights

- Ankle injury prevention is crucial – Plyometric, balance, and PNF training each help but aren't enough alone. A combined approach works best.

- Training impacts muscle activity differently – Plyometrics reduce ankle muscle activation in jump phases. Balance training affects some muscles. PNF shows no effect.

- Combined training is most effective – It strengthens ankles and reduces injury risk better than single-method training, making it ideal for warm-ups.

Plain language summary

This study found that while plyometric, balance, and 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 has little impact. However, combining all three methods strengthens ankles more effectively, making it the best warm-up strategy to prevent injuries. The takeaway? Basketball players should integrate jump, balance, and stretching exercises into their routines for optimal ankle protection.

Background

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 injuries are among the most common types of injuries in basketball, posing a significant challenge for players, coaches, and medical professionals(4). 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 with a had 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 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 are including stretching exercises that are effective in the range of motion, and showed that this group of exercises is designed based on neural patterns, and in addition to increasing the range of motion, it reduces spasms and accelerates recovery and PNF exercises do not have a significant effect on feedback time to the stimulus and 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). Because of that basketball is a sport with high risk of ankle injury a comparative training program is necessary to prevent ankle injury. In this research, the electrical activity of the ankle muscles of basketball players between five training groups in the jumping test has been investigated

Objectives

This study objectively evaluated the effectiveness of plyometric, balance, and PNF training protocols in preventing ankle injuries among 75 competitive basketball players through electromyographic analysis during single-leg jumps. The key findings demonstrated that while plyometric training significantly reduced muscle activation in ankle stabilizers (particularly tibialis anterior and gastrocnemius) during critical jump phases and balance training showed selective benefits, 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 muscle activation patterns across all movement phases. These evidence-based results suggest that multimodal training interventions may offer the most effective strategy for ankle injury prevention in basketball, though further longitudinal research is needed to validate these findings and establish optimal implementation protocols.

Methods

In this study were selected 75 basketball players (aged 17.26±0.24 years; height 182.38±11.7 m; body mass 80.82±3.04 kg; BMI 24.38±1.36 kg.m^2), the study population consisted of all young male basketball players aged 16 to 18 without a history of ankle injury and with two years of basketball sport experiences in the city of Shahrekord city, southwest Iran. The participants were all right-hand and foot dominant, participants were randomly assigned to training groups, and one-way ANOVA confirmed no significant baseline differences in demographic characteristics (all p-values > 0.05), ensuring group comparability at study initiation and participants divided in five group of 15 people with 5diffrent types training in warm up period before starting basketball training including(table 1): plyometric, balance, PNF, combined(plyometric, balance and PNF) and control groups that control group did their basketball routine practice without any redundant training for warm up and the protocol trainings for other groups optimized in the same time for 8 weeks (18) (table 2). Before starting the study, the purpose and work process were explained to the subjects, then all the studied subjects voluntarily signed the consent form to participate in the study. The subjects were also assured they could withdraw from the study whenever they wished. After performing anthropometric measurements (age, height, weight, BMI), functional factors strength, endurance, power and range of motion were measured by the researcher as pre-test. Then, the experimental groups under the same conditions performed 4 types of training methods (plyometric, balance, PNF and combination) in a time of 30 to 45 minutes in each session in addition to their skill exercises in 3 sessions per week during 8 weeks. The researcher directly supervised the groups. The exercise program of the experimental groups was determined by observing the principle of overload and gradually increasing 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 changed from an easy level with low pressure to a hard level with high pressure during eight weeks according to the principle of overload. The control group simultaneously performed their usual exercises in training sessions. After the training period in experimental groups and control group, the functional factors were measured as post-test by the researcher. In this research, has been used to record the electrical activity of muscles by 8-channel biofeedback electromyography device, Pro-Comp Infiniti model, made in Canada, with a bandwidth of 2000-5(19). The targeted muscles encompassed the tibialis anterior, PL, GM, and SL (20). Before of 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 which assessed include: tibialis anterior, peroneus longus, gastrocnemius (media land lateral) and soleus. 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 customize electrode placement. Informed consent was obtained, and ethical considerations were upheld throughout the study, adhering to ethical guidelines. After preparing and set up the measuring and obtaining maximum strength of the ankle muscles (MVIC) were measured and the subjects were performed the single jump test with dominant foot (right) on a 30 cm box (21). After the assessment in the pre-test, the groups performed plyometric, balance, PNF and combined exercises (plyometric and balance and PNF) in addition to basketball exercises, and the control group (only basketball exercises) continued(22). For assessing more accurate the jump test was divided into four different phases , and the activity of each muscle in each phase was examined between five training groups, and here we will divide the phases(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 and 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 and 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 also 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). After obtaining the amount of activity of each muscle in the pre-test and post-test in the jump test, the RMS value of each muscle was measured based on their MVIC value and was measured as the percentage of muscle activity in each phase and the percentage of contraction each muscle was examined and measured in all four phases in the pre-test and post-test (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 timings were extracted for each targeted muscle, allowing for a detailed examination of neuromuscular responses (28). Statistical methods, including paired t-tests or analysis of variance (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.

Table 1. Training protocol of the groups

Group		Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8
Plyometric	**Barrier height**	30cm	35cm	40cm	45cm	60cm	50cm	55cm	65cm
	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	S20*3	S20*3	S20*3	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	S20*3	S20*3	S20*3	S20*3	S20*3	S20*3	S20*3	S20*3
Combined	**Barrier height**	30cm	35cm	40cm	45cm	60cm	50cm	55cm	65cm
	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)

Results

In this part, research hypotheses have been tested using statistics and SPSS software. The 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 progress during a training period in 5 training groups. The difference in the electrical activity of the muscles in the jumping phases is based on the absolute value of the differences. According to the results of the paired T-test comparisons, it can be concluded that in the first phase of jumping, combined training had a significant effect on the activity of TA, PL, medial and lateral GM, and SL muscles, and compared to other groups Exercise showed more and better effect in the first phase of jumping. In addition, plyometric training in the TA muscle and PNF training also played a significant role in the PL muscle (table 3) ~~($p<0.05$).~~ The results of ANOVA test showed that in the TA muscle there was a significant difference in the first phase of jumping between the plyometric, balanced and combined groups with the control group. In addition, there are significant differences between combined training group with the plyometric, balanced and PNF groups. In the PL muscle, there is a significant difference between plyometric with control group and combination with balance and control groups. In the medial GM muscle, there is a significant difference between the combined with balance and control groups. No significant difference was observed in the lateral GM muscle between groups. In the SL muscle, there is a significant difference between balance with control and PNF groups also plyometric with balance and control groups. Also has shown a significant difference between combined with balance and control groups (table 4) ~~($p<0.05$).~~

Table 2. Demographic data of the groups

Variable	Plyometric (M[1] ± SD[2]) (95% CL)	Balance (M ± SD) (95% CL)	PNF (M ± SD) (95% CL)	Combined (M ± SD) (95% CL)	Control (M ± SD) (95% CL)	P value
Age (year)	(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/m^2)	(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

[1] M: mean
[2] SD: standard deviation

Table3. The comparison of electrical activity of groups according to paired T-test in first phase

Muscle	Group	Pre test (M ± SD) (95% CL)	Post test (M ± SD) (95% CL)	95% CL of difference	P value
Tibialis anterior	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	(0.2562±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
Peroneus longus	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
Soleus	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

P<0.05*

Graph1. Electrical activity of muscles in first phase according to pair-t test between groups

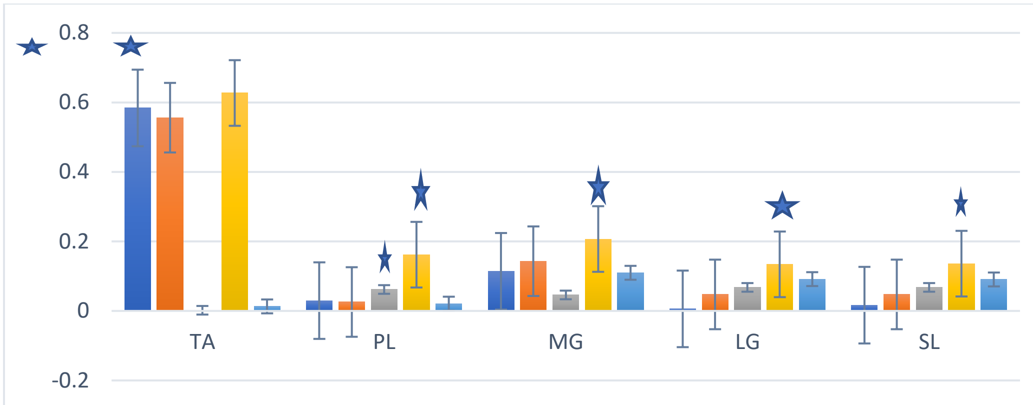

Table4. The comparison of electrical activity of groups according to ANOVA test in first phase

Muscle	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value
Tibialis anterior	Combined-plyometric	(0.130) (0.085-0.175)	.001*	Plyometric- balance	(-0.021) (-0.006-0.024)	.839	Balance-control	(0,084) (0.039-0.129)	.001*
	Combined-balance	(0.151) (0.106-0.196)	.002*	Plyometric- PNF	(0.063) (0.018-0.108)	.638	PNF- control	(0.001) (-0.045-0.045)	.406
	Combined-PNF	(0.067) (0.022-0.112)	.001*	Plyometric-control	(0.063) (0.018-0.108)	.021*			
	Combined- control	(0.127) (0.082-0,172)	.012*	Balance- PNF	(0.084) (0.039-0.129)	.122			
Peroneus longus	Combined-plyometric	(0.081) (-0.004-0.166)	.067	Plyometric- balance	(0.008) (-0.047-0.063)	.999	Balance- control	(0.089) (0.034-0.144)	.375
	Combined- balance	(0.073) (0.018-0.128)	.001*	Plyometric- PNF	(0.031) (-0.024-0.086)	.837	PNF- control	(0.066) (0.011-0.121)	.983
	Combined- PNF	(0.112) (0.057-0.167)	.004*	Plyometric- control	(0.081) (0.026-0.136)	.021*			
	Combined- control	(0.162) (0.107-0.217)	.001*	Balance- PNF	(0.023) (-0.032-0.078)	.696			
Medial GM	Combined-plyometric	(0.085) (-0.030-0.200)	.179	Plyometric- balance	(0.097) (0.012-0.182)	.092	Balance- control	(0.008) (-0.077-0.093)	1. 000
	Combined- balance	(0.182) (0.097-0.267)	.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)	.168	Plyometric- control	(0.089) (0.004-0.174)	.157			
	Combined- control	(0.174) (0.089-0.259)	.000*	Balance- PNF	(0.0960 (0.011-0.181)	.099			
Lateral GM	Combined-plyometric	(0.069) (-0.216-0.354)	.691	Plyometric- balance	(0.131) (-0.154-0.416)	.445	Balance- control	(0.036) (-0.249-0.321)	.237
	Combined- balance	(0.200) (-0.085-0.485)	.995	Plyometric- PNF	(0.028) (-0.257-0.313)	.978	PNF- control	(0.067) (-0.218-0.352)	1. 000
	Combined- PNF	(0.097) (-0.188-0.382)	.340	Plyometric- control	(0.095) (-0.190-0.380)	.993			
	Combined- control	(0.164) (-0.121-0.449)	.439	Balance- PNF	(0.103) (-0.182-0.388)	.168			
Soleus	Combined-plyometric	(0.091) (-0.004-0.186)	.090	Plyometric- balance	(0.109) (0.024-0.194)	.026*	Balance- control	(0.164) (0.079-0.249)	.004*
	Combined- balance	(0.200) (0.115-0.285)	.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)	.064	Plyometric-control	(0.073) (-0.012-0.158)	.283			
	Combined- control	(0.164) (0.079-0.249)	.000*	Balance- PNF	(0.103) (0.018-0.188)	.038*			

P<0.05*

According to the results of the paired T-test, it can be concluded that in the second phase of jumping, combined exercises had an effect on all 5 ankle muscles. Also, plyometric training had an effect on the TA and medial and lateral GM muscles. Balance training had an effect on the SL muscle, While in PNF training did not show any effect on the muscles (table 5) ~~($P<0.05$).~~ According to the ANOVA test has been showed that in the TA there is a difference between the combined with balance, PNF and control groups, and no significant difference was observed in the PL muscle between groups, and in the medial GM muscle illustrated significant differences between the combined with balanced and control groups also there is a difference between plyometrics with balance, PNF and control groups, and in the lateral GM muscle there is a difference between the balance with PNF and control groups, and in the SL muscle there is a difference between the combined with balance, PNF and control groups in addition has observed a difference between plyometrics training with balance, PNF and control groups (table 6) ~~($P<0.05$).~~

Table5. The comparison of electrical activity of groups according to paired T-test in second phase

Muscle	Group	Pre test (M ±SD) (95% CL)	Post test (M ± SD) (95% CL)	M difference (95% CL)	P value
Tibialis anterior	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
Peroneus longus	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
Soleus	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

P<0.05*

Graph2. Electrical activity of muscles in second phase according to pair-t test between groups

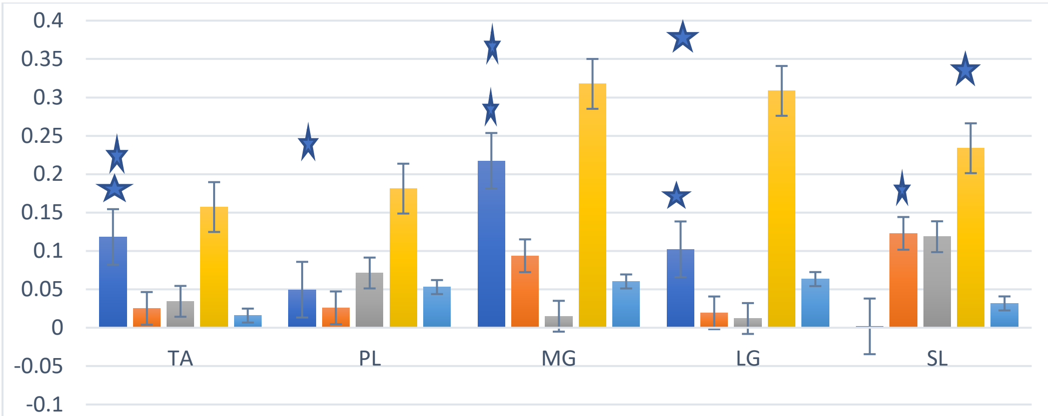

Table6. The comparison of electrical activity of groups according to ANOVA test in second phase

Muscle	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value
Tibialis anterior	Combined-plyometric	(0.058) (-0.052-0.168)	.301	Plyometric- balance	(-0.080) (-0.165-0.005)	.061	Balance-control	(0.043) (-0.042-0.128)	.180
	Combined-balance	(0.138) (0.053-0.223)	.001*	Plyometric- PNF	(0.030) (-0.055-0.115)	.832	PNF- control	(-0.007) (-0.092-0.078)	.977
	Combined-PNF	(0.088) (0.003-0.173)	.030*	Plyometric-control	(0.013) (-0.072-0.098)	.992			
	Combined- control	(0.108) (0.023-0.193)	.004*	Balance- PNF	(0.050) (-0.035-0.135)	.455			
Peroneus longus	Combined- plyometric	(-0.002) (-0.112-0.108)	1. 000	Plyometric- balance	(-0.006) (-0.091-0.079)	.617	Balance- control	(0.008) (-0.081-0.097)	.377
	Combined- balance	(0.004) (-0.081-0.089)	.632	Plyometric- PNF	(0.087) (-0.002-0.176)	.996	PNF- control	(-0.085) (-0.174-0.004)	1. 000
	Combined- PNF	(0.085) (-0.004-0.174)	.995	Plyometric- control	(0.002) (-0.087-0.091)	.994			
	Combined- control	(0.001) (-0.089-0.089)	.992	Balance- PNF	(0.093) (0.004-0.182)	.393			
Medial GM	Combined- plyometric	(-0.122) (-0.232-0.012)	.155	Plyometric- balance	(0.114) (0.029-0.199)	.002*	Balance- control	(0.159) (0.074-0.244)	.933
	Combined- balance	(-0.008) (-0.093-0.077)	.004*	Plyometric- PNF	(0.213) (0.128-0.298)	.001*	PNF- control	(0.060) (-0.025-0.145)	.794
	Combined- PNF	(0.091) (0.006-0.176)	.420	Plyometric- control	(0.273) (0.188-0.358)	.001*			
	Combined- control	(0.151) (0.066-0.236)	.047*	Balance- PNF	(0.099) (0.014-0.184)	.303			
Lateral GM	Combined- plyometric	(0.020) (-0.090-0.130)	.994	Plyometric- balance	(-0.099) (-0.184-0.014)	.305	Balance- control	(0.213) (0.128-0.298)	.001*
	Combined- balance	(-0.079) (-0.164-0.006)	.539	Plyometric- PNF	(0.117) (0.032-0.202)	.159	PNF- control	(-0.003) (-0.088-0.082)	.901
	Combined- PNF	(0.137) (0.052-0.222)	.065	Plyometric- control	(0.114) (0.029-0.199)	.197			
	Combined- control	(0.134) (0.049-0.219)	.085	Balance- PNF	(0.216) (0.131-0.301)	.001*			
Soleus	Combined- plyometric	(-0.011) (-0.121-0.099)	1. 000	Plyometric- balance	(0.222) (0.137-0.307)	.001*	Balance- control	(0.052) (-0.033-0.137)	.969
	Combined- balance	(-0.233) (-0.318-0.148)	.000*	Plyometric- PNF	(0.145) (0.060-0.230)	.025*	PNF- control	(0.129) (0.044-0.214)	.865
	Combined- PNF	(-0.134) (-0.219-0.049)	.044*	Plyometric-control	(0.192) (0.107-0.277)	.002*			
	Combined- control	(-0.181) (-0.266-0.096)	.003*	Balance- PNF	(-0.077) (-0.162-0.008)	.478			

$P<0.05$*

According to the results of the paired T-test for intra-group comparisons, it can be concluded that in the third phase of jumping, combined trainings have 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 that there is a difference in the medial GM muscle between the plyometric with balance, PNF and control groups also between combined group with control group. In the lateral GM muscle has demonstrated a significant difference between the combined group with plyometric, PNF and control groups. There is a significant difference between balance with control and plyometric with control group. There is a significant difference in the SL muscle between the combined group with other groups (table 8) ~~($P<0.05$).~~

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

Muscle	Group	Pre test (M ±SD) (95% CL)	Post test (M ±SD) (95% CL)	Mean differences (95% CL)	P value
Tibialis anterior	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
Peroneus longus	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
Soleus	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

$P<0.05$*

Graph3. Electrical activity of muscles in third phase according to pair-t test between groups

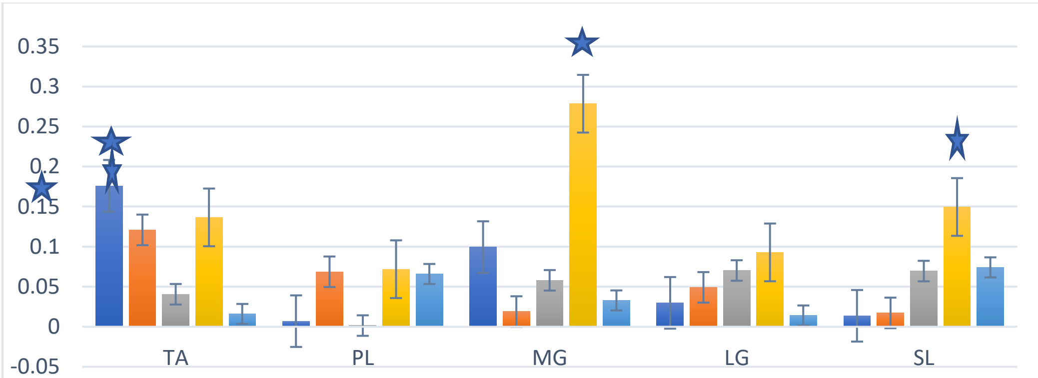

Table 8. The comparison of electrical activity of groups according to ANOVA test in third phase

Muscle	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value
Tibialis anterior	Combined-plyometric	(0.012) (-0.098-0.122)	.999	Plyometric- balance	(-0.120) (-0.205-0.035)	.099	Balance-control	(0.060) (-0.025-0.145)	.313
	Combined-balance	(0.107) (0.022-0.192)	.174	Plyometric- PNF	(-0.108) (-0.193-0.023)	.172	PNF- control	(0.035) (-0.050-0.120)	.457
	Combined-PNF	(0.095) (0.010-0.180)	.281	Plyometric-control	(-0.027) (-0.112-0.058)	.982			
	Combined- control	(0.015) (-0.070-0.100)	.999	Balance- PNF	(0.012) (-0.073-0.097)	.999			
Peroneus longus	Combined- plyometric	(0.061) (-0.101-0.069)	.694	Plyometric- balance	(-0.077) (-0.162-0.008)	.470	Balance- control	(0.164) (0.079-0.249)	.605
	Combined- balance	(0.074) (-0.011-0.159)	.996	Plyometric- PNF	(0.013) (-0.072-0.098)	.999	PNF- control	(0.061) (-0.024-0.146)	.991
	Combined- PNF	(0.060) (-0.025-0.145)	.518	Plyometric- control	(-0.001) (-0.086-0.084)	.996			
	Combined- control	(-0.045) (-0.155-0.065)	.812	Balance- PNF	(0.090) (0.005-0.175)	.311			
Medial GM	Combined- plyometric	(0.161) (0.076-0.246)	.941	Plyometric- balance	(0.206) (0.121-0.291)	.008*	Balance- control	(0.013) (-0.072-0.098)	1. 000
	Combined- balance	(0.134) (0.049-0.219)	.066	Plyometric- PNF	(0.179) (0.094-0.264)	.031*	PNF- control	(0.012) (-0.098-0.122)	.972
	Combined- PNF	(0.171) (0.086-0.256)	.181	Plyometric- control	(0.216) (0.131-0.301)	.006*			
	Combined- control	(0.120) (0.035-0.205)	.049*	Balance- PNF	(-0.027) (-0.112-0.058)	.991			
Lateral GM	Combined- plyometric	(0.002) (-0.083-0.087)	.002*	Plyometric- balance	(-0.118) (-0.203-0.033)	.003*	Balance- control	(0.030) (-0.055-0.115)	.046*
	Combined- balance	(0.090) (0.005-0.175)	1. 000	Plyometric- PNF	(-0.070) (-0.155-0.015)	.866	PNF- control	(0.013) (-0.072-0.098)	.084
	Combined- PNF	(0.084) (0.002-0.169)	.040*	Plyometric- control	(-0.036) (-0.121-0.049)	.002*			
	Combined- control	(0.122) (0.037-0.207)	.006*	Balance- PNF	(0.048) (-0.037-0.133)	.982			
Soleus	Combined- plyometric	(0.187) (0.102-0.272)	.001*	Plyometric- balance	(0.065) (-0.020-0.150)	.133	Balance- control	(0.008) (-0.081-0.097)	.029*
	Combined- balance	(0.106) (0.021-0.191)	.001*	Plyometric- PNF	(-0.017) (-0.102-0.068)	.969	PNF- control	(-0.085) (-0.174-0.004)	.816
	Combined- PNF	(0.061) (-0.049-0.171)	.002*	Plyometric-control	(0.035) (-0.050-0.120)	.717			
	Combined- control	(0.158) (0.073-0.243)	.999	Balance- PNF	(-0.082) (-0.167-0.003)	.311			

P<0.05*

According to the results of the paired t-test for intra-group comparisons, it can be concluded that in the fourth phase of jumping combined trainings effect significantly on TA, PL, medial GM and SL muscles also, plyometric trainings have an effect on TA muscle and balance training has been impacted on the medial GM and SL muscles (table 9). The results of ANOVA test showed that there is a difference in the anterior large muscle between the combined with PNF and control groups. Also, there was a significant difference between plyometric group with control group as well as between balance group with combined and control groups, and there is a difference in the SL muscle between the combined group with balance and control groups (table 10)

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

Muscle	Group	Pre test (M ±SD) (95% CL)	Post test (M ±SD) (95% CL)	Mean differences (95% CL)	P value
Tibialis anterior	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
Peroneus longus	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
Soleus	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

$P<0.05$*

Graph4. Electrical activity of muscles in fourth phase according to pair-t test between groups

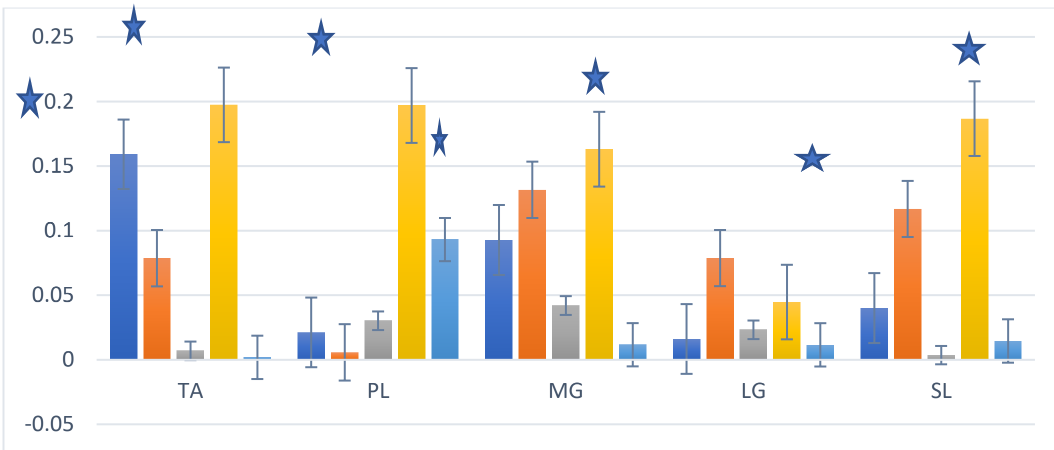

Table 10. The comparison of electrical activity of groups according to ANOVA test in fourth phase

Muscle	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value	Group	Mean difference (95%cl)	P value
Tibialis anterior	Combined-plyometric	(0.106) (-0.026-0.238)	.116	Plyometric- balance	(0.140) (-0.042-0.322)	.385	Balance-control	(0.078) (-0.144-0.300)	.001*
	Combined-balance	(0.246) (0.124-0.368)	.299	Plyometric- PNF	(0.047) (-0.075-0.169)	.120	PNF- control	(-0.065) (-0287-0.157)	.992
	Combined-PNF	(0.153) (0.031-0.257)	.001*	Plyometric-control	(0.037) (-0.085-0.159)	.046*			
	Combined- control	(0.144) (0.022-0.266)	.001*	Balance- PNF	(-0.099) (-0.221-0.023)	.001*			
Peroneus longus	Combined- plyometric	(0.137) (-0.085-0.359)	.968	Plyometric- balance	(-0.024) (0.246-0.198)	.994	Balance- control	(0.047) (-0.075-0.169)	1. 000
	Combined- balance	(0.133) (-0.109-0.355)	.999	Plyometric- PNF	(-0.033) (-0.255-0.189)	.978	PNF- control	(0.037) (-0.085-0.159)	.739
	Combined- PNF	(0.104) (-0.118-0.326)	1. 000	Plyometric- control	(0.185) (-0.037-0.407)	.923			
	Combined- control	(-0.048) (-0.270-0.174)	.596	Balance- PNF	(-0.009) (-0.231-0.213)	.992			
Medial GM	Combined- plyometric	(0.038) (-0.184-0.260)	.970	Plyometric- balance	(0.152) (-0.070-0.374)	.086	Balance- control	(0.275) (0.053-0.497)	.577
	Combined- balance	(-0.190) (-0.412-0.032)	.994	Plyometric- PNF	(-0.016) (-0.238-0.206)	.999	PNF- control	(0.132) (-0.090-0.354)	.996
	Combined- PNF	(-0.022) (-0.244-.200)	.996	Plyometric- control	(0.063) (-0.159-0.285)	.831			
	Combined- control	(0.101) (-0.121-0.321)	.461	Balance- PNF	(-0.168) (-0.390-0.054)	.577			
Lateral GM	Combined- plyometric	(0.112) (-0.110-0.334)	.673	Plyometric- balance	(0.020) (-0.202-0.242)	.110	Balance- control	(-0.016) (-0.238-0.206)	.810
	Combined- balance	(0.132) (-0.090-0.354)	.868	Plyometric- PNF	(-0.053) (-0.275-0.169)	.478	PNF- control	(0.063) (-0.159-0.285)	.831
	Combined- PNF	(0.059) (-0.163-0.281)	.110	Plyometric- control	(0.068) (-0.154-0.290)	.673			
	Combined- control	(-0.004) (-0.226-0.218)	.921	Balance- PNF	(-0.073) (-0.295-0.149)	.921			
Soleus	Combined- plyometric	(0.197) (-0.025-0.419)	.101	Plyometric- balance	(0.078) (-0.144-0.300)	.273	Balance- control	(0.153) (0.031-0.257)	.596
	Combined- balance	(0.275) (0.053-0.497)	.001*	Plyometric- PNF	(-0.065) (-0287-0.157)	.453	PNF- control	(0.144) (0.022-0.266)	.970
	Combined- PNF	(0.132) (-0.090-0.354)	.922	Plyometric-control	(0.024) (-0.198-0.246)	.971			
	Combined- control	(0.221) (-0.001-0.443)	.024*	Balance- PNF	(-0.143) (-0.365-0.079)	.478			

P<0.05*

Discussion

Overall, in this study has been shown that plyometric, balance and PNF trainings each one has a positive impact on electromyography function of ankle muscles and reduce the rate of ankle injury but, there haven't enough for preventing ankle injury thought, has shown that combined training (plyometric, balance and PNF) has a greater impact on function muscles in 4 phases of jumping test. Plyometric training has shown 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 and these adaptations contribute to a reduced risk of ankle injuries during the dynamic movements involved in basketball(31) . Also found that a targeted plyometric program significantly decreased the incidence of ankle sprains in basketball players and plyometric interventions positively impact neuromuscular control, a crucial factor in preventing ankle injuries in addition has been investigated the influence of plyometric training on neuromuscular performance and injury risk in young athletes(32).Balance training has proven to be a valuable component in preventing ankle injuries among basketball players(33). Also observed a significant reduction in the incidence of ankle sprains among basketball players who underwent a targeted balance training program and supported these findings, emphasizing the role of balance training in enhancing proprioception and reducing the risk of ankle injuries in sports, including basketball(34). Also has been investigated that incorporated balance training into the regimen of basketball players and 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).Proprioceptive Neuromuscular Facilitation (PNF) training has demonstrated positive effects on preventing ankle injuries among basketball players and Notable studies, emphasize the efficacy of PNF techniques in enhancing proprioception and reducing the risk of ankle sprains (36). Also has been shown that incorporating PNF exercises of basketball players led to improved joint position sense and reduced the incidence of ankle injuries and 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 and Plyometric exercises focus on explosive movements, while balance training enhances proprioception and stability (38). On the other word, 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, has been shown that athletes who performed plyometric and balance exercises had better overall ankle stability and lower rates of injury compared to those who did not (39). On the other hand, combined training including plyometric and balance improves the power and stability of ankle but, there is no effect on the range of motion and coordination therefore It's crucial to note that individual factors, such as range of motion can influence the Risk factors for ankle sprain in youth sports(40).Has been illustrated that 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 and together, these components can help athletes develop better ankle stability and reduce the risk of injuries(41). While combined training with plyometric and proprioceptive neuromuscular facilitation (PNF) exercises can be beneficial, it's important to consider potential drawbacks and limitations. Some research suggests that integrating these two training modalities can lead to improvements in muscle activation patterns, and functional performance, which may contribute to a reduced risk of ankle injuries in athletes but, has been shown that combined those practice didn't have appropriate impact on balance and coordination (41). Research supports the effectiveness of combined training involving balance and proprioceptive neuromuscular facilitation (PNF) exercises in reducing the rate of ankle injuries and the same practices are Effectiveness in neuromuscular and proprioceptive training program in preventing ankle ligament injuries in athletes also has been demonstrated, the positive impact of neuromuscular and proprioceptive training on injury prevention, emphasizing the importance of balance exercises (42). Balance training and PNF exercises are known to 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 proprioceptive neuromuscular facilitation (PNF) exercises can be beneficial for reducing the rate of ankle injuries, it's crucial to consider potential drawbacks and limitations. Has been demonstrated that combined (balance and PNF) training leads to improve the stability, coordination and range of motion but there is not enough impact on enhancing the strength and power(43). In this research, it was shown that plyometric and balance exercises and PNF in different phases of the jump test on the box have an effect on the ankle muscles, but combined exercises have a better and greater effect on all four phases of the jump between basketball players and their ankle muscles in addition Combined exercises can be used to improve the electrical activity of the ankle muscles among basketball players or even to prevent ankle injuries. Since most of the ankle injuries occur during forward movement, the phasing of the test has significantly contributed to a more accurate examination of the activity of the ankle muscles, and on the other hand, in each of the examined phases, the muscles have concentric and eccentric contractions, and weakness in each of the phases and muscles involved causes ankle injury in certain conditions(44). Thus, it is concluded that there is a series of injury prevention exercises to strengthen and improve each of the muscles involved in different phases. In conclusion, the integration of plyometric, balance, and proprioceptive neuromuscular facilitation (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 information achieved by combining these modalities 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 superiority 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 bridging the gap between biomechanical research and practical training applications, this work establishes a new standard for injury prevention strategies in basketball and similar jumping sports.

Research Limitations:

This research has several important 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 electromyographic (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.

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 electromyographic activity across all four biomechanically defined phases of the jump (preparation, takeoff, flight, and landing), impacting the tibialis anterior, peroneus longus, medial and lateral gastrocnemius, and soleus 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.

Author Contributions

- Nayeb Ahmadpour: Study design, Training implementation data analysis, manuscript writing (corresponding author).

- Banafsheh Mohammadi: supervision, data collection, manuscript review.

- Mohammad Rabiei: Methodology support, statistical analysis, manuscript editing.

Ethical considerations

Compliance with ethical guidelines

Ethical approval was obtained from the ethics committee at the institute of Physical Education and sport sciences (code: IR.SKU.REC.1400.075)

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Conflict of interest

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