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The Effect of Different Frequencies (Low and High) of Training Sessions and Blood Flow Restriction on Exercise Performance, Pressure Perception and Pain Feeling after Delayed Exhaustive Activity in Male Sport Science Students

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Abstract

Objective: To investigate the effect of different frequencies (low and high) of plyometric training with and without blood flow restriction on exercise performance, pressure perception and pain sensation after delayed exhaustive exercise in male sport science students

Methodology: This quasi-experimental study with a pretest-posttest design with a control group was performed on 45 male students (18-23 years old). Participants were randomly divided into five groups: control, low-frequency plyometric training (1 session/week), high-frequency plyometric training (3 sessions/week), low-frequency plyometric training with blood flow restriction, and high-frequency plyometric training with blood flow restriction. Training protocol for duration It lasted for 8 weeks. The intensity of training was 30-50% in the restricted blood flow groups and 70-80% in the non-restricted groups of maximum power. The evaluations were performed 48 hours after the last session and after the Bruce exhaustion test. Dependent variables included muscle strength (RM1), squat, speed (20 and 30 m), anaerobic power (Rust test), perception of pressure (Borg scale), and pain sensation (VAS scale). Data were analyzed using SPSS version 26 and ANCOVA and Bonferroni tests.

Results: The results showed that all training protocols had a significant effect on muscle strength ($F=352.08$, $P<0.001$), 20 m speed ($F=605.02$, $P<0.001$), 30 m speed ($F=383.03$, $P<0.001$), anaerobic power ($F=4699.38$, $P<0.001$), decreased pressure perception ($F=147.90$, $P<0.001$) and decreased pain sensation ($F=254.75$,

The ability to maintain high performance during multiple competitions requires specific physiological adaptations that must be achieved through careful training planning of(Yang et al., 2022). The unique features of competitive sports, which include multiple competitions on the same day, require special preparation on the part of the athletes(Akin & Kesilmiş, 2020). These types of competitions do not allow athletes to fully recover between competitions and require them to be able to continue to perform well despite cumulative fatigue(Trybulski et al., 2025).

Such conditions require special adaptations in energetic systems, the neuromuscular system, and S recovery mechanisms'(Oliva et al., 2024). Therefore, athletes must have the ability to perform better after strenuous activities in order to reap its benefits(Early et al., 2020). This ability, known as the ability to recover quickly and maintain performance after successive attempts, is one of the determining factors for success in competitive sports (Fonda & Sarabon, 2015)(Shareef & khadher, 2024) . The lack of this capability can lead to a significant decrease in performance in the later stages of the race, severely affecting the final result of (Angelopoulos et al., 2022). As one of the main limiting factors in athletic performance, fatigue can lead to a decrease in athletes' strength, speed, accuracy, and concentration (Bielitzki et al., 2024). This complex phenomenon, which is caused by the interaction of various physiological, biochemical, and psychological factors, is considered one of the main challenges in competitive sports. A proper understanding of the mechanisms of fatigue is essential for designing effective strategies to deal with it(Angelopoulos et al., 2022). Fatigue also has negative effects on cognitive function, decision-making and motor coordination (Duffield et al., 2010). These multidimensional effects of fatigue cause athletes to experience a decline in performance not only physically, but also mentally. As a result, fatigue management In this field, it is very necessary and practical(MacRae et al., 2011). Types of fatigue for athletes include central, peripheral, muscular, and metabolic fatigue, which ultimately leads to a decrease in performance(Brekke et al., 2025). Athletic performance includes components such as strength, speed, and anaerobic strength, as well as the level of pressure perception and the level of pain sensation are also important functional factors (Faltus et al., 2018). Strength as the ability to generate force against resistance forms the basic foundation of many sports activities and includes maximum strength, explosive power, and power-endurance (Kriley, 2014). Speed as the ability to perform movements as fast as possible, including not only linear speed but also angular velocity, reaction time Considered(Kriley, 2014). Ability Anaerobic, as the ability to produce energy in conditions of oxygen deficiency, plays a vital role in short-term and vigorous activities(Chen et al., 2025). This capability depends on the efficiency of the anaerobic phosphagen and glycolysis system and is strongly influenced by Compatibility's Practice(Dong et al., 2025). The level of pressure perception and pain sensation as important psychophysiological factors also have a significant impact on athletes' performance They have(Angelopoulos et al., 2022). Fatigue negatively affects all of these factors and can lead to decreased muscle strength, decreased movement speed, increased perception of pressure and pain, and consequently an overall decrease in athletic performance(Bielitzki et al., 2024). With the advancement of science, different methods are always used for exercises. These scientific advances have led to the development of new training techniques that are designed based on a better understanding of exercise physiology and coping mechanisms(Chen et al., 2015). Plyometric training is known as a way to improve explosive strength and athletic performance. Plyometric exercises involve movements in which the muscles work first in an eccentric (stretching) and then rapidly in a concentric manner(Faltus et al., 2018). This type of exercise is based on the stretch-shortening cycle and improves the strength, speed, agility, and overall performance of athletes. The mechanism of action of plyometric exercises includes improving neuromuscular coordination, increasing muscle-tendon stiffness, and strengthening the stretch reflex of(Shaffer, 2007).

Numerous studies have shown the benefits of the effects of plyometric training, including improving explosive power, increasing jumping height, improving running speed, and boosting overall athletic performance.(Duffield et al., 2010),(Freitas, 2021). Duffield Study and colleagues(Duffield et al., 2010) showed that plyometric training can significantly improve vertical jump performance while also having a positive effect on post-workout recovery. Another widely used method is the blood flow restriction methods(Hong et al., 2022). This method is known as Katsu Exercises Also known, it involves applying controlled pressure to the extremities during exercise to restrict venous blood flow while maintaining arterial blood flow (Wharemate, 2021). This technique makes it possible to achieve similar adaptations of intense training using low loads. The applied pressure is usually set between 50 and 80% of the arterial occlusive pressure to achieve optimal effectiveness(Jagim et al., 2024). Various Research on the Effects of Exercise With Blood flow restriction has been shown of (Jagim et al., 2024),(Ziyout et al., 2019). Early Study And colleagues showed that exercise restricting blood flow can improve muscle function, reduce pain, and enhance vascular function(Early et al., 2020). The necessity of using This The method combined with plyometric exercises is that the combination of these two methods can have more reinforcing effects (Yang et al., 2022),(Shaffer, 2007). This combination allows for the simultaneous benefits of both methods and can lead to unique physiological adaptations. Studies show that the combination of these two methods can lead to multiple improvements in athletic performance. The point to consider is the intensity and volume of the exercises. In exercises restricting blood flow, the intensity should be greatly reduced, but special attention should be paid to the volume of exercises per week, since the optimal training method should be determined to achieve peak performance without fatigue and decreased performance(MacRae et al., 2011). Determining the appropriate ratio of intensity and volume of exercise is one of the main challenges in designing training programs. Low intensity in blood flow restriction exercises is usually set between 20 and 40 percent of a maximum repetition, while the training volume should be adjusted in such a way that optimal adaptations are allowed without causing excessive fatigue of(Pignanelli et al., 2021). Gawanda And colleagues showed that low-intensity calf training combined with blood flow restriction resulted in functional and structural adaptations similar to traditional low-load strength training (Gavanda et al., 2020). This finding shows the importance of fine-tuning training parameters and emphasizes that training volume plays a key role in achieving optimal results(Gülfirat& Bişgin, 2021).

What is important in this study is to determine how the number of training sessions affects the process of performance changes after fatigue is reached(Angelopoulos et al., 2022).

Exercise frequency is one of the key variables in the design of exercise programs that can affect the rate and speed of physiological adaptations. Determining the optimal training frequency is important not only to maximize the benefits of the workout, but also to prevent excessive fatigue and reduced performance. Considering the limitations in determining the optimal frequency of plyometric combined exercises and blood flow limitation and its effect on post-fatigue performance, this study seems necessary(Oliva et al., 2024).

Despite the growing evidence on the effectiveness of plyometric exercises and limiting blood flow toe alone in the combination, there is still insufficient evidence on the effect of different frequency of training sessions in this new combination on performance indices and recovery after exhaustive activity. However, although plyometric exercises have been widely used to improve athletic performance, including strength, speed, and aerobic power, they have focused mainly on the moderate effects of exercise and less on investigating the interaction between exercise frequency, blood flow restriction intervention, and mental-physiological variables such as the perception of pressure and pain after exhaustive activity. Have been addressed. This is especially important in situations where athletes are subjected to repetitive strenuous activities (such as sports science students). Therefore, uncertainty about whether a higher or lower frequency of plyometric combined exercises can affect blood flow differently Affecting the maintenance of athletic performance and reducing the perception of pressure and pain after fatigue is an important physiological and training challenge that this study intends to investigate. Therefore, the aim of this study was to investigate the effect of different (low and high) frequencies of a plyometric training course and blood flow restriction on exercise performance, pressure perception and pain sensation after delayed exhaustive exercise in male sport science students.

Methodology

The present study was a quasi-experimental study with a test design and a post-test with a control group. The statistical population of this study consisted of male students of sport sciences at the University of Mazandaran with the age range of 18 to 23 years and normal body mass index.

In order to select the research samples, first, qualified male students were invited to collaborate through a public call at the Faculty of Sport Sciences of the University of Mazandaran. The criteria for participation in the study were clearly communicated. Inclusion criteria included male student of sport sciences at the University of Mazandaran, age range of 18 to 23 years, body mass index in normal range, no history of cardiovascular, respiratory, neuromusculoskeletal and skeletal diseases that affect the individual's ability to perform sports activities (with the confirmation of health questionnaire and initial examination), no use of any drugs, supplements or energetic substances that affect athletic performance or pain perception, at least 6 The month prior to the start of the research was not to participate in plyometric training programs or intense resistance training at least 3 months before the start of the research, and written informed consent to participate in the research and commitment to observe the training protocols. In contrast, exclusion criteria included unwillingness to continue cooperation at any stage of the research, absence of more than two sessions of training sessions, occurrence of any injuries or illnesses during the research period, and non-compliance It was training protocols or not performing the movements correctly. After reviewing the inclusion and exclusion criteria and obtaining preliminary information, the eligible samples were selected from among the candidates. To match participants, participants were asked to complete four forms, including a consent form, a questionnaire of personal information and general health, and a questionnaire on physical activity assessment.

The number of samples required for this study was used by Gpower software and considering the test power level of 0.80, the significance level was 0.05, and the effect size was 0.25 to analyze the covariance of 75 people in five groups: 1. control (without training intervention), 2. low-frequency plyometric training group (1 session per week), 3. high-frequency plyometric training group (3 sessions per week)4. The low-frequency plyometric training group with blood flow restriction and 5. The high-frequency plyometric training group with blood flow restriction was estimated, and finally, according to the inclusion criteria, 45 qualified volunteers were included in the study and 9 people were randomly assigned to each group.

After completing the questionnaires and the briefing session, first, in the first session, the exercise performance and the amount of time to exhaustion were evaluated in the exhaustion test. Forty-eight hours later, in the second session and in tephrites stage, after a period of exhaustion test (Bruce test), when the athletes reached fatigue and exhaustion, the level of Pressure perception and pain sensation were assessed. After the initial recovery, exercise performance (strength, speed and anaerobic power) was evaluated. After applying the interventions in each group 48 hours after the last training session, the second session was repeated again for final evaluation in the post-test stage.

Figure 1. The process and general stages of the research

Plyometric exercises and blood flow restriction

Low-frequency plyometric training group (1 session per week)

In this group, participants performed one weekly plyometric training session. The main goal of this group was to improve explosive power and agility while maintaining constant intensity over the eight-week period. Each session comes with a warm-up step. 10 up to 15 The minute began with a slow run, dynamic stretches, and a few lights jumps such as paired jumps in situ. After warm-up, the main exercises that include vertical jumping (With maximum height from squat mode) Jumping over an obstacle (Starting from the obstacles 25-30 Growth and Growth in the Coming Weeks), box jump (Starting with the boxes 20-25 Centimeters and gradual increase in height) In situ jumps, pairs of legs

(Horizontal forward jump for maximum distance) and multi-directional jumps (To improve agility) They are, it was implemented. Constant and equivalent training intensity during the period 70 up to 80٪ Maximum power considered. This intensity is measured through heart rate monitoring, which must be between 70 up to 80٪ The maximum heart rate maintained by the person was also evaluated. Exercise volume was adjusted progressively over 8 weeks, at weeks 1-4. ii Set of every move with 8 up to 10 Repeat done. At 4-6 weeks, this is a 3 Set with 8 up to 12 Repetition increased. In the final week (Week 8), the exercise consists of 6-8 sets with 10 up to 12 It was a repetition. Rest between sets 90 Seconds up ii It took a few minutes for the restoration to be completed and the quality of the repetitions was maintained.(Aalizadeh et al., 2015).

High-frequency plyometric training group (3 sessions per week)

The group performed three sessions of plyometric exercise per week. Due to its high frequency, a different approach was taken to prevent excessive fatigue and injury. Every session with 10 up to 15 A few minutes later, the same warm-up of the group began at a low pace. Main movements include alternating leg jumps (Long forward jumps with leg displacement), knee-high jumps (Jumping by raising the knees to the chest) Fast vertical jumps. (Back-to-back jumps with minimal contact with the ground), Stair Jumps (Jumping the stairs) and cone jumps. (Quick jumps over cones in a variety of patterns) It was. Constant and equivalent training intensity during the period 70 up to 80٪ Maximum power considered. This intensity is measured through heart rate monitoring, which must be between 75 up to 85٪ The maximum heart rate maintained by the person was also evaluated. The training volume was adjusted progressively over the course of a few weeks. 1 and ii، 1 up to ii Set of every move with 6 up to 8 Repeat Run. In the Weeks 3 -7, this amount is reduced to ii up to 3 Set with 8 up to 10 Repetition increased. In the final week, the exercises include 3 Set with 10 up to 12 They're going to be repetitive. Rest between sets 60 up to 90 Seconds controlled(Aalizadeh et al., 2015).

Plyometric exercise group with low frequency and restricted blood flow

In this group, participants performed a weekly plyometric exercise session with blood flow restriction. General protocol of the same volume and frequency exercises as the group "Low frequency plyometric" However, the intensity of the exercises decreased due to the restrictions on blood flow. Each session began with the same warm-up as the other groups. After warm-up, special cuffs to limit blood flow in the upper thigh area (For lower limb exercises) Put pressure between 40 up to 80 Individual arterial occlusion pressure percentage was applied. This pressure was adjusted so that arterial circulation was not completely interrupted, but venous reflux was limited. The cuff was maintained during the training sets. Movements and Exercise Volume (Number of sets and repetitions) During the five-week period the exact same group "Low frequency plyometric" It was. However, the intensity of the exercises was reduced to about 30 up to 50% Maximum power reduced(Akin M& Kesilmiş, 2020),(Aalizadeh et al., 2015).

Plyometric Training Group with High Frequency and Blood Flow Restriction

This group performed three sessions of plyometric exercise per week with blood flow restriction. General protocol of the same volume and frequency exercises as the group "High-frequency plyometric" However, the intensity of the exercises decreased due to the restrictions on blood flow. Each session began with the same warm-up as the other groups. After warm-up, special cuffs to restrict blood flow were placed in the upper thigh area and pressure was placed between the 40 up to 80 Individual arterial occlusion pressure percentage was applied. Movements and Exercise Volume (Number of sets and repetitions) During the five-week period the exact same group "High-frequency plyometric" It was. However, the intensity of the exercises was reduced to about 30 up to 50% Maximum power decreased to create optimal metabolic pressure(Akin M& Kesilmiş, 2020), Aalizadeh et al., 2015). (

Foreclosure

In order to create delayed fatigue in the participants, Bruce's incremental test was used on the treadmill. This protocol, which is usually used to assess maximum aerobic power, provides the necessary conditions for the creation of exhaustion by bringing the person to the point of exhaustion. Before the test, the participants were introduced to the treadmill and the protocol and were connected to heart rate monitoring sensors. The test began with a light warm-up and then the speed and incline of the treadmill increased every three minutes in a stepwise manner until the participant reached a point of complete exhaustion and was unable to continue the activity. During the test, heart rate and pressure perception will be continuously monitored. After the test was stopped, an active cooling phase consisting of a slow walk on the treadmill was performed to aid recovery. The time of exhaustion was recorded for each participant and the monitoring of the symptoms of exhaustion began in the hours and days after the test(Bruce et al., 1973).Figure 1. Bruce Test Protocol Shows He should give it.

پروتکل آزمون بروس

شیب	سرعت	زمان	مرحله
۱۰	۲/۸	۳دقیقه	۱
۱۲	۴/۱	۳دقیقه	۲
۱۵	۵/۵	۳دقیقه	۳
۱۵	۶/۸	۳دقیقه	٤
۱۵	۸/۱	۳دقیقه	٥
۱۵	۸/۸	۳دقیقه	٦
۱۵	۹/۷	۳دقیقه	۷

Figure 1. Bruce Test Protocol

Speed

To measure the sprint, each participant took the sprint tests after a proper warm-up. 10، 20 and 30 Meter will participate... Each distance was repeated twice. (Lee et al., 2019).

Anaerobic Power Measurement with Lactic

Rust anaerobic test was used to measure anaerobic power. Beginning A distance of 35 metersIt is considered. After the initial warm-up, he traveled a distance of 35 meters for six times, with a 10-second rest between each session. After setting the records in seconds, through Placement In the following formula, the maximum anaerobic power was calculated (Queiroga et al., 2013).

^{3} Time (seconds) ÷ ^{2} Distance (m) × Body Weight (kg) = Power (W)

6 ÷ The sum of the total six stages of running = Average power (watts)

Strength Test

The process of testing strength with squats (A Maximum Repetition) In this study, lower body strength was measured using a maximum repetition squat test. This method specifies the maximum weight a person can lift for a complete repetition with the correct technique. The exam process included the following steps. Before starting the main test, participants were introduced to the correct squat technique. This familiarity includes teaching the correct movement form, the right squat depth. (90) Degree of flexion of the knee joint) And there were safety tips... Afterwards, a general warm-up includes light aerobic activities such as stationary cycling or treadmills (5) up to 10 minute) And dynamic stretching movements will be performed. Then, special warm-up using an empty barbell rod (5) up to 10 Repetition) And then it will gradually increase with lighter weights. The goal of this stage was to prepare the muscles and joints to bear heavier weights and prevent injuries. After proper warm-ups, participants began to do a squat test with increasing weights. The process will be such that in the first set, the participant starts with a weight that he can 5 up to 10 Repeat do. In the second set, weights were added so that the participant could 3 up to 5 Repeat do. In the next sets, the weight will gradually increase and the number of reps will decrease (For example ii up to 3 Repetition), until the person reaches a weight where he can only do one correct and complete repetition. Between each set, enough rest (3) up to 5 minute) It will be provided for a full recovery. The maximum weight that the participant can lift for only one full repetition and with the correct squat technique will be recorded as the strength of one maximum rep. Attempts to Determine 1RM It should not be more than 3 up to 5 Set to avoid excessive fatigue of the participant. Throughout all stages of the test, an experienced observer familiar with squat technique and safety protocols carefully supervised the execution of the movement and provided the necessary support if needed(Bayles, 2023).

Measurement of pressure perception (Borg scale)

To assess the level of pressure perception caused by exercises, the Borg Pressure Perception Scale from 6 to 20 was used. The scale, introduced by Borg in 1998, is a valid and common tool for measuring exercise intensity based on a person's subjective feeling. Participants were asked to choose a number between 6 (no pressure) and 20 (maximum pressure) at the end of each training session and immediately after the delay exhaustive activity. The number 6 on this scale was equivalent to a very light situation, 10-11 is equivalent to light, 12-14 is equivalent to a little difficult, 15-17 is equivalent to a hard equivalent, and 19-20 is equivalent to very hard or maximum effort. This approach helped the researchers assess the internal load of exercise regardless of the external load (such as weights or repetitions) and better understand the participants' physiological and psychological reactions of (Borg, 1998).

Measuring the amount of pain felt on an analog visual scale

To assess the amount of pain felt after the delayed exhaustive activity, an analog visual scale was used (VAS) were used. This scale, which was established in 1983 by Price and colleagues developed, a simple yet effective tool for measuring the severity of mental pain. Scale VAS There was a horizontal line 10 centimeters long, with one end marked with "0" or "no pain" and the other end with "10" or "the worst pain imaginable." Participants will be asked to mark the dot on this line that best reflects the intensity of their current pain. The distance from the "painless" point to marked by the person was recorded as a pain score. This measurement will be done at specific intervals (24, 48 and 72 hours after exhaustive activity) to examine the trend of changes in delayed muscle pain of(Price, 1983).

Data Analysis Method

In this study, to analyze the data, descriptive statistics were first used to present the mean and standard deviation of the data in the form of tables and figures. To investigate the normality of the data distribution, Shapiro-Wilk test was used. Also, to investigate the homogeneity of variances, Luhn test was used. Covariance test was used to investigate the differences between groups and within groups. If the results of this test were significant, Bonferroni's post hoc test was used to determine the paired differences between the groups. The statistical significance level in this study was considered to be $p<0.05$. All statistical operations were performed using SPSS software version 25.

Results

Descriptive information including age, height, weight, and body mass index of the participants by group is presented in Table1.

Table 1. Mean standard deviation of demographic characteristics of the subjection relevant groups

Body mass index (kg/m2)	Weight (kg)	Height (cm)	Age (years)	Group
38/1±84/22	53/10±44/69	12/8±77/173	58/1±66/20	Control
06/1±95/22	69/9±00/71	29/8±44/175	81/1±55/20	Low frequency
21/1±10/22	21/6±54/70	21/4±44/174	79/1±88/20	High frequency
21/7±19/23	07/4±54/71	51/7±32/177	80/1±33/21	Low frequency−restriction of blood flow
44/4±20/23	88/8±44/72	19/9±00/176	18/2±22/21	High Frequency−Blood Flow Restriction

According to Figure 1. The results of analysis of covariance for strength showed that there was a significant difference between the groups ($F1, 39, 352.08$, $P=_{0.000}$).

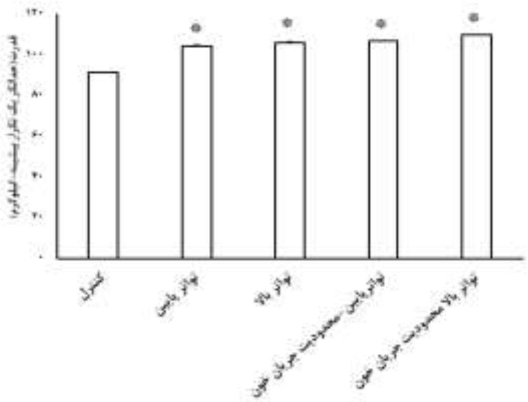

Figure 1. Status of the groups with the adjusted mean of the analysis of covariance for strength

*: Significant difference with control group

Figure 2 shows the results of the analysis of covariance for velocity. According to the results, it was found that there was a significant difference between the groups for the speed of 20 m (Fig. 2.A) (F_{1}, 605.02, $P=0.000$) and the velocity of 30 m ($P=0.000$, F_{1}, 39.03) (Fig. 2.B).

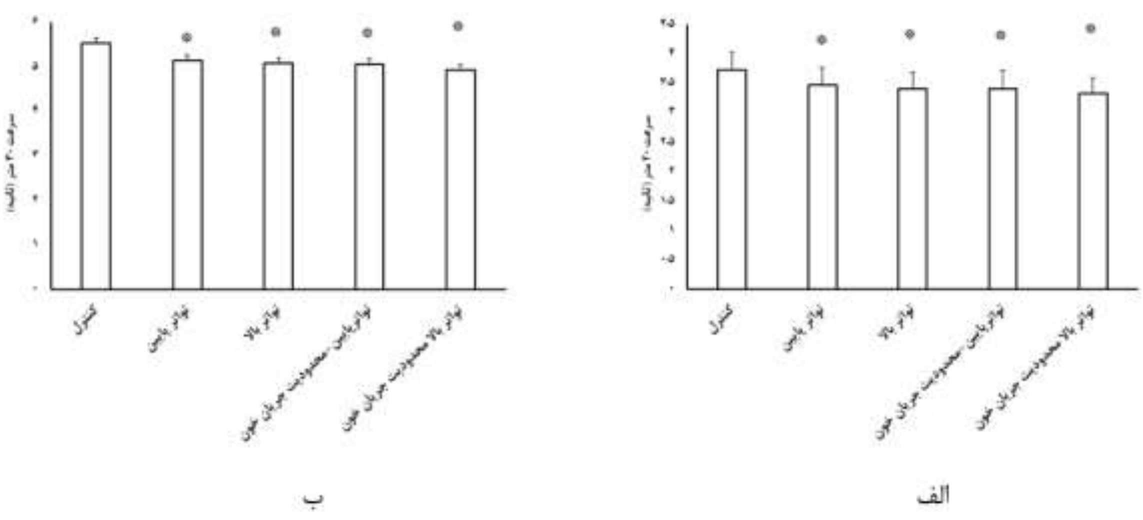

Figure 2. The status of the groups with the adjusted mean of the analysis of covariance for the speed of 20 m (A) and 30 m (B)

*: Significant difference with control group

Figure 3. The results of the test show the analysis of covariance for power. According to the results, it was found that there was a significant difference between the groups for power ($F1,_{4699.38,}$ P=0.000).

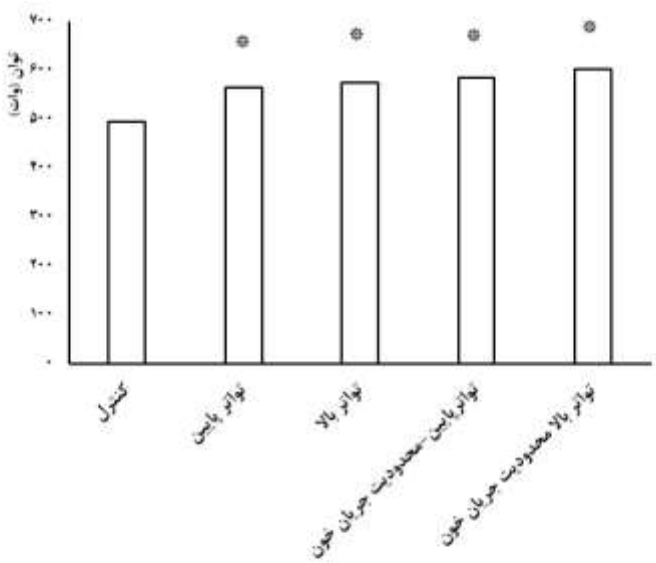

Figure 3. Status of the groups with the adjusted mean of the analysis of covariance for power

*: Significant difference with control group

Figure 4. The results of the test show analysis of covariance for perception of pressure and pain. According to the results, it was found that there was a significant difference between the groups for perception of pressure (Fig. 4.A) ($F1, 147.90_{, P=}0.000$) and pain ($F1, 254.75_{, F=0.39}$) (Fig. 4.B).

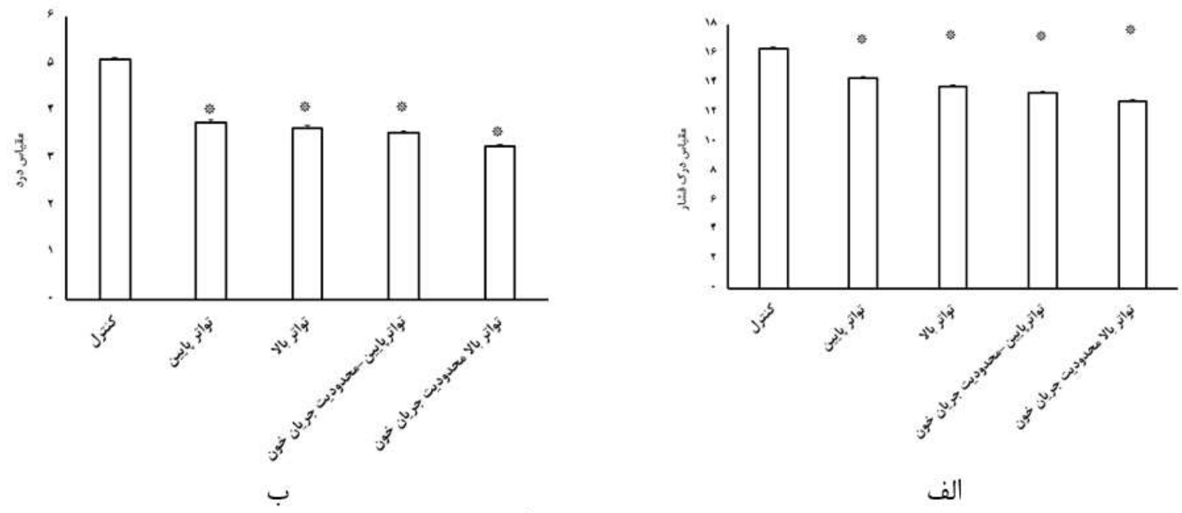

Figure 4. The status of the groups with the adjusted mean of the analysis of covariance to understand pressure (A) and pain (B)

*: Significant difference with control group

Table 2 shows the results of the Cohen effect. According to the size of the Cohen effect, it was found that plyometric training with high frequency and blood flow restriction had the greatest effect on functional variables.

Table 2 Results of the size of the Cohen effect

Cohens' d						Group
Pain Scale	Perception of pressure	Ability (Watt)	power (1RM)	Speed 30m(s)	Speed: 20 meters (seconds)	Stage
–	–	–	–	–	–	Control
01/1−	01/1	97/0	94/0	80/0−	79/0−	Lower frequency
32/1−	28/1	14/1	05/1	00/1−	05/1−	High frequency
25/1−	38/1	19/1	08/1	98/0−	99/0−	Lower frequency BFR
51/1−	50/1	48/1	34/1	45/1−	47/1−	Frequency BFR

The aim of this study was to investigate the effect of different frequencies of plyometric training (low and high) with and without blood flow restriction on performance and perceptual indices of male sport science students after delayed exhaustive exercise. The findings showed that all training protocols had a significant effect on muscle strength, speed, anaerobic power, reduction in pressure perception and reduction of pain sensation, but the highest effect was related to the high-frequency plyometric training group It was with the restriction of blood flow.

The findings of this study are in line with several studies that have reported the positive effect of plyometric training on muscle strength. Chatznikova and colleagues(Chatzinikolaou et al., 2010) showed that acute plyometric training had no negative effect on strength performance. Deng and colleagues(Deng et al., 2024)In their systematic review, they reported that plyometric training had a positive effect on health-related physical fitness indicators in non-athletes. In the context of combining blood flow restriction with resistance training, Akgol and colleagues(Akgül et al., 2025) showed that resistance training with blood flow restriction was more effective than traditional resistance training in developing quadriceps muscle adaptations in young untrained men. Kirkukias and colleagues(Krekoukias et al., 2023)They also confirmed the effect of combining blood flow restriction with plyometric training on quadriceps muscle strength. Deng et al(Deng et al., 2025) In their meta-analysis, they showed that the combination of blood flow restriction with resistance training had a positive effect on lower limb strength, muscle hypertrophy, jump ability, and sprint speed in athletes.

The mechanism of effectiveness of plyometric training on muscle strength is related to several factors. These exercises store and release elastic energy through the stretch-shortening cycle of the muscle, which leads to the production of more force. Plyometric training activates the stretch reflex and improves neuromuscular coordination(Kuibida et al., 2021). Holmes and colleagues(Holmes et al., 2023)showed that plyometric training based on high-intensity intervals has positive effects on body composition, aerobic capacity, and muscle function in young women.

Restriction of blood flow reduces oxygen delivery to the muscles, leading to the creation of a local hypoxic environment and the accumulation of metabolites including lactate, hydrogen ions, and inorganic phosphates. This accumulation of metabolites stimulates metabolic receptors and increases the utilization of motor units. you stumbled and colleagues(Neto et al., 2014)The effects of high-intensity training combined with blood flow restriction on muscle fatigue were noted. Father and colleagues(Abe et al., 2006) They showed that muscle size and strength increased after walking exercise with limited venous blood flow. Gao and colleagues(Gao et al., 2025) In their meta-analysis, they confirmed the effects of aerobic exercise with restricted blood flow on aerobic capacity, muscle strength, and hypertrophy in young adults.

The combination of plyometric exercises with blood flow restriction can lead to further improvement in muscle strength due to the synergistic effects of these two methods. Restricting blood flow can increase the metabolic stress caused by plyometric exercises and cause more recruitment of type II muscle fibers. The finding of the superiority of high-frequency plyometric training with blood flow restriction indicates that increasing the training frequency can lead to better neuromuscular and metabolic adaptations. In their meta-analysis, Dong et al. showed that the combination of blood flow restriction with endurance training had a positive effect on aerobic capacity, lower limb muscle strength, anaerobic strength, and athletic performance in athletesof(Dong et al., 2025).

The findings on speed improvement are in line with several studies. Deng et al(Deng et al., 2025) showed that the combination of blood flow restriction with resistance training had a positive effect on sprint speed in athletes. Perfection and colleagues(Elgammal et al., 2020)reported that repetitive sprint training with restricted blood flow affected strength, anaerobic and aerobic performance in basketball. Lobby and colleagues(Lubis et al., 2024) They showed that plyometric training for six weeks was effective on body composition, power, and stroke speed in athletes.

In the field of anaerobic power, dong and colleagues(Dong et al., 2025)In their meta-analysis, they showed that the combination of blood flow restriction with endurance training had a positive effect on lower extremity muscle strength, anaerobic power, and athletic performance in athletes. Bhubaneswar and Partners(Boobani & Licis, 2019)confirmed the effectiveness of plyometric exercises with blood flow restriction on explosive power in taekwondo athletes. Bhai and colleagues(Behi et al., 2017) reported the effect of high-intensity interval training with blood restriction on anaerobic performance. Chen et al(Chen et al., 2025) showed that moderate intensity interval training with restricted blood flow had an effect on aerobic and anaerobic abilities and lower limb function in male college basketball players.

The mechanism of effectiveness of plyometric training on anaerobic speed and power is related to neuromuscular and metabolic factors. Plyometric exercises lead to increased force generation and movement speed by improving the muscle stretch-shortening cycle, increasing the storage and release of elastic energy, strengthening the stretch reflex, and increasing the synchronization of motor units (30). Restriction of blood flow reduces oxygen supply to the muscles and creates a local hypoxic environment that leads to the accumulation of metabolites. This accumulation stimulates metabolic receptors, increases the recruitment of motor units, especially type II fast fibers, and increases the secretion of anabolic hormones(Abe et al., 2006),(Gao et al., 2025), (Wang et al., 2025). The combination of plyometric exercises with blood flow restriction can have synergistic effects as both methods use complementary mechanism pathways to improve performance. Blood flow restriction can exacerbate the metabolic stress caused by plyometric exercises and increase the use of fast-moving units(BO & Mitranun, 2025).

The findings of this study are in line with studies that have investigated the effects of exercises with restricted blood flow on pain and pressure perception. Ogrezano and colleagues(Ogrezeanu et al., 2024) showed that resistance training with blood flow restriction affects neuromuscular responses, perceptions of health status and pain-related constructs in patients with advanced knee osteoarthritis. Collins and colleagues(Kolind et al., 2023) reported that low-load exercises with and without blood flow restriction had an effect on microvascular oxygenation, muscle irritability, and perceived pain. Brandner and Warmington.(Brandner& Warmington, 2017) They showed that delayed muscle pain and perceived effort after exercises were affected by restricted blood flow. The mechanism of effectiveness of plyometric exercises on the perception of pressure and pain is related to physiological and psychological factors. These exercises can influence pain perception and pressure by developing neuromuscular adaptations, improving motor control, increasing pain tolerance thresholds, and strengthening endogenous pain control mechanisms. Plyometric exercises stimulate the release of endorphins and other analgesic neurotransmitters that can reduce pain perception(Trybulski et al., 2025),(De et al., 2010). The mechanism of effectiveness of blood flow restriction on the perception of pressure and pain is more complex. On the one hand, restricting blood flow can increase feelings of discomfort during exercise, but on the other hand, regular use of blood flow restriction can lead to adaptations that ultimately improve pain and strain tolerance. These adaptations can include increasing pain tolerance thresholds, improving the functioning of the endogenous opioid system, and decreasing the sensitivity of peripheral pain receptors(Early et al., 2020), (Dong et al., 2025).

Conclusion

The results of the present study showed that the combination of high-frequency plyometric training and blood flow restriction acts as the most effective training protocol in simultaneous improvement of muscle strength, speed, anaerobic power, and management of pressure and pain perception after delayed fatigue. These findings show that increasing the training frequency along with blood flow restriction can create superior neuromuscular, metabolic, and perceptual adaptations over other protocols. All The applied training protocols had positive and significant effects on the studied variables, which indicates the wide application potential of these training methods in various fields of physical fitness, athletic performance, and rehabilitation. Targeted use of a combination of plyometric training with different frequencies and blood flow restriction can be used as an evidence-based strategy to optimize physical performance, increase tolerance to training pressures, and improve multimodal adaptations.

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