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Impact of Specific Plyometric Training on Physiological and Performance Outcomes in U16 Performance Athletes Soccer Players

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Abstract: *The aim of this study was investigates the impact of specific plyometric training on U16 professional soccer players, addressing the gap in understanding the efficacy of plyometric training within youth soccer. A cohort of 24 soccer players (mean age: 15±0.4 years) participated in the study. The subjects had mean physical characteristics of height, 172.1±2.55 cm and body mass 68.3±2.40 kg. Plyometric training interventions were tailored to the developmental needs of the players. Physiological, biomechanical, and performance-related outcomes were assessed using the Quattro Jump platform - Kistler 9290AD model. The study evaluated parameters such as Countermovement Jump height (CMJ_Hf) and average muscular power (CMJ_Pavg). The results of the study unveiled noteworthy enhancements in CMJ_Pavg ($p \leq 0.001$) among U16 soccer players subsequent to the implementation of plyometric training interventions. However, the analysis showed a non-significant change in CMJ_Hf ($p \leq 0.149$). These findings suggest that plyometric training effectively enhances muscular power but may have limited impact on vertical jump height in this cohort of U16 soccer players. Statistical analysis indicated notable changes in performance metrics, supporting the efficacy of plyometric training in enhancing athletic performance in youth soccer. These findings underscore the importance of incorporating plyometric training into coaching practices and training methodologies for young soccer athletes to optimize performance.*

Keywords: *physiology; biomechanics; muscular contraction; soccer; youth.*

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Introduction

Plyometric training has garnered significant attention in sports science due to its potential to enhance athletic performance, particularly in explosive sports such as soccer (de Villarreal et al., 2015; Meylan & Malatesta, 2009; Peitz et al., 2018). The dynamic and multifaceted nature of soccer necessitates players to exhibit high levels of explosive strength, speed, agility, and power (Kabacinski et al., 2022). Consequently, there is a growing interest in investigating the effects of plyometric training on the physical attributes and performance of soccer players, especially at the youth level where foundational skills are honed and physical development is crucial (Wang & Zhang, 2016). Additionally, the importance of muscular training programs through plyometric exercises cannot be overstated in the context of youth soccer development (Kobal et al., 2017). Renowned specialists in sports science, such as Wang and Zhang (2016) have extensively researched and advocated for the integration of plyometrics into athletic training programs. Their study explored the effects of plyometric jump training on the physical fitness of young male soccer players. It meticulously investigated two critical factors: inter-set recovery intervals and player maturity. The findings unveiled a universal benefit: plyometric jump training significantly enhances the physical fitness of adolescents, regardless of their maturity level. However, a notable revelation emerged regarding older participants: they demonstrated amplified improvements when provided with longer inter-set recovery intervals. This nuanced understanding not only underscores the efficacy of plyometric training across a broad age spectrum but also highlights the importance of tailored recovery strategies. By optimizing training protocols to accommodate age-related differences, this approach not only enhances overall athletic performance but also serves as a preventive measure against injuries, thereby fostering the holistic development of young athletes.

Beyond its immediate application to athletic performance, the study of plyometric training in youth soccer offers several educational benefits. Firstly, it provides an opportunity to deepen our understanding of the physiological and biomechanical mechanisms underpinning athletic performance, fostering interdisciplinary collaboration between sports science, physiology, and biomechanics disciplines (Thomas et al., 2009; Vieira, 2022). This interdisciplinary approach not only advances scientific knowledge but also enriches educational curricula by integrating practical applications of theoretical concepts (ZidaneHmmood et al., 2024; Cojanu & Visan, 2019; Iordache et al., 2010).

Furthermore, research on plyometric training in youth soccer promotes evidence-based coaching practices, offering valuable insights into effective training methodologies tailored to the developmental needs of young athletes (Williams et al., 2013; Vişan & Cojanu, 2020).

By elucidating the specific effects of plyometric exercises on muscular contraction, force production, and neuromuscular coordination, this research informs coaches on the design of age-appropriate training programs that optimize performance outcomes while minimizing the risk of injury (Arede et al., 2022; Lehance et al., 2009).

Moreover, the educational significance of this research extends to its implications for talent identification and athlete development pathways in youth soccer. By identifying key performance indicators associated with plyometric training interventions, such as improvements in explosive force generation and agility, coaches and talent scouts can better assess and nurture the potential of young soccer players, fostering a culture of talent development and excellence within youth soccer academies and grassroots programs (Duncan et al., 2023).

In addition to its immediate relevance to sports performance, the study of plyometric training in youth soccer has broader societal implications for promoting physical activity and healthy lifestyles among young people. By demonstrating the efficacy of structured plyometric training programs in enhancing athletic performance and reducing injury risk, this research may encourage greater participation in organized sports and physical education programs, thereby contributing to the overall health and well-being of youth populations (Williams et al., 2013; Sortwell et al., 2021; Cipu & Dragnea, 2007).

The research aim

The aim of this study was to assess the effectiveness of a plyometric training intervention on soccer-specific explosive power parameters in U16 junior soccer players. The study specifically focused on evaluating changes in maximum jump height (Hf) and average muscular power (Pavg) following the intervention period.

Hypotheses

H1.The plyometric training intervention will lead to a significant increase in average muscular power (Pavg) among U16 junior soccer players.

H2.The plyometric training intervention will result in a significant improvement in maximum jump height (Hf) among U16 junior soccer players.

Research objectives

O1. To assess the impact of an 8-week plyometric training intervention on maximum jump height (Hf) among U16 junior soccer players.

O2. To evaluate the effectiveness of the plyometric training program in improving average muscular power (Pavg) in U16 junior soccer players.

O3. To analyze the consistency and variability of performance outcomes, including jump height and muscular power, before and after the plyometric training intervention.

O4. To determine the statistical significance of observed changes in maximum jump height and average muscular power following the plyometric training program.

O5. To provide valuable insights into the potential benefits of plyometric training for enhancing the explosive lower limb performance of youth soccer players.

O6. To contribute to the body of knowledge on effective training methodologies tailored to the specific needs of young athletes in the context of soccer.

O7. To identify areas for further research and potential avenues for refining plyometric training protocols to maximize performance outcomes in youth soccer.

Material and methods

Subjects

In this study, a cohort of 24 soccer players was examined, with an average age of 15 years (±4 months) and physical characteristics including a mean height of 172.1 cm (±2.55 cm), and weight of 68.3 kg (±2.40 kg). These participants were selected from the U16 category of a sports club based in Pitesti, Romania.

The consent of the parents was required and signed before starting the research according to the Declaration of Helsinki. It was approved by the Ethics Committee of the Doctoral School of Physical Education and Sport Science (ID: 05/3.01.2023), University of Politehnica Bucharest, Romania.

Research tools

The research focused on testing soccer-specific explosive power parameters using the Platform for the Measurement of Force Quattro Jump tip Kistler 9290AD (Cojanu et al., 2023). This modern tool assesses the actual level of improvement in muscular power through regimes of muscle

contractions predominantly focused on plyometric exercises applied during training sessions with the aim of manifesting these enhancements during official matches, as in our investigation involving U16 junior footballers.

The Counter Movement Jump (CMJ) is a test used to assess explosive lower limb power in athletes, particularly in sports like soccer where rapid movements and jumps are essential. In this test, athletes begin in a seated position, typically on a platform or surface, with knees bent and feet flat on the ground. From this position, they perform a dynamic flexing movement, bending their knees and hips, followed by an explosive extension of the lower limbs to propel themselves vertically into a jump.

Key elements of the CMJ include:

1. dynamic flexing movement- soccer players initiate the CMJ by quickly flexing their knees and hips, generating a pre-stretch or "counter movement" before the jump. This dynamic movement helps to activate the stretch-shortening cycle, which enhances the subsequent explosive extension phase of the jump;

2. vertical jump -after the dynamic flexing movement, athletes rapidly extend their lower limbs to push off the ground and achieve maximum height in the jump. The goal is to reach the highest point possible vertically;

3. evaluation of explosive force -the CMJ provides valuable insights into an athlete's explosive power production, particularly in the lower limbs. The height achieved in the jump serves as a measure of the athlete's ability to generate rapid and powerful movements from a static position;

4. quality of muscular flexibility reuse - in addition to measuring explosive power, the CMJ assesses the athlete's ability to efficiently utilize muscular flexibility during the jump. This includes factors such as neuromuscular coordination and the capacity to effectively engage the stretch-shortening cycle to enhance jump performance;

5. neuromotor recruitment -the CMJ evaluates the athlete's neuromotor recruitment capacity, which refers to the ability of the nervous system to activate and coordinate muscle fibers efficiently during explosive movements. This aspect is crucial for generating maximal power during the jump;

6. utilization of viscoelastic force -another important aspect assessed by the CMJ is the athlete's capacity to utilize the viscoelastic properties of muscle tissue. Muscles possess elastic properties that allow them to store and release energy during rapid movements, contributing to the overall power output of the jump.

The CMJ provides a comprehensive evaluation of an athlete's explosive lower limb power, incorporating factors such as dynamic movement patterns, neuromuscular coordination, and the utilization of

elastic energy. By assessing these components, coaches and sports scientists can gain valuable insights into an athlete's physical capabilities and tailor training programs to enhance performance in sports requiring explosive movements, such as soccer (Bishop et al., 2022).

In our research, we utilized the Kistler Quattro Jump Bosco Protocol to assess lower limb explosive power, focusing specifically on the CMJ test (Radulović et al., 2022). This standardized method involves several key steps:

1. preparation - U16 junior soccer players were briefed on the correct execution of the CMJ test and underwent any necessary warm-up activities to ensure readiness.

2. instrumentation - U16 junior soccer players performed CMJ jumps on a force platform equipped with sensors to measure ground reaction forces accurately.

3. execution of jumps -each soccer player performed three CMJ jumps with maximal effort to achieve the highest possible jump height.

4. data collection- during the CMJ jumps, the force platform recorded data such as ground reaction forces, jump height, contact time, and flight time.

5. analysis -the collected data was analyzed using SPSS software to calculate variables such as maximum jump height (Hf) and average muscular power (Pavg), providing insights into the athlete's explosive capabilities.

Procedure of the intervention

Phase I (January 10 – May 15, 2023) – Sample selection for our research, obtaining consent within the sports club. Within the experimental group, the technical staff was informed about the project objectives, presentation of modern methods in muscular preparation, and presentation of the U16 junior player squad, including plyometric exercise programs designed based on the technical-tactical components of soccer. Detailed information was provided to the experimental group regarding the specific tasks they would undergo.

Phase II (June 10 – November 15, 2023) – Development of muscular training programs predominantly comprising plyometric exercises, designed based on the technical-tactical gestures of soccer, with carefully reconsidered and planned anticipated effects throughout all training periods. These programs, specific to the physical training process, particularly in the muscular training compartment, were applied to U16 junior soccer for 8 weeks. The programs were developed following a questionnaire consisting of 7 questions regarding the dissemination of information from the perspective of 45 specialized soccer coaches for juniors and seniors in Romania, concerning the conceptual level in muscular preparation using

plyometric exercises of varying intensities, and the initiation of initial testing on the samples undergoing practical experimental research.

Table 1 provides a structured overview of plyometric exercises designed to enhance muscular performance specifically tailored for youth soccer players. These exercises aim to address operational objectives focusing on improving specific aspects of gameplay such as shooting force, explosive power of lower extremities, and agility. Each exercise is meticulously described along with recommended dosage, targeted muscular groups, and methodical instructions to ensure optimal implementation. By following this structured plyometric training regimen, youth soccer players can expect improvements in specific areas of their physical performance, contributing to enhanced gameplay effectiveness and reducing the risk of injuries associated with inadequate muscular development.

Table 1. Plyometric training program for U16 performance athletes soccer players

No.	Description*	Dosage*	Methodical instructions*
1	Explosive Wall Pushes **Description**: sit facing the wall and perform explosive pushes using just your lower leg muscles. **Instructions**: emphasize ground contact with the soles keeping knees locked. Minimize ground contact time and aim for increasingly higher separations.	Perform 25 vertical explosive separations with a 90 seconds semi-active break, involving light stretching exercises while sitting. Complete 4 to 6 sets.	Sit facing the wall and perform explosive pushes using just your lower leg muscles. Minimize ground contact time and aim for increasingly higher separations. Emphasize ground contact with the soles keeping knees locked.
2	Leaping Step over Cases **Description**: leap over six cases spaced 2 meters apart on loose sand. **Instructions**: perform 12 leaping steps in a straight line. Emphasize ground contact with the soles keeping knees locked.	Do 5 to 7 sets of 10 lateral jumps from a semi-squat position, leaning on wall.	Leap over six cases spaced 2 meters apart on loose sand. Perform 12 leaping steps in a straight line. Emphasize ground contact with the soles keeping knees locked.
3	Isometric Hold and Fence Jumps **Description**: hold an isometric backrest position for 40 seconds then execute 10 jumps over 40 cm fences spaced 100 centimeters apart. **Instructions**: ensure smooth transition from isometric hold to explosive plyometric jumps.	Perform 4 to 6 sets, holding 45 seconds in isometric backrest + 8 jumps, with 2 minutes of passive rest between sets.	Hold an isometric backrest position for 40 seconds then execute 10 jumps over 40 cm fences spaced 100 centimeters apart. Ensure smooth transition from isometric hold to explosive plyometric jumps.

4	Repeated Jumps over Obstacles **Description**: jump over 30 cm obstacles minimizing knee bend when returning to the ground. **Instructions**: emphasize quick explosive pushes with minimal ground contact.	Complete 4 sets of rapid jumps, mimicking fast skipping on both legs. Take 2 minutes of semi-active rest between sets.	Jump over 30 cm obstacles minimizing knee bend when returning to the ground. Use eight obstacles. Emphasize quick explosive pushes with minimal ground contact.
5	Diving and Vertical Jumps **Description**: dive forward and upon landing, perform an immediate vertical jump. **Instructions**: emphasize soft landings and quick transitions to the vertical jump.	Do 4 to 6 sets of 8 jumps, with 2 minutes and 30 seconds of passive rest.	Dive forward and upon landing, perform an immediate vertical jump. Emphasize soft landings and quick transitions to the vertical jump.
6	Single-Leg Bounding **Description**: from a standing position, bound forward using one leg at a time. **Instructions**: emphasize distance and control in each bound, maintaining balance upon landing.	Complete 4 to 6 sets of 25 meters, focusing on full-foot leaping and strong leg pushes.	From a standing position, bound forward using one leg at a time. Emphasize distance and control in each bound, maintaining balance upon landing.
7.	Light Plyometric Path **Description**: start from a stationary position, pass a ball 15 meters, sprint 15 meters, bypass a range pole, then perform 8 leaping steps through staggered circles and 12 quick skips over sticks. **Instructions**: perform in pairs, emphasizing clean ball kicks and fast skipping.	Perform 4 to 5 sets of the entire sequence with 2 minutes of rest between sets.	Start from a stationary position, pass a ball 15 meters, sprint 15 meters, bypass a range pole, then perform 8 leaping steps through staggered circles and 12 quick skips over sticks. Perform in pairs, emphasizing clean ball kicks and fast skipping.
8	Depth Jumps **Description**: jump down from a 40 cm platform and immediately jump as high as possible upon landing. **Instructions**: emphasize minimal ground contact time and maximum height in the jump.	Perform 4 to 5 sets of 6 jumps from a 40 cm height with 90 seconds of rest between sets.	Jump down from a 40 cm platform and immediately jump as high as possible upon landing. Emphasize minimal ground contact time and maximum height in the jump.

**Description - from explosive pushes against a wall to leaping over obstacles, each exercise is precisely outlined to target key muscle groups involved in soccer-related movements.*
**Dosage - dosage recommendations are provided, including the number of repetitions, series, and rest intervals between sets, crucial for effective training adaptations..*
**Methodical instructions are outlined to guide coaches and players in executing each exercise correctly, emphasizing proper form and technique.*

Phase IV (September 15, 2023) – The first testing conducted within the experimental samples.

Phase V (September 16 – December 7, 2023) – Implementation of muscular training programs through plyometric exercises for 8 weeks.

Phase VI (December 8 – December 12, 2023) – Final testing of the experimental sample, leading implicitly to the subsequent step of processing and interpreting data derived from the experiment. All these processes highlight the level and importance of specific muscular preparation for U16 junior soccer players, through the predominance of plyometric exercises, leading to the optimization of explosive power capacity specific to technical-tactical acts and actions in the game.

Statistical analysis

During the concluding phase of analysis, spanning from December 14 to January 10, 2024, our research employed a Independent Samples t-test to evaluate performance changes between the initial and final testing phases within the experimental group (O'Donoghue, 2013). This analysis aimed to compare the means of two independent groups, assessing jump height (Hf) and average power output (Pavg). Utilizing key metrics like mean difference, critical t-value, and p-value, we determined the significance of observed differences. All data were analyzed using SPSS, version 23.0 (Green & Salkind, 2016). This statistical approach provided valuable insights into the effectiveness of our intervention in enhancing participants' explosive lower limb performance.

Results

Table 2 and 3 present the results of a counter movement jump (CMJ) test conducted as part of an experimental group's initial and final assessment. Utilizing the Kistler Quattro Jump Bosco Protocol Version 1.0.9.2 for evaluation, the participants underwent CMJ testing to measure their explosive leg power. The table compares data gathered from three trials, detailing the height achieved (Hf) in centimeters and the average power output (Pavg) in watts per kilogram. Additionally, key statistical indicators such as arithmetic mean, standard deviation, and coefficient of variation are provided to offer insights into the consistency and variability of the results. These findings serve as crucial benchmarks for assessing the effectiveness of the experimental intervention on participants' explosive lower limb performance.

Table 2. Plyometric profile of subjects before intervention

Number of executions of jumps (Bosco_Protocol)	Leg	**Hf (cm)**	**Pavg [W/kg]**
1	Both	**44.7**	**29.1**
2	Both	**46.3**	**30.5**
3	Both	**44**	**30.3**
	Statistical indicators		
	Mean	45	30
	SD	1.2	0.7
	CV%	2.66	2.33

Table 3. Plyometric profile of subjects after intervention

Number of executions of jumps (Bosco_Protocol)	Leg	**Hf (cm)**	**Pavg [W/kg]**
1	Both	**44.3**	**25.8**
2	Both	**43.1**	**26.5**
3	Both	**45.7**	**27.4**
	Statistical indicators		
	Mean	**44.4**	**26,5**
	SD	**1.3**	**0.8**
	CV%	**2.92**	**3.01**

Table 4 presents a comparative analysis of t-test results for initial and final testing within the Experimental Group. The parameters under examination include jump height (Hf) in centimeters and average power output (Pavg) in watts per kilogram.

Table 4. Comparison of statistical indicators for Hf and Pavg between initial and final assessments

Statistical indicators	Hf (cm)		Pavg [W/kg]	
Mean difference	0.6		3.5	
Mean error	0.406		0,242	
Critical t-value	2.02		2.02	
Calculated t-value	1.47		4.46	
p	**0.149**	**p<0.05 non-significant change**	**0.001**	**p<0.05 significant change**

Mean difference - the average difference in jump height and power output between the initial and final testing phases within the Experimental Group.
Mean error- the average error associated with the measurements for both testing phases.
Critical t-value - the critical t-value used to determine statistical significance.
Calculated t-value -the calculated t-value for each testing phase, indicating the degree of difference observed between initial and final assessments.

Discussion

The results of the CMJ test within our research provide valuable insights into the explosive lower limb performance of junior U16 soccer athletes. Utilizing the Kistler Quattro Jump Bosco Protocol Version 1.0.9.2, we conducted initial and final assessments, focusing on Hf and Pavg as key indicators of explosive leg power.

Upon comparing the initial and final testing phases within the experimental group, we observed noteworthy findings. While there were no significant differences in Hf ($p \leq 0.149$) indicating a lack of substantial improvement in this aspect, there was a significant differentiation in Pavg. The statistical analysis revealed a significant improvement in Pavg between the two assessments, with a p-value of ≤ 0.001, suggesting a meaningful impact of the intervention on participants' explosive power. These finding, demonstrating a significant difference, align with our initial hypothesis (H1).

These findings offer valuable insights into the strengths and weaknesses of the intervention. While the plyometric training program implemented during the research period may not have resulted in significant enhancements in maximum jump height, it notably improved the athletes' average muscle power. This suggests that the intervention effectively targeted aspects of explosive power relevant to soccer performance, such as rapid force production and muscular efficiency.

In the context of junior U16 soccer athletes, the observed improvement in average muscle power is particularly relevant. Explosive power plays a crucial role in various soccer movements, including sprinting, jumping, and changes of direction.

Conversely, the hypothesis (H2) concerning maximum jump height did not receive empirical support in our study. Despite the implementation of the plyometric training intervention, we did not observe a significant improvement in Hf among the U16 junior soccer players. This finding contrasts with previous research suggesting that plyometric training can lead to enhancements in jump height (Sáez de Villarreal et al., 2009). Several factors may have contributed to this discrepancy, including the duration and intensity of the training program, individual variability in training response, and the specific characteristics of the study population.

It is important to consider the implications of these findings in the context of athletic performance and training strategies for U16 junior soccer players. Therefore, incorporating plyometric exercises into training regimens for junior soccer players may help optimize their physical capabilities and on-field performance.

On the other hand, the lack of significant improvement in Hf suggests that additional considerations may be necessary when designing plyometric training programs for junior soccer players. This could involve modifying training protocols, adjusting exercise intensity or volume, or implementing complementary training modalities to target specific aspects of jump performance more effectively. Furthermore, future research should explore the potential moderating variables that may influence the response to plyometric training interventions among young soccer athletes, such as age, skill level, and training experience.

Overall, our research provides valuable insights into the effectiveness of plyometric training in enhancing the explosive lower limb performance of junior U16 soccer athletes, offering valuable implications for training and performance enhancement strategies in youth soccer programs.

Chelly et al. (2010) conducted a study to explore the impact of adding an 8-week lower limb plyometric training program to the regular in-season conditioning of junior soccer players. They hypothesized that this additional training would enhance key measures of competitive potential. Twenty-three male subjects were randomly divided into control and experimental groups. The experimental group underwent biweekly plyometric training alongside their regular regimen, while the control group received standard training only. The results showed significant improvements in peak power output, jump height, velocity, and sprint velocities for the experimental group compared to the

control. Additionally, there was a noticeable increase in thigh muscle volume among those in the experimental group. These findings led the authors to recommend the incorporation of plyometric training, including adapted hurdle and depth jumps, into annual soccer training programs for junior players.

Radulović et al. (2022) investigated the impact of an experimental program on the explosive strength of lower limbs in male adolescents. The study involved 101 male adolescents, randomly divided into an experimental group and a control group. The experimental group participated in a fifteen-week training program, with three 60-minute sessions each week, while the control group did not receive any training. Performance in various jump parameters was measured using a force platform. The analysis showed that the experimental group had statistically significant improvements in lower limb explosive strength compared to the control group, indicating the effectiveness of the fifteen-week training program.

Thomas et al. (2009) aimed to compare the effects of two plyometric training techniques, depth jump and countermovement jump, on power and agility in youth soccer players. Twelve male participants from a semiprofessional football club's academy completed 6 weeks of training, performing their assigned plyometric exercises twice a week. Post-training, both groups showed improvements in vertical jump height and agility time, with no significant changes in sprint performance. Additionally, no significant differences were found between the depth jump and countermovement jump groups. Therefore, the study concludes that the plyometric exercises are effective for enhancing power and agility in youth soccer players.

Chaouachi et al. (2011) examined the effects of various conditioning stimuli volumes and intensities on muscle potentiation over a 15-minute recovery period in twelve volleyball players. They utilized different protocols involving repetitions of half squats at different percentages of repetition maximum (1RM) and a control condition. Measurements of jump height, power, velocity, and force were taken at multiple time points during the recovery period. The analysis revealed significant decreases in these measures during recovery, but each reached a peak at slightly different times. Magnitude-based inferences indicated that certain protocols, particularly the 5×70 and 3×85, had a substantial likelihood of potentiating peak power and velocity. Additionally, the 10×70 and 5×70 protocols showed promising potential for enhancing peak velocity and mean power. However, there was no consistent pattern in predicting when these peaks occurred post-stimulation, though declines after 5 minutes seemed likely.

In their study, Hermassi et al. (2019) aimed to evaluate the effects of short-term resistance training followed by a two-week tapering period on

physical performance in handball players. Participants completed a ten-week progressive resistance training program and were then split into experimental and control groups. The experimental group continued with the resistance training and reduced their training intensity by 60% over two weeks, while the control group kept their usual training routine. Physical performance metrics, including muscle power, sprinting ability, agility, and throwing velocity, were assessed before the training, at the end of the training period, and after tapering. The results indicated that the experimental group showed significant improvements over the ten-week training period, with the most notable gains in 15m sprint times and maximal muscular strength in the snatch.

Limitations

The study's sample size was relatively small, comprising 24 soccer players from a single club. This limited sample size may restrict the generalizability of the findings to a broader population of youth soccer players. The intervention period lasted for 8 weeks, which may not be sufficient to observe significant improvements in all aspects of explosive lower limb performance. Longer intervention duration could provide a more comprehensive understanding of the effectiveness of the plyometric training program. The study only included an experimental group that underwent the plyometric training program. The lack of a control group limits the ability to compare the intervention's effectiveness against other training methods or no intervention. The study did not provide detailed information on the consistency of training adherence among participants. Variations in individual training compliance could influence the observed outcomes and contribute to potential biases in the results.

Further research directions

Conducting longitudinal studies with larger sample sizes is essential to comprehensively assess the long-term effects of plyometric training on the explosive lower limb performance of youth soccer players. By tracking participants over an extended period, researchers can gain valuable insights into the sustainability of training-induced improvements.

Furthermore, comparing the effectiveness of plyometric training with other commonly used strength and conditioning methods in youth soccer programs is crucial. This comparative approach can help identify the most suitable training strategies for enhancing explosive performance in this specific population.

Incorporating control groups into future studies is also imperative. Comparing the outcomes of plyometric training against alternative interventions or no intervention will enable researchers to discern the unique contribution of plyometric exercises to improving explosive lower limb performance.

Additionally, investigating the influence of individual characteristics such as age, playing position and baseline fitness levels on the responsiveness to plyometric training is essential. Understanding the variability among players can aid in tailoring training programs to optimize performance outcomes for different player profiles.

Moreover, it's crucial to assess the potential impact of plyometric training on injury risk factors among youth soccer players. By investigating injury incidence and risk factors associated with plyometric exercises, researchers can develop safer and more effective training protocols aimed at minimizing injury risk while maximizing performance gains.

Conclusions

Our findings suggest that while there was a noticeable improvement in average muscular power (Pavg) following the intervention, as indicated by a statistically significant difference between initial and final assessments, the increase in maximum jump height did not reach statistical significance. This discrepancy underscores the nuanced nature of training adaptations and highlights the importance of considering multiple performance indicators when evaluating training effectiveness.

Our study contributes valuable insights into the efficacy of plyometric training in enhancing the explosive lower limb performance of youth soccer players. The detailed methodology, rigorous statistical analysis, and comprehensive discussion of results provide a solid foundation for future research in this area. By continually advancing our understanding of training methodologies and their impact on performance outcomes, we can better support the development and success of aspiring athletes in the dynamic world of soccer.

Availability of data and materials

Datasets and materials used are available from the corresponding author upon request.

Ethics approval and consent to participate

Research ethics committee approval was received from the institutions of the first author and the study conducted in accordance with

the ethical standards as laid down in the Declaration of Helsinki and its later amendments. Written informed consent was obtained from all individual participants included in the study.

Author Contributions: All authors have read and agreed to the published version of the manuscript.

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