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A Systematic Review: Significance of Plyometric Training on Functional Performance and Bone Mineral Density in Basketball Players of Different Age Groups

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ABSTRACT

Aim: Basketball necessitates a holistic approach to player development, encompassing both skill and physicality, with a critical emphasis on understanding these requirements due to its complex tactics. Plyometric training's potential in sport performance lacks comprehensive research. This systematic review, guided by PRISMA guidelines, aims to analyse diverse range of literature concerning healthy athletes, investigating its significance on functional performance and bone mineral density in basketball players of different age groups (pre-teen, adolescent, and young adult).

Methods: The study conducted electronic searches in databases like PubMed, ScienceDirect, and ResearchGate, supplemented with manual reference searches, covering the period from 2013 to June 2023. Initially, 783 items were identified. Inclusion criteria involved English-language publications focusing on basketball players aged 8 to 28 years, assessing plyometric training's effect on functional performance with quantitative measurements. Screening began with titles and abstracts, followed by full-text evaluation to ensure eligibility.

Results: A database search yielded 26 peer-reviewed articles, primarily randomized controlled trials, showing significant functional improvements through plyometric training (4-36 weeks, 2-3 times weekly). Assessments covered explosive leg power, agility, sprinting, muscle strength, and bone density. Male participants dominated, but female and mixed-gender groups were included. Results consistently highlighted plyometric training's positive impact with statistical significance.

Conclusion: This review provides evidence that plyometric training improves agility, sprinting ability, leg power, basketball skills as well as BMD across different age groups of players. It establishes plyometrics as effective for boosting on-court performance. Integrating plyometric training holds great promise in advancing athlete success in basketball.

Keywords: basketball, plyometric training, leg power, jumping, sprint, agility, muscle strength, bone mineral density, performance

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Систематический обзор: Значимость плиометрических тренировок для функциональных показателей и минеральной плотности костной ткани у баскетболистов разных возрастных групп

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РЕЗЮМЕ

Цель: Баскетбол требует всестороннего подхода к развитию игрока, включающего в себя навыки, физическую подготовку. Потенциал плиометрических тренировок для повышения спортивной результативности изучен недостаточно. Этот систематический обзор, проводимый в соответствии с рекомендациями PRISMA, анализирует разнообразные литературные источники, включающие здоровых спортсменов. Обзор исследует роль плиометрики для функциональных показателей и минеральной плотности костей у баскетболистов разных возрастных групп.

Методы: Был производен поиск в электронных базах данных PubMed, ScienceDirect и ResearchGate в период с 2013 года по июнь 2023 года. Изначально было выявлено 783 публикации. В исследование включались публикации на английском языке, фокусирующиеся на баскетболистах в возрасте от 8 до 28 лет и оценивающие влияние плиометрической тренировки на функциональные показатели с использованием количественных измерений. Сначала проводилась проверка по названиям и аннотациям, а затем был проведен анализ полных текстов статей для определения соответствия критериям включения.

Результаты: По результатам поиска в базе данных было найдено 26 публикаций, в основном рандомизированных контролируемых исследований, демонстрирующих значительные улучшения функциональных показателей при использовании плиометрических тренировок (4–36 недель, 2–3 раза в неделю). Оценивались взрывная сила ног, ловкость, спринтерская способность, мышечная сила и плотность костей. В исследованиях в основном изучались мужчины, но имелись исследования только среди женщин и без разделения по половому признаку. Результаты продемонстрировали статистически значимое положительное влияние плиометрических тренировок на все изучаемые показатели.

Заключение: Плиометрические тренировки улучшают ловкость, спринтерскую способность, силу ног, навыки баскетбола, а также плотность минералов в костях у игроков разных возрастных групп. Интеграция плиометрических тренировок эффективна для повышения спортивной результативности в баскетболе.

Ключевые слова: баскетбол, плиометрическая тренировка, сила ног, прыжки, спринт, ловкость, мышечная сила, минеральная плотность костей, результативность

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1. Introduction

Sports encompass physical activities that are engaged in for leisure or competition, aiming to enhance and maintain an individual's physical fitness and overall well-being. The participation in sports is steadily increasing worldwide, transcending age barriers, as it fosters a positive self-perception, encourages a healthy lifestyle, and cultivates stronger social connections within society [1]. Sports policies and frameworks play a pivotal role in determining the success of a nation's sporting endeavours on the global stage. The medal tally in prestigious international events such as the Olympics serves as a testament to an individual's achievements, cultural diversity, and a nation's strength. The accomplishments of athletes hinge on their personal or collective performances, strategic approaches, and the allocation of resources dedicated to their respective sports. Beyond personal achievements, sports possess the potential to generate substantial socio-economic benefits for a nation and its populace. Furthermore, sports assume a crucial responsibility in promoting physical fitness and fostering a healthy lifestyle. Consequently, there is a growing demand for enhanced sports facilities and comprehensive programs. However, a noticeable trend in recent times is the increasing involvement of youth in sports, characterized by early specialization and year-round training. This trend has correspondingly resulted in an upsurge of sports-related injuries among junior athletes [2].

Basketball is a globally revered team sport that demands both effective aerobic recovery from high-intensity activities and robust anaerobic capacity. It encompasses a wide range of techniques and skill-based forceful movements, such as sprints, jumps, and the ability to swiftly change directions during gameplay. In a competitive environment, players strive to showcase their skills and perform assertively. However, the success rate of players relies significantly on their individual skill level and physical strength. Given the intricate movements involved, there is a risk of physical injuries, influenced by factors such as age, training level, and physical fitness of the players. These demands necessitate improved functional performance, which can be achieved through a combination of regular, intense training sessions focused on skill development and a well-designed conditioning program.

A. Functional Performance Indicators and BMD

Developing junior basketball athletes poses a significant challenge in enhancing their physiological, physical, practical, and strategic competences. To effectively improve these capabilities, training must align with the specific requirements of competitive play. The physical and physiological demands of basketball are influenced by factors such as player tactics, the strength and style of the opposition, and the level of competition. It is essential to accurately assess the impact of these demands on junior athletes and develop optimal training programs to foster their long-term development as athletes. However, the availability of research on the physiological and physical demands specific to basketball sports is limited, and there is a scarcity of studies investigating key performance indicators in junior basketball competitions.

When comparing basketball with sports like handball and volleyball, it becomes evident that basketball necessitates the highest proportion of high intensity running to sprinting. Furthermore, basketball involves the most frequent occurrence of lateral movements, with players engaging in up to 450 lateral movements per game. Additionally, basketball players are required to execute a substantial number of jumps during each match, ranging from 42 to 56 jumps [3]. Usually, heavy static resistance strength training has been widely advocated in sports-related fitness to improve functional performance and prevent injuries. However, it is essential to recognize that this approach may not be universally applicable to all sports. In the context of basketball, specific aspects play a pivotal role in determining functional performance, such as increased muscle strength, explosive leg power, sprinting capabilities, and agility, as well as bone mineral density using Dual-energy X-ray absorptiometry scans. Within the realm of basketball sports, the development of explosive power in the legs holds paramount importance. Vertical jumping, a fundamental element of explosive performance, significantly influences the execution of various skills. Notably, jumping entails a complex coordination of multiple joints and requires the generation of significant force and power output. Enhancing degree of coordination and skill proficiency in executing movements, as well as optimizing the utilization of the stretch-shortening cycle within the muscles, are essential elements influencing vertical jump performance [4].

Agility holds significant importance as a key component of fitness in basketball sports. It encompasses the ability to initiate rapid acceleration, efficiently decelerate and stabilize, and swiftly change direction while maintaining optimal posture [5]. Agility demands excellent neuromuscular efficiency, enabling athletes to effectively control their centre of gravity over their base of support when executing directional changes at varying speeds. Additionally, sprint running plays a varying but significant role in achieving success in basketball sports contributing to various aspects of performance such as fast breaks, transition offense, defensive transitions, rebounding, court coverage, penetration and driving to the basket. Developing sprinting technique, speed, and acceleration is crucial for basketball players, and it can be achieved through targeted training drills and exercises. Integrating sprinting into their comprehensive conditioning program holds the potential to significantly enhance their overall performance on the basketball court [6].

Bone mineral density (BMD) holds utmost importance in the well-being and performance of basketball players [7]. The nature of basketball, with its high-impact movements like jumping and landing, subjects the skeletal system to substantial stress. Therefore, ensuring optimal BMD is crucial for minimizing the likelihood of stress fractures and other bone-related injuries. Regular participation in basketball, especially during the growing years, can have a positive impact on bone health and development. The repetitive loading and impact forces experienced during basketball activities stimulate bone remodelling, leading to increased bone mineral content and density. However, it is important to note that factors such as nutritional status, hormonal balance, and training load can influence BMD in basketball players. Monitoring BMD through periodic assessments, such as dual-energy X-ray absorptiometry (DXA) scans, can provide valuable information about an athlete's bone health [8]. These assessments can help identify any deficiencies or potential risks and guide interventions to optimize bone health.

B. Plyometric Training

Plyometric training, also known as "jump training" or "plyos," is a highly regarded and widely adopted method of training in dynamic sports. It involves executing exercises that demand muscles to generate maximal force within short time intervals [9]. The primary goal of plyometric exercises, such as jumping, hopping, skipping, and bounding, is to enhance dynamic muscular performance. Extensive research has demonstrated the effectiveness and safety of plyometric training in improving physical performance, particularly in young basketball players. Moreover, the versatility and practicality of plyometric exercises allow for easy integration into regular training routines [10].

Plyometric Training (PT) is an effective method for developing explosive strength and enhancing body power. This training approach involves exercises that facilitate quick and forceful movements, characterized by explosive concentric muscle contractions preceded by eccentric muscle actions [11]. Plyometric exercises evoke the elastic properties of muscle fibers and connective tissues, allowing for the storage and release of energy during the deceleration and acceleration phases. By incorporating plyometric drills that involve explosive changes in direction, rapid starts and stops, athletes can develop key components such as agility [5]. Improving sprinting performance encompasses various training methodologies, and plyometric training is a commonly employed technique. Alongside sprint drills, over-speed training, resistance sprinting, and weight training, plyometric training plays a significant role [12].

Research has indicated that Plyometric training can have positive effects on bone mass, resulting in relative gains ranging from 1 % to 8 %. Notably, jump training programs implemented in school have demonstrated an increase in bone mass among children, along with improvements in bone structure and strength. Furthermore, plyometric training in junior athletes has shown a long-term impact that surpasses the effects of typical growth and development [6]. More recent findings suggest that when appropriate training guidelines are followed, plyometric training can also be safe and effective for adolescents [4].

2. Literature review

A. Objective

This systematic review adhered to the guidelines outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [13], ensuring the appropriate conduct and transparent reporting of the study refer Figure1. It is important to note that no review protocol was registered for this review since it exclusively focused on healthy athletes of varying age groups. This review answers the research question, "Does plyometric training intervention have any impact on functional performance and bone mineral density in Basketball players of different age groups?". This paper surveys into the profound impact of plyometric training on various aspects crucial to basketball sports. Specifically, it studies the effects of plyometric training on improving agility, sprint performance, vertical jump, explosive leg power, muscle strength, and bone mineral density of athletes within the competitive basketball environment. By examining a wide range of relevant factors, this review paper sheds light on the multifaceted benefits of plyometric training and its potential to significantly enhance athletic performance in basketball.

B. Data Source and Search Criteria

This study involved an electronic data source search, encompassing the National Library of Medicine (NLM) — PubMed, Elsevier — ScienceDirect, ResearchGate databases and other journal websites. The search spanned a period of the past 10 years, starting from 2013 up to June 2023, to retrieve relevant studies. The search focused on English-language, peer-reviewed randomized controlled trials (or) clinical trials research that used the following terms either individually or in combination: "plyometric training," "plyometrics," "basketball," "sports", "junior," "adolescents," "athletes," "jump training," "functional performance," "bone mineral density," "agility," "muscle strength," and "sprint." The following exclusion criteria were applied: Participants whose characteristics did not align with the search parameters of selected databases, Data extracted from theses or non-English articles and Data obtained from chapters within books.

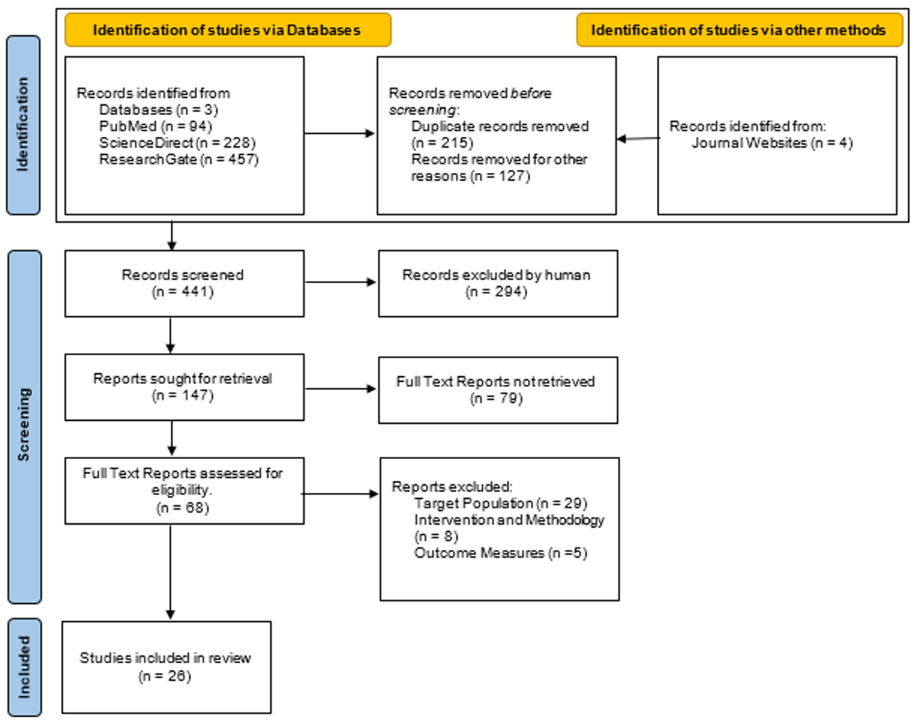

Fig.1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Flow Diagram for identifying and including articles for systematic review

Рисунок 1. PRISMA (Предпочитаемые элементы отчетности для систематических обзоров и метаанализов) Блок-схема выявления и включения статей для систематического обзора

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A. Data Retrieval

The analysis covered a diverse array of characteristics, including participant characteristics/demographics, gender, performance level, the nature of interventions, outcome measures, statistical analysis technique, results, and study inference.

B. Study articles profile

A systematic assessment of study methods in accordance with PRISMA resulted in the selection of 26 original-research peer-reviewed articles. Each of these works underwent careful analysis to evaluate the actual effects (expressed as relative effect %) of Plyometric Training (PT) either independently or when combined with strength/other technique training on different age group (pre-teen to young adult) basketball players functional performance using clinical trials (or) randomized controlled trials, wherein they compared the impact of plyometric training interventions with a control group.

Table 1 presents a compilation of research articles related to basketball player with plyometric training interventions. This compilation encompasses studies conducted over a significant period, ranging from 2013 to 2023. The articles cover a broad spectrum of sample sizes, with participant groups varying in numbers from 10 to 200 individuals. Likewise, the different age groups involved in these studies span a wide range from 8 to 28 years (pre-teen, adolescent, young adult), making the research findings relevant to a diverse set of basketball players. Among the different intervention types explored in these studies, plyometric training emerges as the most prevalent approach.

Researchers have extensively examined the impact of plyometric exercises on basketball players, suggesting its significance as a training modality for this sport. Additionally, the trial designs employed to evaluate these interventions primarily favoured randomized controlled trials, highlighting the rigorous methodology used in the research. Training durations varied between 4 and 36 weeks, 6 weeks duration was mostly used with a common frequency of 2 (or) 3 days per week. Regarding participant demographics, male participants predominated, however, it is essential to acknowledge that research on female participants and mixed-gender groups is also present, contributing to a more comprehensive understanding of training interventions across various populations. The table provides valuable insights into diverse plyometric training approaches and their study on basketball players of various age groups and skill levels.

C. Methods to minimize bias assessment

To ensure the integrity of research in plyometric training studies with basketball players, it is imperative to address potential systematic errors or bias. This can be achieved through rigorous measures such as randomization and blinding during participant assignment, the inclusion of control groups for accurate baseline comparisons, and the use of adequate sample sizes and baseline measurements to maintain statistical validity. Standardization of training protocols and outcome measures across studies is essential for drawing meaningful conclusions, and thorough statistical analyses are necessary for bias detection and correction. In addition, the inclusion of a diverse range of participants enhances the generalizability of findings, and transparent reporting of methods and results is paramount.

D. Functional Performance and Outcome Measures

Within the realm of basketball sports, the effects of PT on players were categorized into following outcome measures extracted from the study: jumping performance indicating explosive leg power, agility, sprinting, flexibility and stability using physical/muscle strength as well as bone mineral density measure using dual-energy X-ray absorptiometry (DXA) scans.

i. Explosive Leg Power — Jumping

The outcome measures mentioned in Table2. are various tests used to assess different aspects of an individual's jumping ability, and explosive leg power capabilities, helping to evaluate athletic performance, track progress, and identify areas for improvement.

ii. Change of Direction — Agility

The outcome measures summarized in Table 3. are commonly used agility tests in sports performance assessments, rehabilitation, and research to evaluate an individual's ability to change direction quickly, react to stimuli, and maintain balance during dynamic movements. They provide valuable insights into an individual's agility and athletic performance, helping to identify strengths and areas for improvement in multidirectional movement and overall athletic ability.

iii. Speed/Running — Sprinting

The outcome measures in Table 4. are speed-related tests commonly used in sports performance assessments, talent identification, and training programs to evaluate an individual's sprinting abilities, acceleration, and overall speed performance in different contexts and distances.

iv. Physical/Muscle Strength — Flexibility and Stability

These outcome measures summarized in Table 5. are commonly used in fitness assessments, sports performance evaluations, and clinical settings to gain insights into an individual's physical abilities, health, and performance levels. Each test provides valuable information about specific aspects of fitness and function, allowing professionals to tailor exercise programs or interventions to meet individual needs.

v. Bone Mineral Density

Dual-Energy X-ray Absorptiometry (DXA) is widely considered a reliable and accurate method for assessing bone health and body. It is a medical imaging technique used to assess body composition, particularly bone mineral density (BMD), lean mass, and fat mass. The scan provides

Table 1

Study Articles Profile Summary

Таблица 1

Статьи, включенные в систематический обзор

Article Profile	Category	No. of Articles
Publication Year	2013 [14]	1
	2014 [15, 16]	2
	2015 [17, 18]	2
	2016 [19]	1
	2017 [20, 21]	2
	2018 [22, 23]	2
	2019 [24, 25, 26]	3
	2020 [27, 28]	2
	2021 [29, 30, 31]	3
	2022 [32, 33, 34, 35, 36]	5
	2023 [37, 38, 39]	3
Sample Size Range	10–20 [14, 17, 18, 19, 23, 24, 27, 30, 37]	9
	21–30 [20, 22, 25, 29, 32, 33, 36, 39]	8
	31–40 [15, 26, 28, 31, 34, 35]	6
	51–200 [16, 21, 38]	3
Age Range	Pre-teen ~8–12 Years [16, 21, 23]	3
	Adolescent/Young ~13–19 Years [15, 17, 18, 19, 20, 24–31, 34, 35, 37, 39]	17
	Young Adult ~20–28 Years [14, 22, 32, 36, 39]	6
Type of Population — Development Level	Prepubertal basketball players [16, 21, 23]	3
	Young/Adolescent/High-School basketball players [15, 18–20, 24–28, 31, 32, 34–36, 39]	17
	University/Collegiate basketball players [17, 29, 33]	3
	Elite/Professional basketball players [14, 22, 30]	3
Intervention Training Type	Plyometric* [14–20, 23–30, 32, 34–38]	22
	Plyometric* + Isometric [21]	1
	Plyometric* + Strength + Change of Direction [31]	1
	Plyometric* + Whole-body Vibration [33]	1
	High Intensity [39]	1
Intervention Trial Type	Single Arm Clinical Trial [14, 37]	2
	Parallel Group Clinical Trial [20]	1
	Randomized Controlled Trial [15–19, 21–32, 34–36, 39]	22
	Randomized Crossover Trial [33]	1
Intervention Training Period	4 Weeks [17, 24, 27, 29, 30]	5
	6 Weeks [14, 15, 18, 19, 28, 32, 34, 36]	9
	7 Weeks [23, 31]	2
	8 Weeks [37, 39]	2
	9 Weeks [16]	1
	10 Weeks [21, 26]	2
	12 Weeks [25, 35, 38]	3
	36 Weeks [20]	1
	Period not specified [33]	1
Intervention Training Frequency	2 days per Week [15–19, 21–24, 26, 27, 29, 31]	13
	3 days per Week [28, 30, 32, 34, 36, 37, 38, 39]	8
	5 days per Week [14, 25, 35]	3
	Frequency not specified [20, 33]	2
Gender	Male [14, 16–18, 20–27, 30–33, 35, 36, 37, 38]	20
	Female [15, 19]	2
	Male and Female [28, 29, 34, 37]	4

Note: *Plyometric with regular basketball training.

Примечание: *Плиометрия при регулярных тренировках по баскетболу.

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Table 2

Explosive Leg Power — Jumping Performance Outcome Measures

Таблица 2

Взрывная сила ног — показатели результатов прыжка

Outcome Measure	Description
Counter Movement Jump Test (CMJT) [14–16, 19, 21, 23, 28, 31, 33, 37]	Vertical jump height and lower body power with preliminary movement
Two Step Run Up Jump Test (TRJT) [14]	Vertical jump performance with short run-up for power generation
Squat/Vertical Jump Test (SJT) [15–17, 21, 27, 28, 35, 36, 38]	Vertical jump and Lower body explosive power from static squatting position
Drop Jump Test (DJT) [21, 23]	Reactive strength and neuromuscular control by jumping after stepping off a platform
Standing Long Jump/Stead Jump (SLJT) [19, 21, 25, 27, 38]	Horizontal jumping ability and lower body power from a stationary position
High Jump Test (HJT) [25]	Vertical jumping ability and clearance height with a running jump
Single Leg Triple Hop Test (SLTHT) [29, 38]	Single-leg power and symmetry by horizontal jumping on one leg
Approach Jump Test (AJT) [27]	Jumping performance with an approach for increased momentum
Abalakov jump (ABKJT) [31]	Evaluating jump height, distance, technique efficiency, difficulty level, and progress over time in ice climbing
Jump from Place to Length Test (JPLT) [24]	Explosive power and distance covered by horizontal jumping
Jump from place to Height Test (JPHT) [24]	Explosive power and distance covered by vertical jumping
High Jump with One Foot Test (HJOFT) [24]	Vertical jumping ability and clearance height with single-foot take-off using a running approach

Table 3

Change of Direction — Agility Performance Outcome Measures

Таблица 3

Изменение направления — показатели эффективности гибкости

Outcome Measure	Description
Agility — "T" Drill Test (ATT) [14, 16, 21–25, 27, 33, 36, 37]	Rapid changes of direction and quick movements in a "T" pattern
Hexagonal Obstacle Test (HOT) [14]	Navigating through a hexagonal pattern of obstacles
Illinois Agility Test (IAT) [24, 27, 30, 34]	Quick changes of direction through a specific course
Reactive Agility Test (RAT) [29]	Reacting to visual or auditory cues to change direction quickly
Lateral Hop Test (LHT) [19]	Hopping side-to-side over an obstacle or line
Lateral Shuffle Test (LST) [19]	Shuffling sideways as quickly as possible
Star Excursion Balance Test (SEBT) [18]	Reaching in multiple directions from a single-leg stance
Zigzag Barrow Test (ZBT) [22]	Running in a zigzag pattern while pushing a barrow/sled, assessing agility, speed and lateral movements
10 m Zig-Zag Test (ZT) [31]	Change of Direction in a zigzag pattern over a 10-meter distance, testing agility and speed

Table 4

Speed/Running — Sprinting Performance Outcome Measures

Таблица 4

Скорость/бег — показатели результативности спринта

Outcome Measure	Description
Shuttle Run Test (SRT) [36]	Back-and-forth running between two points, testing speed and agility with changes of direction
5/10/15/20/30/80/100-Meter Sprint Test (MST) [16, 17, 21, 23–27, 30–34, 37, 38]	Sprinting as fast as possible over a 5/10/20/30/80/100-meter distance from a stationary start testing acceleration and top-end speed

Table 5

Physical/Muscle Strength — Flexibility and Stability Outcome Measures

Таблица 5

Физическая/мышечная сила — показатели гибкости и стабильности

Outcome Measure	Description
Push-Up Test (PUT) [24, 27]	Assesses upper body strength and endurance. Participants perform as many push-ups as they can with proper form, and the number of completed push-ups is recorded
Abdominal Muscle Test (AMT) [24, 25, 27]	Evaluates the strength and endurance of the abdominal muscles. Participants typically perform a set number of abdominal crunches or sit-ups, and the number of completed repetitions is recorded
Medicine Ball Throw Distance Test (MBDT) [24, 25, 27]	Measures upper body power. Participants throw a medicine ball as far as they can, and the distance achieved is measured
Sit and Reach Flexibility Test (SRFT) [24, 25, 27, 31, 32, 36]	Assesses the flexibility of the lower back and hamstrings. Participants sit with their legs extended and reach forward as far as they can. Distance reached is recorded
Balance Error Scoring System (BESS) [29]	Evaluates static balance. Participants perform various stances on a firm or foam surface, and errors in maintaining balance are scored
SpO2 Test [32]	Measures blood oxygen saturation levels (SpO2). Usually performed with a pulse oximeter by clipping it onto a finger
Anaerobic Power Test (APT) [32]	Assesses anaerobic power and capacity. Involves short, intense bursts of activity like cycling or running to measure peak power output
Flamingo Balance Test (FBT) [36]	Assessing balance and stability by measuring the duration of one-legged stance.
Isokinetic Muscle Strength Test (IMST) [35]	Measures muscle strength and endurance at a constant velocity. Participants perform exercises on specialized machines that control the speed of movement, and the peak torque generated by the muscles is recorded

Table 6

Summary Mapping of Article Study — Functional Performance Indicators and BMD

Таблица 6

Сводная карта исследования статьи — показатели функциональной эффективности и BMD

S.No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Article Ref.No.		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
FUNCTIONAL PERFORMANCE INDICATORS	Explosive Leg Power - Jumping	yes	yes	yes	yes		yes		yes		yes	yes	yes		yes	yes	yes		yes		yes		yes	yes	yes	yes	High Intensity Training
	Change of Direction - Agility	yes			yes	yes	yes		yes	yes	yes	yes	yes		yes		yes	yes	yes		yes	yes		yes	yes		
	Speed/ Running Power - Sprinting			yes	yes				yes		yes	yes	yes	yes	yes			yes	yes	yes	yes	yes		yes	yes	yes	
	Physical/ Muscle Strength - Flexibility and Stability											yes	yes		yes		yes		yes	yes			yes	yes			
Bone Mineral Density (BMD)				yes				yes																			yes

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information about bone mineral density (BMD), which is crucial for diagnosing osteoporosis and assessing fracture or injury risk. DXA scans are commonly used to diagnose osteoporosis and monitor changes in body composition over time. [16, 20, 39] It is often used in clinical settings, research studies, and sports performance evaluations to gain insights into the overall health and physical characteristics of individuals.

The Table 6 summarizes the plyometric training used to evaluate different aspects of physical fitness in basketball players including explosive power, agility, speed, strength, flexibility, stability, and bone health extracted from study articles.

The table reveals that 18 articles [14–17, 19, 21, 23, 24, 25, 27, 28, 29, 31, 33, 35, 36, 37] conducted exercises to assess explosive leg power, 17 articles [14, 17–19, 21–25, 30–34, 36, 37] focused on evaluating change of direction agility, 16 articles [16, 17, 21, 23–27, 30–34, 36–38] included exercises that measured speed and running power, 8 articles [24, 25, 27, 29, 31, 32, 35, 36] conducted test specific to evaluate physical/muscle strength, flexibility, and stability, and 3 articles [16, 20, 39] assessed bone mineral density (BMD) through DXA. Only 5 articles [24, 25, 27, 31, 36] focus on all considered functional performance except BMD. Presence of «Yes» entries in the table indicates that the respective functional performance measures and BMD were assessed in the corresponding articles. This compilation serves as a valuable resource for researchers, trainers, and practitioners seeking to design effective plyometrics exercise programs for competitive players of different age groups and enhance various aspects in basketball sports.

E. Statistical Analysis Techniques

The diverse statistical analysis techniques used to examine data in the study articles providing valuable insights into the methods employed to draw meaningful conclusions from the data. The analysis includes tests related to data normality using Shapiro — Wilk test [17, 18, 32–36], and Kolmogorov-Smirnov test [21.26, 31], descriptive statistics using mean and standard deviation (Mean ± STD) [14–21, 24, 25, 28, 30–37], variance homogeneity using Levene's test [7, 8, 13, 31], reliability using Intraclass Correlation Coefficient (ICC) [15, 18, 26, 31], bivariate correlation [3] and Pearson/partial correlation [20], covariance using ANCOVA [16, 19–21, 26], repeated measures using Univariate — ANOVA [14, 16, 18, 19, 21, 23, 27–31, 33, 34, 35] or Multivariate — MANOVA [15, 27], chi-square [14], Paired T-test [17, 22] and Unpaired *T*-test [4, 22, 24, 25, 30, 32, 35, 36], and post hoc paired mean difference using Bonferroni *post hoc* test [29, 31, 33], LSD de Fisher post hoc test [16] and Wilcoxon paired test [14]. Mostly all the studies employed a hypothesis testing statistical significance level *p*-value (probability value) of $p < 0.01$ [8, 33] (or) $p < 0.05$ [14, 16, 18–21, 27, 30, 32, 33, 35–38] (or) $p \leq 0.05$ [15, 17, 22–26, 29, 31, 34], with a confidence interval set at either 90 % (or) 95 %. Different statistical analysis tools like Statistica v8.0 and v10.0 [14, 16, 23], SPSS version varying from v10.0 to v25.0 [15, 18, 19, 21, 24–38], and BioEstat v5.0 [20] were used for these analyses.

F. Results

A variety of plyometric training programs, ranging from 4 to 12 weeks in duration, have demonstrated significant improvements in speed, agility, jumping ability, sprint performance, explosive strength, and overall physical performance in basketball players [14, 15, 17–19, 21–38]. These training interventions have shown positive effects on different aspects of athletic performance, including neuromuscular control, joint position sense, and injury risk reduction [15, 18, 35]. Notably, plyometric training has also been linked to improved bone health and density, which is especially beneficial for young athletes engaged in basketball, a sport known for its impact on bones and joints [16, 20, 39]. However, it's worth acknowledging the variability in individual responses and shorter duration programs, potential limitations in directly affecting certain attributes, and the need for tailored training strategies, longer and more intensive training regimens to optimize outcomes [14, 21, 23, 28, 36].

The Table 7 summarizes the outcomes of various studies on plyometric training's effects on basketball performance, including the Statistical Significance Improvement (SSI) results in terms of p-value within the experimental group (EG) and between the EG and control group (CG). It offers insights into the varied effects of plyometric training on different aspects of basketball performance. While some studies demonstrate significant improvements in jumping ability, agility, and sprint speed, others indicate mixed or no effects. Individual responses, training approaches, and duration play a crucial role in determining the impact of plyometric training on basketball players' performance and BMD.

These studies have extensively explored the significant effects of plyometric training on various facets of basketball performance, including jumping ability, sprint speed, agility, overall physical capabilities as well as bone health. The collective findings provide valuable insights into the potential benefits of integrating plyometric training to elevate athletic prowess among basketball players.

G. Discussion

Attene et al. [15], Begu et al. [25], and GAF Correia et al. [28], indicate that plyometric training contributes to significant improvements in jumping ability. Plyometric exercises seem to enhance explosive strength, thereby enhancing vertical jump performance, which is crucial for basketball players. Research by Nikola Aksović [26], Poomsalood and Pakulanon [17], and Androutsopoulos et al. [23] highlights the positive effects of plyometric training on sprint speed. This improvement is particularly important for basketball players during fast breaks and defensive drills. Research by Sáez de Villarreal et al. [31], Murşide Türki & Önder Dağlıoğlu [32], and GAF Correia et al. [28] uniformly underscore the affirmative impact of plyometric training on vertical jump performance.

Table 7

Result Summary of Plyometric Training Significant Effects on Basketball Performance Measures and BMD

Таблица 7

Сводка результатов плиометрической тренировки. Значительное влияние на показатели баскетбольной результативности и минеральной плотности костей

S.No.	Article Ref.No.	Outcome Measure — SSI Result (p -value)	Within EG	Between EG and CG
1	14	**Jump** — CMJT: $p = 0.32$↓*; TRJT: $p = 0.32$↓* **Agility** — ATT: $p = 0.21$↓*; HOT: $p = 0.01$↑*	No SSI in Jump and Agility except HOT	
2	15	**Jump** — CMJT: $p > 0.001$↑**, SJT: $p > 0.05$↑**		SSI in Jump
3	16	**Jump** — CMJT: $p > 0.001$↑**; SJT: $p > 0.001$↑** **Sprint** — xMST: $p > 0.001$↑** **BMD**- DXA: $p > 0.05$↓**		SSI in Jump, Sprint except BMD
4	17	**Jump** — SJT: $p = 0.003$↑*, $p = 0.262$↓** **Agility** — ATT: $p = 0.001$↑*, $p = 0.011$↑** **Sprint** — xMST: $p = 0.018$↑*, $p = 0.003$↑**	SSI in Jump, Agility and Sprint	SSI in Agility and Sprint except Jump
5	18	**Agility** — SEBT: $p = 0.001$↑**		SSI in Agility (COD)
6	19	**Jump** — CMJT: $p = 0.0001$↑*, $p > 0.05$↓**; SLJT: $p = 0.0001$↑*, $p > 0.05$↓** **Agility** — LHT: $p = .006$↑*, $p > 0.05$↓**; LST: $p = 0.002$↑*, $p > 0.05$↓**	SSI in Jump and Agility	No SSI in Jump and Agility
7	20	**BMD**- DXA: $p = 0.008$↑**		SSI in BMD
8	21	**Jump** — CMJT: $p > 0.001$↑**; SJT: $p > 0.04$↑**; DJT: $p = 0.014$↑**; SLJT: $p = 0.579$↓** **Agility** — ATT: $p = 0.004$↑** **Sprint** — xMST: $p > 0.002$↑**		SSI in Agility, Sprint, and Jump except SLJT
9	22	**Agility** — ATT: $p = 0.000$↑*, $p = 0.303$↓**; ZBT: $p = 0.001$↑*, $p = 0.002$↑**	SSI in Agility	SSI in Agility — ZBT and Not in ATT
10	23	**Jump** — CMJT: $p > 0.03$↑**; DJT: $p > 0.01$↑** **Agility** — ATT: $p = 0.004$↑** **Sprint** — xMST: $p > 0.03$↑**		SSI in Jump, Agility and Sprint
11	24	**Jump** — JPLT: $p = 0.003$↑*; JPHT: $p = 0.147$↓*; HJOFT: $p = 0.035$↑* **Agility** — ATT: $p = 0.821$↓*; IAT: $p = 0.012$↑* **Sprint** — xMST: $p = 0.023$↑* **Strength** — PUT: $p = 0.004$↑*; AMT: $p = 0.036$↑*; MBDT: $p = 0.078$↓*; SRFT: $p = -0.581$↓*	SSI in Jump except JPHT, Agility except ATT, Sprint, Strength except MBDT, SRFT	
12	25	**Jump** — SLJT: $p = 0.004$↑*, $p = 0.015$↑**; HJT: $p = 0.001$↑*, $p = 0.05$↑** **Agility** — ATT: $p = 0.000$↑*, $p = 0.303$↓** **Sprint** — xMST: $p = 0.185$↓*, $p = 0.072$↓** **Strength** — AMT: $p = p = 0.05$↑*, $p = 0.279$↓**; MBDT: $p = 0.133$↓*, $p = 0.242$↓**; SRFT: $p = 0.063$↓*, $p = 0.194$↓**	SSI in Jump, Agility, Strength except MBDT, SRFT and Not in Sprint	No SSI in Agility, Sprint and Strength except Jump
13	26	**Sprint** — xMST: $p = 0.012$↑**		SSI in Sprint

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14	27	**Jump** — SLJT: $p = 0.244$↓*, $p = 0.024$↑**; SJT: $p = 0.064$↑*, $p = 0.007$↑**; AJT: $p = 0.442$↓*, $p = 0.939$↓** **Agility** — ATT: $p = 0.668$↓*, $p = 0.179$↓** IAT: $p = 0.063$↑*, $p = 0.533$↓** **Sprint** — xMST: $p = 0.185$↓*, $p = 0.072$↓** **Strength** — AMT: $p = 0.05$↑*, $p = 0.279$↓**; MBDT: $p = 0.133$↓*, $p =$ 0.242↓**; SRFT: $p = 0.063$↓*, $p = 0.194$↓**	No SSI in Jump except SJT, Agility except IAT, Sprint, and Strength except AMT	No SSI in Agility, Sprint, Strength and Jump except SLJT, SJT
15	28	**Jump** — CMJT: $p = 0.007$↑*(m), $p = 0.58$↓**(m); $p = 0.008$↑*(f), $p >$ 0.05↓**(f) ; SJT: $p = 0.007$↑*(m), $p = 0.1$↓**(m); $p = 0.009$↑*(f), $p = 0.05$↑**(f)	SSI in Jump(f) and Jump(m) except SJT(m)	No SSI in Jump (m) and Jump(f) except SJT(f)
16	29	**Jump**- SLTHT: $p = 0.8$↓**; **Agility**- RAT: $p = 0.001$↑**; **Strength** — BESS: $p = 0.06$↓**		SSI in Agility and Not in Jump and Strength
17	30	**Agility** — IAT: $p > 0.001$↑*, $p = 0.028$↑** **Sprint** — xMST: $p > 0.001$↑*, $p = 0.004$↑**	SSI in Agility and Sprint	SSI in Agility and Sprint
18	31	**Jump**- CMJT: $p = 0.02$↑*, $p > 0.05$↓**; ABKJT: $p = 0.009$↑*, $p > 0.05$↓** **Agility**- ZT: $p = 0.012$↑*, $p = 0.001$↑** **Sprint** — xMST: $p = 0.015$↑*, $p = 0.004$↑** **Strength** — SRFT: $p > 0.05$↑*, $p = 0.036$↑**	SSI in Jump, Agility, Sprint and Strength	SSI in Agility, Sprint and Strength except Jump
19	32	**Sprint** — xMST: $p = 0.001$↑* **Strength** — SRFT: $p = 0.001$↑*; SpO2: $p = 0.001$↑*; APT: $p = 0.001$↑*	SSI in Sprint and Strength	
20	33	**Jump**- CMJT: $p = 0.001$↑*, $p = 0.807$↓** **Agility**- ATT: $p = 0.001$↑*, $p = 0.135$↓** **Sprint** — xMST: $p = 0.001$↑*, $p = 0.156$↓**	SSI in Jump, Agility and Sprint	No SSI in Jump, Agility and Sprint
21	34	**Agility** — IAT: $p = 0.002$↑*(m), $p = 0.86$↓*(f) **Sprint** — xMST: $p = 0.006$↑*(m), $p = 0.008$↑*(f)	SSI in Agility(m), Sprint(m&f) except Agility(f)	
22	35	**Jump**- SJT: $p < 0.05$↑*, $p < 0.05$↑** **Strength** — IMST: $p > 0.05$↑*, $p > 0.05$↓**	SSI in Jump and Strength	SSI in Jump and Not in Strength
23	36	**Jump**- SJT: $p = 0.000$↑* **Agility** — ATT: $p = 0.000$↑* **Sprint** — SRT: $p = 0.001$↑*; xMST: $p = 0.001$↑* **Strength** — SRFT: $p = 0.000$↑*; APT: $p = 0.000$↑*	SSI in Jump, Agility, Sprint and Strength	
24	37	**Jump**- CMJT: $p < 0.05$↑* **Agility**- ATT: $p < 0.05$↑* **Sprint** — xMST: $p < 0.05$↑*	SSI in Jump, Agility and Sprint	
25	38	**Jump**- SJT: $p = 0.000$↑*, $p < 0.05$↑**; SLJT: $p = 0.020$↑*, $p < 0.05$↑**. SLTHT: $p = 0.035$↑*, $p < 0.05$↑** **Sprint** — xMST: $p = 0.028$↑*, $p < 0.05$↑**	SSI in Jump and Sprint	SSI in Jump and Sprint
26	39	**BMD**- DXA: $p > 0.05$↑**		SSI in BMD

Note: SSI — Statistically Significance Improvement
p: Statistical Significance Test Result, Significance level set to $p < 0.01$ (or) $p < 0.05$ (or) $p \leq 0.05$
*: Statistically Significance difference within the Plyometric Experimental group (EG) over pre and post test
**: Statistically Significance difference between the Plyometric Experimental Group (EG) and Control Group (CG) over pre and post test
↑: Statistically Significance improvement effect
↓: No Statistically Significance improvement effect
(*m*) — male, (*f*) — female, xMST — x indicates 5/10/15/20/30/80/100 Metre

This crucial enhancement directly influences players' scoring, defensive tactics, and rebounding proficiency.

Charan Singh [22], Hernández et al. [23], and Androutsopoulos et al. [30] underscore plyometric training's ability to enhance agility, allowing players to execute quick shifts, cuts, and changes of direction on the court. The studies by Murşide Türki & Önder Dağlıoğlu [32], Munshi et al. [33], and Xia Jin et al. [39] collectively advocate for plyometric training's positive effects on sprint speed and agility. These dynamic attributes prove pivotal in executing rapid on-court movements, contributing to agile defensive plays, swift breakaways, and court coverage. Zribi et al. [16], Júnior et al. [20] and Xia Jin et al. [39], demonstrate that plyometric training can positively influence bone health markers like BMD, especially in young athletes. This is particularly relevant in basketball, a sport that places considerable strain on bones and joints.

Lehnert et al. [14] and Kryeziu, A.R. [24]'s studies reveal that individual responses to plyometric training can vary. Additionally, players with higher initial fitness levels might experience challenges in achieving significant improvements, Lehnert et al. [14] and Latorre Román et al. [21]'s findings. Attene et al. [15] and McCormick et al. [19] emphasize that plyometric training's mechanical specificity and varied exercises contribute to its effectiveness. Incorporating different jump drills, as suggested by Hernández et al.,[23] may enhance performance outcomes. Sáez de Villarreal et al. [31] champion a comprehensive training regimen encompassing plyometric, strength, and change of direction exercises. Their study demonstrates that a holistic approach results in broader physical enhancements, highlighting the multifaceted demands of basketball performance. It accentuates plyometric training's potential, coupled with neuromuscular and resistance exercises, to mitigate injury risks. This insight holds particular significance within basketball, where players face diverse injury vulnerabilities due to the sport's high-intensity nature.

Kryeziu et al. [24] and Charan Singh [22]'s studies suggest that relatively short-term plyometric training programs (4-12 weeks) can lead to significant improvements. Both Murşide Türki & Önder Dağlıoğlu [32] and Mehmet Emin Demiri & Önder Dağlıoğlu [36] converge on the effectiveness of relatively brief well designed plyometric training interventions (6-7 weeks) in driving substantial advancements in physical performance and significant gains in muscle power and explosive strength. These findings underscore the potency of even short-duration training in elevating the athletic capabilities of basketball players. While short-term plyometric training can yield notable improvements, the collective studies indicate that longer and more intensive training regimens might be necessary to unlock the full potential of muscle strength enhancement, indicating the long-term commitment required for optimal outcomes.

Studies by Androutsopoulos et al. [23] and Munshi et al. [33] observed no significant enhancements in sprint performance despite plyometric training. Similarly, GAF Correia et al. [28] found that certain plyometric exercises had no significant impact on jumping ability. These findings highlight the variability in individual responses and the potential limitations of plyometric training in directly affecting these attributes. Munshi et al. [33] conducted a comparative study involving plyometric and whole-body vibration (WBV) exercises, revealing that neither modality offered additional benefits for improving jump height and agility compared to plyometric training alone. This suggests that while plyometric training has its merits, other training approaches may yield comparable outcomes for specific performance aspects. Lehnert et al. [14] and Latorre Román et al. [21] discovered that players with higher initial fitness levels experienced challenges in achieving significant improvements through plyometric training. This emphasizes the interplay between an athlete's starting point and the potential for further advancements, highlighting the need for tailored training strategies.

Kryeziu AR et al. [24, 38] stress the significance of customized plyometric training programs that cater to distinct skills and age groups. These studies advocate for targeted training interventions that yield remarkable improvements in speed, explosive strength, and other pertinent attributes essential for basketball excellence. Sáez de Villarreal et al. [31] introduce the concept of gender-specific training strategies grounded in maturity levels. Acknowledging the distinct physiological and developmental trajectories of male and female basketball players, this approach underscores the importance of tailored training modalities to optimize performance outcomes.

The limitations identified in this discussion regarding plyometric training for basketball players encompass several key factors. Firstly, there is considerable variability in individual responses to plyometric training, implying that not all athletes may experience the same degree of improvement. Secondly, athletes with higher initial fitness levels may encounter challenges in achieving significant enhancements through plyometric training. Additionally, the effectiveness of plyometric training is contingent on exercise specificity and variation, necessitating the incorporation of diverse jump drills. While short-term plyometric programs can yield notable improvements, longer and more intensive training regimens may be needed for maximal muscle strength enhancement. Some studies observed no significant impact on sprint performance or jumping ability, highlighting the variability in individual outcomes. Finally, the importance of customized training programs tailored to distinct skills, age groups, and gender-specific considerations is underscored, emphasizing the need for personalized training modalities to optimize performance outcomes in basketball players.

In summary, plyometric training holds promise as an effective method for enhancing various physical attributes crucial to basketball performance. Its positive impact on jumping ability, sprint speed, agility, muscle strength and bone health make it a valuable tool in the training means of basketball players belonging to different age groups. While individual responses, initial fitness level, specificity, duration, and gender-specific considerations can influence outcomes, integrating plyometric exercises into basketball training programs, tailored to the athletes' needs, can lead to meaningful performance gains, and can propel basketball athletes toward heightened excellence.

3. Conclusion

In conclusion, the systematic review of literature on plyometric training's effect on functional performance and bone mineral density in basketball players of varying age groups reveals significant insights and valuable implications for sports training and performance enhancement. Plyometric training, characterized by dynamic and explosive movements, has emerged as a highly effective method for improving key physical attributes essential for success in basketball sports.

The findings of the reviewed studies consistently suggest that plyometric training positively affects various aspects of functional performance crucial for basketball players. The improvements in explosive leg power, as seen in vertical and horizontal jump tests, indicate enhanced jumping ability. The agility tests underscored the training's effectiveness in facilitating rapid changes of direction, a vital skill in basketball. Plyometric training also demonstrated the potential to enhance sprinting speed, a crucial aspect of fast breaks and overall court coverage. By enhancing agility, plyometric training enables players to execute rapid changes of direction, crucial for evasive moves and defensive strategies.

Additionally, the reviewed research highlights plyometric training's potential to promote bone health, particularly important in a high-impact sport like basketball. Notably, improvements in bone mineral density (BMD) were observed, indicating reduced risk of stress fractures and injuries. Plyometric training's effectiveness in enhancing physical/muscle strength, flexibility, and stability further underlines its comprehensive impact on functional performance and BMD. Diversity of statistical analysis techniques employed in the studies enhances the robustness of the findings. While the overall findings are promising, it's important to consider individual variability in responses to plyometric training. Factors such as initial fitness levels, training duration, and exercise specificity can influence outcomes. Short- to medium-term interventions (4–12 weeks) have demonstrated significant improvements, but longer and more intensive training might be necessary for optimal results. Tailoring plyometric training programs to the specific needs and characteristics of basketball players can enhance the benefits derived from this training modality.

In essence, plyometric training emerges as a powerful tool for enhancing explosive leg power, agility, sprinting speed, muscle strength, BMD and overall functional performance in basketball players. The review underscores the importance of incorporating plyometric exercises into training regimens to unlock the full potential of athletes, contributing to their success and advancement in the realm of basketball sports. As the demand for comprehensive sports training programs continues to grow, plyometric training stands out as a valuable and scientifically supported approach to developing well-rounded and high-performing basketball players.

Author contributions:

Ahamed Thajudeen Anversha — concept and publication design, writing the first draft of manuscript;

Vinodhkumar Ramalingam — editing of the text, collection and analysis of study data, collection and analysis of literature.

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Ахамед Таюдин Анверша — концепция и дизайн публикации, написание первой версии текста;

Винодхумар Рамалингам — написание и редактирование текста, сбор и анализ данных исследования, сбор и анализ литературных данных.

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