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Original Article

The Comparison of the Effects of Unilateral vs. Bilateral Plyometric Exercise Training on Performance Indicators in Trained Adolescent Male Students

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Abstract

Introduction: Previous studies have established the positive effects of plyometric exercises on athletic performance, but a lack of consensus regarding the effectiveness of unilateral versus bilateral exercise training as a variable in plyometric exercises has yet remained.
Objective: This study aimed to evaluate the effect of eight weeks of unilateral vs. bilateral plyometric exercises on the performance indicators of adolescent boys.
Methods: 30 male students with the age range of 14-17 years were placed in two groups of unilateral and bilateral plyometric exercise training groups. Before and after eight weeks of training, anthropometric indicators, including height, weight and body mass index, as well as speed (30 m sprint), agility (T agility test), explosive power (vertical jump), lower limb strength (leg dynamometer) and the anaerobic capacity (RAST anaerobic test) were measured. Adolescent male students conducted the exercise training program for eight weeks with a frequency of three sessions per week. ANCOVA statistical method was used to analyze the data.
Results: Speed and agility showed significant decrease following bilateral plyometric training compared to unilateral plyometric exercise training (P=0.047 and p=0.028 respectively). But significant difference was not observed in explosive power (P=0.793), lower limb static power (P=0.660), peak anaerobic power (P=0.912), average anaerobic power (P=0.891), Minimum anaerobic power (P=0.114) and fatigue index (P=0.893) between training groups.
Conclusion: It seems that bilateral plyometric exercise training schedules improves anaerobic characteristics of physical fitness (speed and agility) more positively compared to unilateral training schedules.

Keywords: Plyometric Exercise, Athletic Performance, Adolescence, Physical Fitness, Male Student

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1. Introduction

The adaptations resulting from engagement in sports activities stem from various changes, including alterations in muscle phenotype, energy reserves, metabolic enzymes, contractile proteins, and connective tissues (1). Notably, various factors such as training variables, age, genetics, gender, nutrition, and an individual's training history significantly influence these adaptations. Along with the evolution of sports science, achieving optimal performance in elite level necessitates a high level of physical fitness, which varies according to the specific physiological demands of each sport (2). Manipulation of training schedules constitutes a systemic strategy that leads to athletic high performance possible. Moreover, effective planning is crucial for organizing training programs during the pre-season as a primary training period to prepare athletes for the key competitions of the season. This approach ensures both physical and mental readiness, enabling athletes to achieve optimal performance levels (3). The variety of training programs continues to expand, providing coaches with essential tools for prescribing effective training regimens. Beyond technical skills and functional tactics, physical preparedness characteristics such as strength, explosive power, endurance, and speed are critical determinants of success in various sports disciplines. Consequently, a deeper understanding of how to optimally plan and adjust training programs for athletes necessitates ongoing collaboration among sports science researchers, coaches, and athletes (4).

Plyometric exercises represent a category of anaerobic physical activities that is recognized to enhance strength and speed performance (5). Plyometric movements are characterized by the stretch-contraction cycle, which involve both concentric and eccentric contractions performed in sequence or in combination by skeletal muscles. Another perspective defines the eccentric and concentric actions in skeletal muscle as the stretching-shortening cycle, with the interval between these cycles (6). It is evident that the primary energy system utilized during plyometric exercises is derived from anaerobic pathways, basically fed from the phosphagen pathway. A significant outcome of this training regimen is the enhancement of neuromuscular function, which includes the development of muscle proprioception, thereby contributing to improved motor learning and neuromuscular efficiency. This, in turn, leads to increased power generation, movement unit recall, stimulation frequency, and coordination (7).

Previous studies has demonstrated the beneficial impact of plyometric exercises on enhancing athletic performance (8-10). However, the manipulation of specific variables within plyometric exercise training is crucial for achieving physiological and functional adaptations (11). Lower-limb type of plyometric exercise is performed with two main classifications, unilateral and bilateral lower limb jumping (12-14). From a physiological point of view, unilateral exercises are often more advantageous than bilateral ones by recruitment of motor units while reducing the dispersion of motor unit activation, leading to more significant adaptations (15). In this regard, studies showed that unilateral plyometric training over a six-week period was more effective than bilateral training in enhancing explosive power and jumping ability among women (16). Additionally, another study indicated that unilateral plyometric training resulted in substantial improvements in both unilateral and bilateral jumping performance, as well as muscle strength promotion and force development in trained individuals (17). Conversely, several studies reported that unilateral plyometric exercises in short training period increase power and jumping performance more significantly compared to bilateral plyometric exercises, while bilateral plyometric training may enhance countermovement leg jumping in women in long training period more significantly (16). Furthermore, the necessity of incorporating both training methods into a preparation program has been highlighted (16). While previous studies have established the positive effects of plyometric exercise training on athletic performance in wide variety of sports, a lack of consensus regarding the effectiveness of unilateral versus bilateral training as a variable in plyometric exercises has yet remained, necessitating further investigation to ascertain which method is superior. Consequently, present study aims to compare the effects of unilateral and bilateral plyometric training on performance indicators in adolescent males.

2. Methods

2.1. Design and participants

This study employed a semi-experimental methodology utilizing a pre-test-post-test design, involving two groups: one focused on unilateral plyometric exercises and the other on bilateral plyometric exercises. Participants consisted of adolescent male students engaged in volleyball, basketball, and handball. Based on the established inclusion criteria, a total of 30 participants voluntarily participated in this study. The inclusion criteria were as follows: 1. General health as assessed by the Goldberg General Health Questionnaire, 2. Age between 14 and 17 years, 3. male mass index ranging from 20 to 24.9 kg/m^2, 4. Experience in basketball, volleyball, or handball, 5. Participation in at least provincial-level competitions, 6. Capability to perform back squats at a minimum of 1.5 times their body weight, and 7. No use of nutritional supplements. The exclusion criteria included: 1. Absence from more than two training sessions per week, 2. Engagement in other sports activities, 3. Involvement in musculoskeletal injuries during training period, 4. Use of chamomile supplements, and 5. Non-participation in the pre-test. Prior to participation, each individual read and signed an informed consent form, and written consent was also obtained from their families.

2.2. Grouping

Following the final selection process, participants were randomly assigned to two groups, each consisting of 15 male students, designated for unilateral and bilateral plyometric exercises, respectively.

2.3. Measurements

2.3.1. Measurement of Anthropometric Indicators (Height and Weight)

The assessment of anthropometric indicators, specifically height and weight, was conducted in the morning using the Seka brand height and weight measuring device, Model 220, manufactured in Germany. This device possesses a sensitivity of 0.01 meters and 100 grams. Participant's height and weight were measured in accordance with the Frankfurt method, with height recorded in centimeters and body weight in kilograms (18).

2.3.2. Speed measurement

The assessment of speed was conducted using a 30-meter sprint. Following an appropriate warm-up facilitated by a qualified trainer, each participant completed 30-meter sprint on two occasions, with a three-minute rest interval provided between each attempt (19).

2.3.3. Measurement of Explosive Power

The explosive power of each participant was assessed through vertical jump tests utilizing Harman's formula. Initially, a wall was marked or a tape measure was employed to quantify the jump height. Following a preliminary warm-up, participants executed 3 jumps to be familiarized with the testing procedure. After this familiarization and a subsequent 5-minute rest period, each participant immersed his hand in plaster. They then positioned themselves sideways next to the marked wall or board and extended their hand upward to make contact with the surface. The point of contact, noted by the examiner, served as the base reference point. Subsequently, the individual dipped their fingers in plaster powder and, after standing adjacent to the wall or board, performed a vertical jump without taking a preparatory step. The highest point reached by their middle finger on the wall or board was recorded, and the difference in height between this mark and the base reference was used to calculate the participant's jump rate in centimeters using the specified formula (20).

maximum explosive power (watts) = 61.9 x (jump height in centimeters) + 36 x (body weight in kilograms)-1822

2.3.4. Measuring the Static Strength of the Lower Limb

Assessment of static strength in the lower limb was conducted using a leg dynamometer. Initially, each participant received a detailed explanation of the proper technique for executing the movement pattern. Following a 10-minute warm-up period, individuals were instructed to flex their knee on the device while maintaining an upright trunk. They were then required to adjust the chain length so that the handle rested at the thigh level before extending their knees, at which point the stability of the pointer was recorded. This evaluation was performed twice, with a resting interval of 20 seconds between attempts (20).

2.3.5. Agility Assessment

A t-test was employed to evaluate agility. In this assessment, each participant followed the procedure illustrated in the figure 1. Initially, the individual sprints 10 meters to reach the first cone, subsequently moves five meters to the right to the second cone, then runs 10 meters to the left to the third cone, and finally sprints the last 10 meters back to the starting point at maximum speed, with the time recorded in seconds (21).

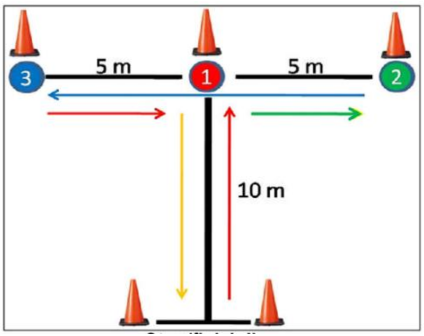

Figure 1. Execution of Agility Test.

2.3.6. Anaerobic Power Measurement

Assessment of anaerobic power was conducted using the RAST anaerobic test. The procedure for this test is outlined as follows: initially, a distance of 35 meters was established. Following a preliminary warm-up, the subject completed six runs of 35 meters each, with a 10-second rest interval between each run. After documenting the times in seconds, the maximum, average and minimum power output; and fatigue index of anaerobic power were calculated using the subsequent formula (22).

Power Output (watts) = body weight (kilograms) × distance2 (meters) ÷ time3 (seconds)
Average Power Output (watts) = sum of all six stages of running ÷ 6
Fatigue Index = total time of six repetitions in seconds ÷ minimum power-maximum power

2.3.7. Unilateral Versus Bilateral Plyometric Training Protocol

The program was conducted over eight weeks period, featuring two sessions each week, as detailed in Table 1. The jumps performed included both horizontal and vertical variations, encompassing unilateral and bilateral jumps. Participants were allowed a passive rest period of 30 to 60 seconds between sets, while a 120-second passive rest was observed between different types of jumps. To adhere to the principle of progressive overload, the total number of foot contacts was incrementally increased on a weekly basis (23).

2.4. Data Analysis

All data are presented as mean ± standard deviation. The ANOVA statistical test was utilized to evaluate the data. Initially, the normality of the data distribution was verified through the Shapiro-Wilk test, adhering to the assumptions required for the statistical analysis of intergroup variations. Additionally, Bonferroni's post hoc test was conducted to assess inter-group differences. A significance level of $P \le 0.05$ was considered, and all data were analyzed using SPSS version 16.

3. Results

The descriptive statistics concerning demographic indicators reveal that male participants in both groups were aged between 14 and 17 years. The mean weight and standard deviation for unilateral plyometric training group were recorded as 67.46±7.04 kg, while for the bilateral plyometric training group, these figures were 67.08±6 kg. In terms of height, the unilateral group had a mean of 177.07±6.87 cm, and the bilateral group had a mean of 175.60±4.29 cm. Regarding body mass index, the unilateral group exhibited a mean of 21.47±1.39 kg/m^2, whereas the bilateral group showed a mean of 21.72±1.55 kg/m^2. Also, the normality of the distribution was seen in both groups during the pre-test and post-test. Furthermore, no significant differences were found in body weight ($F=0.024$, $P=0.877$), height ($F=0.497$, $P=0.487$), or body mass index ($F=0.226$, $P=0.628$) during the pre-test.

Table 1. Plyometric Training Program.

Jumping Type	Training	Week	Week1			Week2			Week3			Week4			Week5			Week6			Week7			Week8		
		Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Bilateral	Vertical Jump	Set	3	3	2	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	-	-	-	-	-	-
		Reps.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	-	-	-	-	-	-
		Rest	30	30	30	30	30	30	30	30	30	30	30	30	-	-	-	-	-	-	-	-	-	-	-	-
	Vertical Jump in Half Squat Position	Set	3	2	2	3	2	2	2	2	2	2	2	1	2	2	1	1	-	-	1	1	1	1	1	1
		Reps.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	-	-	10	10	10	10	10	10
		Rest	30	30	30	30	30	30	30	30	30	30	30	-	30	30	-	-	-	-	-	-	-	-	-	-
	Horizontal Jump in Half Squat Position	Set	-	1	3	-	1	3	3	3	3	1	1	2	2	1	1	1	1	1	2	2	2	2	2	2
		Reps.	-	10	5	-	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
		Rest	-	30	30	-	30	30	60	60	60	-	-	60	60	-	-	-	-	-	60	60	60	60	60	60
Unilateral	Left Or Right Foot Jump Vertically	Set	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	1	1	1	2	2	2	2	2	2
		Reps.	5	5	5	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10	15	10	10	15	10	10
		Rest	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	-	-	-	60	60	60	60	60	60
	Jumping From the Left or Right Foot In a Half Squat	Set	2	2	2	2	2	2	3	2	2	2	2	2	3	2	2	2	2	2	1	1	1	1	1	1
		Reps.	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10	10
		Rest	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	60	60	60	-	-	-	-	-	-
	Horizontal Jump as Half Left or Right Squat	Set	1	2	2	1	2	2	2	3	3	2	2	2	2	3	3	4	4	4	2	2	2	2	2	2
		Reps.	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10	10
		Rest	-	45	45	-	45	45	45	45	45	45	45	45	45	60	60	60	60	60	60	60	60	60	60	60
	Jump From Foot to Foot	Set	2	2	2	2	2	2	2	3	3	1	2	2	3	2	2	2	2	2	3	3	4	3	3	4
		Reps.	5	5	5	5	5	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
		Rest	45	45	45	45	45	45	45	45	45	-	45	45	45	45	45	45	60	60	60	60	60	60	60	60

3.1. Speed and Agility

Between-group analysis indicated a significant improvement in speed and agility between bilateral plyometric and unilateral training groups (p=0.047, p=0.028 respectively) (Table 2). Consequently, these results demonstrate that the bilateral plyometric training group experienced a significant enhancement in speed and agility compared to the unilateral group.

3.2. Explosive Power and Static Power of the Lower Limb

The findings derived from the ANOVA statistical analysis concerning the variations in explosive power and static strength of the lower limb within bilateral plyometric training group indicate no significant differences when compared to unilateral group (p=0.793, p=0.660). As illustrated in Table 2, while there were substantial increases within both groups, the enhancements in explosive power and muscle strength in the plyometric training group were not statistically significant in comparison to the other group.

3.3. Anaerobic Power Output

The evaluation of peak anaerobic power output, average anaerobic power output, minimum anaerobic power output, and fatigue index was conducted using the ANCOVA statistical test. The analysis revealed no significant differences between unilateral and bilateral plyometric training groups for peak anaerobic power output (p=0.912), average anaerobic power output (p=0.891), minimum anaerobic power output (p=0.114), and fatigue index (p=0.893). Nevertheless, within the correlated t group, a significant increase in peak anaerobic power output was observed exclusively in the bilateral plyometric training group (p=0.001), while the unilateral plyometric training group exhibited a significant increase in minimum anaerobic power output (p=0.024), as detailed in Table 2.

Table 2. The Results of the Analysis of Covariance Test Related to the Changes of Functional Factors between the Two Groups.

Variable	Groups	Pre-test	Post-test	Adjusted Mean	Within Group	Between Groups
Speed (sec)	Unilateral	4.49 ± 0.18	4.39 ± 0.15	4.43	0.001*	F=4.35
	Bilateral	4.63 ± 0.21	4.37 ± 0.20	4.33	0.006*	P=0.047*
Explosive Power Output (Watts Per Second)	Unilateral	3172.70 ± 489.80	3317.89 ± 496.94	28.27	0.001*	F=0.07
	Bilateral	3389.85 ± 403.69	3529.88 ± 397.30	26.99	0.001*	P=0.793
Lower Limb Static Strength (kg)	Unilateral	123.46 ± 21.88	132.06 ± 19.83	154.83	0.001*	F=0.190
	Bilateral	128.13 ± 23.11	135.60 ± 22.79	161.01	0.001*	P=0.660
Agility (Seconds)	Unilateral	10.86 ± 0.41	10.66 ± 0.38	10.65	0.001*	F=5.39
	Bilateral	10.83 ± 0.55	10.51 ± 0.51	10.52	0.001*	P=0.028*
Peak Anaerobic Power Output (Watts per Second)	Unilateral	602.80 ± 111.95	635.25 ± 131.17	11.19	0.197	F=0.01
	Bilateral	589.96 ± 79.26	621.20 ± 77.95	121.97	0.001*	P=0.912
Average Anaerobic Power Output (Watts per Second)	Unilateral	504.34 ± 113.01	497.40 ± 85.93	50.11	0.610	F=0.01
	Bilateral	503.29 ± 103.29	498.58 ± 82.01	50.39	0.707	P=0.891
Minimum Anaerobic Power Output (Watts per Second)	Unilateral	437.18 ± 86.43	406.54 ± 67.10	25.17	0.024*	F=2.66
	Bilateral	419.86 ± 85.56	423.08 ± 85.42	25.14	0.836	P=0.114
Fatigue Index (Ratio)	Unilateral	17.64 ± 4.06	19.37 ± 11.62	23.77	0.564	F=0.01
	Bilateral	23.69 ± 6.12	23.18 ± 10.09	23.85	0.849	P=0.893

* A Significance Level of Less than 0.05 is Considered

4. Discussion

Present study was undertaken to explore the impact of bilateral versus unilateral plyometric training on the performance metrics of adolescent male athletes. The results indicated a significant enhancement in speed and agility within the bilateral plyometric exercise training group when compared to the unilateral plyometric exercise training group. Notably, within-group assessments revealed substantial improvements after one of the eight weeks of training. Conversely, both groups exhibited significant increases in explosive power output and static strength of the lower limbs, although no significant differences were observed between the two groups. Ultimately, the peak, average and minimum power output; and fatigue indices of anaerobic power did not show significant differences between the unilateral and bilateral plyometric training groups. Nevertheless, a notable increase in peak anaerobic power output was recorded in the bilateral plyometric training group, while the unilateral plyometric training group demonstrated a significant increase in minimum anaerobic power. It appears that bilateral plyometric training may have a more favorable impact on enhancing performance indicators. The findings of this study is in contrary with those of previous studies (24-26), who reported that unilateral or bilateral plyometric training, whether conducted independently or in conjunction with speed training, positively influenced the physical-motor characteristics of participants. However, Aloui et al. (26) did not find a significant effect in their study, which is inconsistent with the results of the current investigation.

The essential components of physical fitness for athletes across various sports include explosive power, speed, agility, anaerobic power, and muscle strength. These factors are crucial for enhancing the athletic performance of both professional and amateur athletes (27). It has been demonstrated the beneficial impact of plyometric exercises on futsal players, particularly in improving agility and explosive jumping ability during the pre-season (28). The manipulation of exercise variables remains a significant challenge in the design of training programs. Plyometric exercise training, characterized by its extensive range of movement variables, presents a unique opportunity for such manipulation. One key variable is the choice between unilateral and bilateral exercise designs. Previous studies has indicated that unilateral plyometric exercises may yield superior results compared to bilateral exercises; however, some studies have contested these findings, reporting no significant differences (16,29). Notably, unilateral training is linked to an increase in muscle fiber recruitment and greater force production compared to bilateral training. Van Soest et al. (30) conducted measurements of electromyographic activity, revealing that the inward contraction during bilateral anti-gravity jump was up to 20% less than that of unilateral jumps. Additionally, unilateral jumps tend to engage stabilizing muscles more effectively due to the misalignment of the center of gravity with the base of support.

Increasing the activation of stabilizing muscles has been suggested to improve the orientation of the head, arms, and trunk with respect to the lower limbs during jumping and landing tasks (30). Also, the contact time is one of the possible mechanisms of unilateral jumps compared to bilateral jumps, which are longer and require greater stimulus strength, while the bilateral exercise training program has a greater effect on movement speed (16). On the other hand, muscle contraction in unilateral leg movements compared to bilateral leg movements is the sum of the force or force produced by one or two organs. It is different than in bilateral movements, the force is applied simultaneously and helps to improve the movement efficacy (31). Bilateral deficiency actually reflects the reduction of neural power and the lack of maximum activation of muscles on both sides of the body during simultaneous contraction (32). Therefore, in unilateral exercises, the increase in produced force converges with the involvement of lower body muscles; But there is a significant difference in bilateral exercises. Enhancing the activation of stabilizing muscles has been proposed as a means to improve the alignment of the head, arms, and trunk in relation to the lower limbs during jumping and landing activities. Additionally, the duration of contact is another factor that differentiates unilateral jumps from bilateral jumps, with unilateral jumps typically exhibiting longer contact times and necessitating greater stimulus strength. Conversely, a bilateral training regimen tends to have a more pronounced impact on movement velocity. Furthermore, in unilateral leg movements, muscle contraction is characterized by the cumulative force generated by one or two limbs, whereas in bilateral movements, force is exerted simultaneously, facilitating the progression of the movement. A deficiency in bilateral performance indicates a decrease in neural power and an insufficient maximum activation of muscles on both sides of the body during concurrent contractions. Consequently, in unilateral exercises, the increase in force production aligns with the engagement of lower body muscles; however, a significant distinction exists in bilateral exercises.

The findings of the current study indicate that bilateral plyometric exercise training significantly enhances speed and agility when compared to unilateral plyometric exercise training. A bidirectional training regimen is believed to foster explosive force in activities such as sprinting and directional changes, attributed to ground contact force generation times of less than 250 milliseconds, which facilitates higher rates of force development (33). It was determined that plyometric exercises lead to improvements in change of direction of performance, maximum velocity, and repeated sprint capabilities (25). Additionally, Krakan et al. (23) established that plyometric exercise training effectively boosts both acceleration and maximum speed. Also, reports showed that activities involving route changes resulted in enhanced running speed after a six-week period, as evidenced by reduced travel time (24). It appears that engaging in a plyometric exercise training program, particularly in a bilateral format as opposed to unilateral, augments the rate of force development through mechanisms such as post-activation potentiation, which may involve increased phosphorylation of myosin light chain or heightened motor unit stimulation (25). Nevertheless, Aloui et al. (26) noted that employing both training modalities can be beneficial for improving athletic performance metrics, and they advocate for further research projects in this area. These researchers highlighted that the participants in their study were elite Finnish soccer players in a transitional phase, who had not engaged in weight training or plyometric activities during this time. Overall, they emphasized that the level of physical fitness is a crucial factor in enhancing movement performance following training. Plyometric exercise training enhances the rate at which muscles convert contraction and tension, thereby improving sprinting performance and agility. Additionally, the central nervous system's signals and proprioceptive feedback contribute to neural adaptation. This study indicates that neuromuscular adaptation has a beneficial impact on muscle spindles, Golgi tendon organs, tendons, joints, balance, and postural control. It has been found that bilateral plyometric exercise training is more effective than unilateral training in enhancing speed and agility, primarily due to a greater rate of force development and superior neuromuscular adaptations. While the current study demonstrated improvements in both explosive and static power outputs for all participants, it is noteworthy that the subjects were active adolescent males aged 14 to 17. It is believed that the incomplete maturation of their skeletal muscles significantly influenced the observed differences between the groups.

Conversely, plyometric and speed training exercises heavily depend on anaerobic phosphagen systems for energy generation. It is conceivable that the intensity and combination of the training regimen influenced the participants' ability to recover adequately between sets over time, despite the absence of aerobic capacity measurements in this study. During recovery periods, energy or phosphocreatine levels are replenished via the creatine shuttle and aerobic pathways. However, the insufficient levels of high aerobic fitness, coupled with inadequate recovery of phosphocreatine or energy between sets, may have led to a decline in training quality, thereby increasing the likelihood of fatigue. This is evidenced by the lack of improvement in the physical-motor performance indicators of the participants. Future study that manipulates and optimizes the design of training volume, intensity, and rest intervals may provide more insightful answers in this area.

In this study, unilateral and bilateral plyometric exercises utilizing only body weight were implemented, without the incorporation of any equipment such as obstacles, free loads or boxes in the training regimen. It appears that the significant tension associated with plyometric exercises, combined with the participants' ongoing muscle strength maturation and hypertrophy - processes that continue until approximately the age of 20, resulted in insufficient stress to enhance the rate of force development. Consequently, this led to a lack of transfer of the effects and adaptations from unilateral and bilateral plyometric training, alongside speed training, to physical-motor performance indicators. A notable limitation of this research study was the absence of an assessment of the participants' maturity stages. Additionally, psychological factors such as motivation and sleep quality were not monitored, despite participants being instructed to exert maximum effort during the movements and to maintain good sleep hygiene.

4.1. Conclusion

Following an eight-week study comparing unilateral and bilateral plyometric exercise training in male adolescents, it has been determined that both training methods significantly enhance performance factors. However, improvements in speed and agility are more pronounced in the bilateral plyometric exercise training regimen. Ultimately, the plyometric exercise training program does not influence adaptations related to anaerobic power.

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Footnotes

Authors' Contribution: This study was carried out solely by the corresponding author.

Conflict of Interests: The researcher confirms that there is no conflict of interests in this study with any participant.

Data Availability: The data that support the findings of this study are openly available upon request from the corresponding author.

Ethical Approval: The author confirms that all steps and requirements of this study comply with ethical guidelines. Participants were informed about the characteristics of the study and gave written informed consent.

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