DOCTORAL THESIS

UCAM
UNIVERSIDAD CATÓLICA DE MURCIA

INTERNATIONAL DOCTORAL SCHOOL

Doctoral Program in Sports Science

A unique specific jumping test to estimate explosive power for basketball players: validity, reliability and differences in age, gender and position

Author:
Asaf Shalom

Supervisors:
Dr. D. Pedro E. Alcaraz Ramón
Dr. D. Julio Calleja González

Murcia, July 2023

DOCTORAL THESIS

INTERNATIONAL DOCTORAL SCHOOL

Doctoral Program in Sports Science

A unique specific jumping test to estimate explosive power for basketball players: validity, reliability and differences in age, gender and position

Author:

Asaf Shalom

Supervisors:

Dr. D. Pedro E. Alcaraz Ramón

Dr. D. Julio Calleja González

Murcia, July 2023

EIDUCAM
Escuela Internacional
de Doctorado

UCAM
UNIVERSIDAD CATÓLICA
DE MURCIA

THESIS SUPERVISORS' AUTHORISATION
FOR THESIS SUBMISSION

Prof. Dr. Pedro E. Alcaraz Ramón and Prof. Dr. Julio Calleja González, as Supervisors of the Doctoral Thesis A unique specific jumping test to estimate explosive power for basketball players: validity, reliability and differences in age, gender and position by Mr. Asaf Shalom in the Doctorate Programme in Sport Science , **authorise(s) its submission**, given that it meets the required conditions for its defence.

Which I hereby sign in compliance with Spanish Royal Decree 99/2011, of 28 January, in Murcia, on July 2th, 2023.

ABSTRACT

The first stage of this thesis project began with review the field tests in the literature and examine in depth the need for an explosive power test, unique ones with very specific requirements for the game of basketball.

Basketball playing entails the repetitive performance of short intense actions using lower limb explosive power. As such, it is important to measure this capability in basketball players, and to optimize training programs and game plans. This review of the literature depicts the horizontal and vertical physical movements and physiological requirements entailed in playing basketball, and presents eight standardized anaerobic alactic measurement tools relevant to the game: 5-meter and 10-meter sprint speed tests; standing broad jump assessment; horizontal and vertical drop jump tests; 2x5-meter change of direction ability test; countermovement jump test; squat jump test; bounding power test; and spike jump test. As some of these tests suit a number of ball games, the findings of this review thesis are important for making order of the elements unique to basketball as well as additional parameters to consider when testing basketball players. By reliably and validly testing the anaerobic alactic capabilities of basketball players, test results can be used for training purposes and for improving game outcomes. Moreover, these tests enable assessment of team players as a whole and of each player individually.

The second stage of this thesis project continued with two original research studies. The main aim of study 1 was to develop and assess the reliability and validity of an innovative field test that measures lower limb explosive power in basketball players (i.e., alactic anaerobic capacity) for the dominant and non-dominant leg. The test examines the performance of vertical, horizontal, and combined movements while holding the ball – similar to penetration of the basket or layup. Such capabilities are required throughout basketball practice and games, combined with upper and lower body coordination. The study included 22 male basketball players, ages 16-18, members of an elite youth league team in Israel. To assess validity, the participants performed the test for each leg, followed by nine standardized tests that were developed for a range of ball games, including

basketball. To assess reliability, the participants performed a retest of the unique test 72-hours later. The findings indicated the validity and reliability of the proposed anaerobic alactic field test for basketball players, for the dominant and non-dominant leg. Moreover, strong correlations were seen between the novel test and the standardized tests, with a high correlation for horizontal explosive power ($0.5<r<0.7$), a very high correlation for vertical explosive power ($0.7<r<0.9$), and a nearly perfect correlation for the two combined ($r>0.9$). In conclusion, this unique field test for basketball players could assist coaches in developing and applying optimal training programs and game plans, for players individually, and for the team as a whole. As the test measures each leg separately, it could also offer an assessment tool following players' injuries.

The main aim of study 2 was to examine differences in players unique movements by gender, age, and playing positions using the novel Test for Basketball Players. The study included 232 young basketball players, male and female, from a range of Israeli leagues, who were divided into three categories: under-14, under-16, and under-18. The findings showed that, male presented better results than female in all age categories. Moreover, female in the under-18 category presented better results than those in the under-14 category, but not more than those in the under-16. Differences in playing positions were examined between males and females only in the under-18 category, where players begin to specialize in playing positions. Males presented better results than females in all playing positions, while only the male groups showed differences between playing positions. When guards showed better results than forwards and centers. The conclusions highlight the importance of including sport-unique tests in talent identification and selection processes, as these tests can provide valuable information about a players skill set and potential for success. The findings are presented in an achievement table that presents the expected physical fitness results by age and gender, for the benefit of basketball coaches and fitness trainers when assessing their players.

RESUMEN

La primera etapa de este proyecto de tesis comenzó con la revisión de los test de campo en la literatura científica y el examen en profundidad de la necesidad de un test de potencia explosiva único y con requisitos muy específicos para el juego de baloncesto. Jugar a baloncesto implica la realización repetitiva de acciones cortas e intensas utilizando la potencia explosiva de las extremidades inferiores. Por lo tanto, es importante medir dicha capacidad en los jugadores de baloncesto y optimizar los programas de entrenamiento y planes de juego. Esta revisión de la literatura describe los movimientos físicos horizontales y verticales, así como los requisitos fisiológicos implicados en el juego de baloncesto y presenta ocho herramientas de medición anaeróbicas alácticas estandarizadas relevantes para el juego: test de velocidad de sprint de 5 metros y 10 metros, evaluación de salto horizontal, test de salto vertical y de caída horizontal, test de habilidad de cambio de dirección 2x5 metros, test de salto con contramovimiento, test de salto en cuclillas, test de potencia de impulso y test de salto de clavada. Como algunos de estos test se adaptan a varios deportes de equipo, los hallazgos de esta revisión de tesis son importantes para ordenar los elementos únicos del baloncesto, así como los parámetros adicionales a considerar al evaluar a los jugadores de baloncesto. Al evaluar de manera fiable y válida las capacidades anaeróbicas alácticas de los jugadores de baloncesto, los resultados de los test se pueden utilizar para fines de entrenamiento y para mejorar los resultados del juego. Además, dichos test permiten la evaluación de los jugadores como equipo y de cada jugador individualmente.

La segunda etapa de este proyecto de tesis continuó con dos estudios de investigación originales. El objetivo principal del estudio 1 fue desarrollar y evaluar la fiabilidad y validez de un innovador test de campo que mide la capacidad de poder explosivo en las extremidades inferiores en jugadores de baloncesto (es decir, capacidad anaeróbica aláctica) para la pierna dominante y no dominante. El test examina el rendimiento de movimientos verticales, horizontales y combinados mientras se sostiene el balón, similar a la penetración hacia la canasta o el layup. Tales capacidades se requieren en toda la práctica y los juegos de baloncesto, combinados con la coordinación del cuerpo superior e inferior. El estudio incluyó a 22 jugadores de baloncesto masculinos, de edades comprendidas entre los 16 y 18

años, miembros de un equipo de élite juvenil en Israel. Para evaluar la validez, los participantes realizaron el test para cada pierna, seguido de nueve test estandarizados que fueron desarrollados para una variedad de juegos de pelota, incluyendo baloncesto. Para evaluar la fiabilidad, los participantes realizaron una repetición del test único 72 horas después. Los resultados indican la validez y fiabilidad del propuesto test anaeróbico aláctico de campo para jugadores de baloncesto, tanto para la pierna dominante como la no dominante. Además, se observaron fuertes correlaciones entre el nuevo test y los test estandarizados, con una alta correlación para el poder explosivo horizontal ($0.5 < r < 0.7$), una correlación muy alta para el poder explosivo vertical ($0.7 < r < 0.9$) y una correlación casi perfecta para los dos combinados ($r > 0.9$). En conclusión, este test de campo único para jugadores de baloncesto podría ayudar a los entrenadores a desarrollar y aplicar programas de entrenamiento y planes de juego óptimos, tanto para jugadores individualmente como para el equipo en su conjunto. Como el test mide cada pierna por separado, también podría ofrecer una herramienta de evaluación después de las lesiones de los jugadores.

El objetivo principal del estudio 2 fue examinar las diferencias en los movimientos únicos de los jugadores por género, edad y posición de juego utilizando la nueva prueba para jugadores de baloncesto. El estudio incluyó a 232 jóvenes jugadores de baloncesto, hombres y mujeres, de diversas ligas israelíes, que se dividieron en tres categorías: menores de 14 años, menores de 16 años y menores de 18 años. Los resultados mostraron que los hombres presentaron mejores resultados que las mujeres en todas las categorías de edad. Además, las mujeres en la categoría de menores de 18 años presentaron mejores resultados que las de la categoría de menores de 14 años, pero no más que las de la categoría de menores de 16 años. Se examinaron las diferencias en las posiciones de juego entre hombres y mujeres solo en la categoría de menores de 18 años, donde los jugadores comienzan a especializarse en posiciones de juego. Los hombres presentaron mejores resultados que las mujeres en todas las posiciones de juego, mientras que solo los grupos masculinos mostraron diferencias entre las posiciones de juego, donde los bases presentaron mejores resultados que los aleros y los pivotes. Las conclusiones destacan la importancia de incluir pruebas únicas para el deporte en los procesos de identificación y selección de talentos, ya que estas pruebas pueden proporcionar información valiosa sobre el conjunto de habilidades de un jugador

y su potencial para el éxito. Los resultados se presentan en una tabla de logros que muestra los resultados esperados de aptitud física por edad y género, en beneficio de los entrenadores de baloncesto y entrenadores de acondicionamiento físico al evaluar a sus jugadores.

KEY WORDS

Basketball, alactic, anaerobic, specific, athletic performance, Performance analysis of sport, fitness field test, explosive power, jumping, age, gender, positions

ACKNOWLEDGEMENTS

A Research in the field of sports science requires hard work. The doctoral learning process requires a supportive environment. It requires tremendous teamwork effort, which can only happen if you are part of a winning team. Therefore, I want to thank my "team partners", without them this thesis would not have come to fruition.

Firstly, I want to thank my thesis supervisors. Dr. Julio Calleja- Gonzalez, my mentor, who believed in me from day one and turned me into the professional I am today. Thank you for all the studies, the introduction to the science and sports performance field, and the availability at any time of the day. You are a great professional and an even better person. Dr. Pedro Alcaraz, for the guidance and for always being present when things were complicated. You are an amazing person, and I always want you on my team. Thank you very much for your trust and support. I really appreciate all your help.

Secondly, I want to thank Dr. Thomas Freitas, my doctoral program tutor. Thank you very much for all your help and guidance during this period. You are an amazing person. I truly appreciate everything.

The interesting doctoral program at the Catholic University of Murcia (UCAM) improved me a lot as a researcher in the academic world. Thank you very much.

Thanks to all the academic staff of the university who have always been available and supportive of me.

Special thanks to Dr. Linda Chang for all her support, guidance, and assistance. I appreciate it very much.

I want to thank all the players I coached and trained during my doctoral studies and the sports clubs where I worked for all the excellent and special collaboration.

Great thanks to my partner from Israel, Roni Gottlieb, we are together in the same research group and also collaborate in studies at the university and in Israel. It was a pleasure for me to go through this important and special process with you.

It's also important for me to thank The Academic College Levinsky-Wingate in Israel for the collaboration, tips, and advice. I started my academic journey with you, and this place will always be my home.

Enormous thanks to my amazing parents, Yehuda and Simcha, for all the support and encouragement. There are no words to describe my appreciation for you. The education you gave me from when I was a young child until today has helped me greatly in this process. I love you very much and thank you for everything. To my sisters, Meital and Inbal, for their great support, praise and faith, I appreciate and love you very much. And of course, a huge thank you to my dear wife Maayan and my amazing daughters Yuval and Gali for all the help, understanding, support, and encouragement throughout the entire period of studies. I believe that now I will also have more free time and we will be able to spend more quality time together as a family. I love and appreciate you all very much.

To all thank you very much!

"Success is not final, failure is not fatal: It is the courage to continue that counts." - **Winston Churchill**

GENERAL TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

The abbreviations of the units from the International System Units are not included in the following list as there are internationally accepted standards for their use. In addition, no abbreviations universally used in statistics are presented in this section.

ADP, Adenosine Diphosphate

ATP, Adenosine Triphosphate

BP, Bounding Power Test

CODA, Change of Direction Ability

CMJ, Countermovement Jump

CMJDF, Countermovement Jump Dominant Leg, Hands Free

CMJF, Countermovement Jump both Legs, Hands Free

CMJDWH, Countermovement Jump Dominant Leg, with Hands on Hips

CMJNDF, Countermovement Jump Non-Dominant Leg, Hands Free

CMJNDWH, Countermovement Jump Non-Dominant Leg, with Hands on Hips

CMJWH, Countermovement Jump both Legs, with Hands on Hips

CP, Creatine Phosphate

CPK, Creatine Phosphokinase

ESI, Explosive Strength Index

FT, Fast Twitch

HDJ, Horizontal Drop Jump

P, Phosphate

RFD, Rate of Force Development

RSA, Repeated Sprint Ability

U, Under

USJT, Unique Specific Jumping Test

UD, Unique Test Dominant Leg

UND, Unique Test Non-Dominant Leg

LIST OF FIGURES, TABLES AND APPENDIXES

LIST OF FIGURES

LIST OF TABLES

APPENDIXES

I – INTRODUCTION

I - INTRODUCTION

In sports in general and in competitive team sports in particular, it is important to frequently assess players' physiological capabilities as a means for designing, implementing, and evaluating training programs and tracking the players' progress throughout the season[1, 2]. Among team sports, the game of basketball is characterized by short, intense, anaerobic actions that are performed throughout the game[1, 3, 4], using anerobic power, i.e., explosive power up to 10 seconds[2, 5]. In other words, the main energy source that contributes to these alactic anaerobic activities are adenosine triphosphate (ATP) / creatine phosphate (CP), referred to as ATP-CP, that are stored in the muscles and are easily accessible[6, 7]. In addition, the glycolysis system also contributes to anaerobic activities. For explosive power performance that lasts more than 10 seconds and up to three minutes, the body's anaerobic glycolysis is required[8].

Although in basketball the more dominant source is the anaerobic alactic energy source[2, 5], it is also characterized by specific anaerobic actions, such as: jumps, sudden stops, short sprints, and change of direction[1]. The body's aerobic system also plays a key role in players' recovery, ensuring the successful frequent repetition of high intensity anaerobic actions[9, 10]. Moreover, the introduction of new rules to the game of basketball in May 2000 (e.g., reduced attack time from 30 to 24 seconds and reduced time on the backcourt from 10 to 8 seconds) are believed to have altered the demands of basketball – both tactical and physical – increasing the speed of the game faster and intensifying the game[11, 12]. In turn, these changes also impact the players' physiological characteristics, resulting in higher physical demands on the players and expected improved athletic abilities. Such new demands mainly relate to the players' need to recruit their explosive power for performing and maintaining the rapid anaerobic pace of the game[13, 14].

These physical activities place a heavy load on players' muscles and joints, and developing them up to withstand such physical pressures is not an easy feat – especially as the skeletal muscular and the nervous systems must be improved simultaneously[4, 5]. For example, scientific research indicates that the greater the load on muscles, the slower their rate of contraction[3, 15]. To determine the necessary ratio between the strength and agility required for enhancing explosive power, specific aspects of the sport must be examined[2, 16, 17]. For example, while ball game players and sprinters must perform fast movements with their relatively low body mass, wrestlers and weightlifters must overcome high resistance from external objects[18]. Specifically in basketball, the relationship between body mass status and the performance of jumping and running varies according to age[5, 8, 11, 13, 19].

In summary, in most basketball related activities, both the aerobic and the anaerobic energy systems are involved, yet the ratio between the two energy sources varies according to the demands of the specific exercise[2, 5, 20–22], including the intensity and duration of the activity (Table 1).

Table 1. Physiological Energy Systems

Energy System / Meaning	Anaerobic		Aerobic
Physiological requirement and importance for the game of basketball	**Alactic / ATP-CP (explosive power)**	Glycolysis	VO_2Max
Relates to the physical ability components that are commonly addressed in the literature in relation to the energy system	**Anaerobic Power**	Anaerobic Capacity	Aerobic Capacity
Length of activity time of each energy system in general from a physiological aspect	**0-10sec**	10sec-3min	> 3min
Specific contribution to the game of basketball	**Sprints, change of direction, jumping, fast break, layup, etc.**	Mainly RSA, continued transition	For the duration of the game. Mainly supports recovery times during the game and helps athletes to perform short (alactic) actions and explosive power in an optimal manner

Dominant system in Basketball

In addition, the game of basketball demands a unique combination of technical skills that require players to perform horizontal, vertical, and combined movements on the court[1, 2, 20]. These movements rely heavily on the anaerobic alactic physiological system and explosive power, which are crucial attributes for basketball players. Understanding the technical requirements associated with these movements and their physiological underpinnings is essential for optimizing performance and success in the game[5, 12].

Technical proficiency in basketball encompasses a wide range of skills, including shooting, passing, dribbling, and executing specific movements that involve horizontal, vertical, or a combination of both directions. These movements are fundamental to the game, enabling players to navigate the court, create scoring opportunities, and outmaneuver opponents[2, 12]. Horizontal movements, such as lateral shuffling or moving laterally while dribbling, allow players to change directions quickly and maintain their balance while evading defenders or guarding opponents[23–25]. Vertical movements, such as jumping for rebounds or executing powerful slam dunks, showcase an athlete's explosive power and ability to generate force vertically. Additionally, combining horizontal and vertical movements is crucial in performing skills like layups, where players need to accelerate horizontally towards the basket and finish with an explosive vertical jump[1, 2].

The anaerobic alactic physiological system plays a vital role in supporting the technical requirements of basketball movements. This energy system provides athletes with the ability to generate explosive power in short bursts without relying on oxygen consumption[2, 6, 7]. During intense game situations that require horizontal or vertical movements, such as fast breaks, aggressive drives to the basket, or executing quick changes in direction, the anaerobic alactic system enables players to tap into their energy reserves and produce maximum force output[2, 11, 26]. The rapid and forceful execution of these movements relies on the efficient utilization of the anaerobic alactic system, allowing players to perform with speed, agility, and power[2].

Explosive power is a key attribute closely tied to the anaerobic alactic system and is specifically emphasized in basketball. The ability to generate rapid and forceful movements is essential for executing the technical requirements of the game[5]. Vertical explosive power is particularly important for skills like jumping for rebounds, blocking shots, or executing powerful dunks, which can significantly impact the outcome of a game[27]. Horizontal explosive power enables players to quickly change directions, maintain balance while dribbling, and execute lateral movements with speed and agility. Moreover, the combination of horizontal and vertical explosive power is critical in skills like layups, where players need to accelerate horizontally towards the basket and finish with an explosive vertical jump to avoid defenders and score efficiently[2, 27].

The technical requirements in basketball, encompassing horizontal, vertical, and combined movements, are intricately linked to the anaerobic alactic physiological system and explosive power[12]. Developing and refining these skills require targeted training programs that enhance muscle strength, power output, speed, and coordination[1, 28, 29]. Training interventions often incorporate exercises such as plyometrics, resistance training, sprint intervals, and skill-specific drills to optimize explosive power and technical proficiency[2, 12].

The introduction of this thesis highlights significant and interesting subjects related to basketball. These subjects have provided a basis for the development of original research ideas. The topics discussed include the dominant physiological energy system in basketball, the concept of explosive power in basketball, specific movements in basketball, variations in explosive power based on age and gender among basketball players, disparities in explosive power across different playing positions, and the measurement of specific capabilities related to explosive power according to the physiological demands of the anaerobic alactic system.

1.1. THE PHYSIOLOGICAL ANAEROBIC ALACTIC SYSTEM THAT IS DOMINANT IN BASKETBALL

The body's energetic potential is utilized by breaking down ATP which is adenosine triphosphate[30]. Energy is released from the molecule when one of the three phosphate groups is degraded through a rapid chemical process by the ATPase enzyme[6, 30]. As a result, two new molecules are created: adenosine diphosphate (ADP), with only two phosphate bonds, and the free phosphate (P), as seen in Figure 1.

Figure 1. Flowchart, Energy potential from ATP molecules

The ATP, often referred to as the body's "energy currency", enables the body to perform a range of biological activities[7]. These include complex and rapid actions needed for per-forming, completing, and recovering from actions performed in basketball[2]. Despite their vast importance, ATP resources in muscles are relatively small. With only 5-7 millimoles per kg of muscle during rest, this energy source is only sufficient for very short periods of time[6, 7]. The fastest and simplest way to renew ATP is by also utilizing the body's CP re-sources, which offer about 3-5 times more energy (about 20-25 millimoles per kg of muscle) than the ATP[5, 7]. As such, CP resources are an important and immediate energy re-source for the body's cells, transferring their phosphate to the ADP to create new ATP molecules[2, 5, 31], as seen in Figure 2.

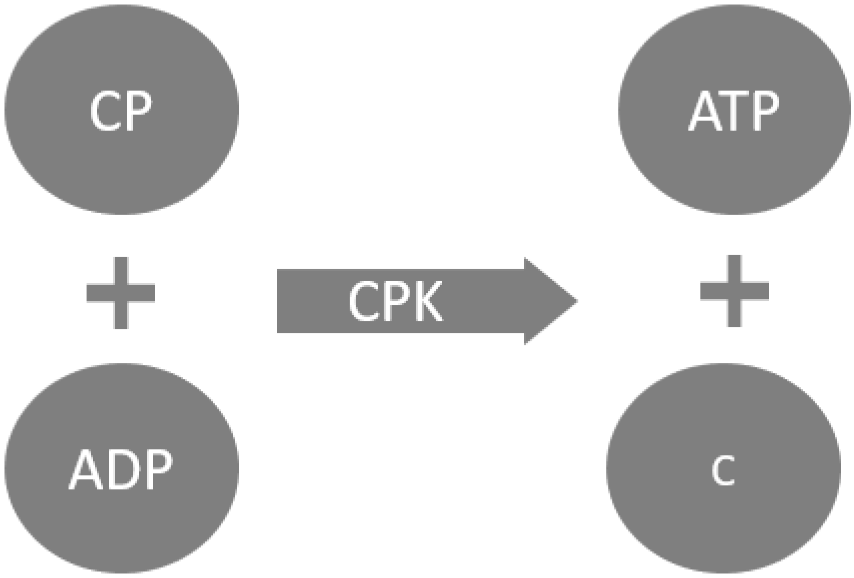


Figure 2. Flowchart, ATP-CP energy system.

This rapid process takes place within the cell through a reaction that is enhanced by the creatine phosphokinase (CPK) enzyme. As CP is readily available in the body's cells and this chemical process is extremely fast, this anaerobic means for renewing muscle energy is referred to as the "immediate anaerobic system"[31, 32]. However, as the quan-tity of CP in the muscle is also relatively small, it too is limited to only providing energy for a number of seconds. The combined ATP-CP resources in the muscles provide imme-diate energy for quickly contracting the muscle. Without the intervention of CP, the ATP resources would suffice for a maximum of 1-2 seconds of activity[3, 5, 7]. In addition, the optimal anaerobic supply reflects the ability of the immediate anaerobic system (ATP-CP) to release energy and activate muscles at maximum pace for short periods, of up to 10 seconds[3, 5]. Greater efficacy of the ATP-CP enzyme activity is seen among athletes and people with a high percentage of fast twitch (FT) muscle fibers[30, 31].

As such, athletes with greater anaerobic capabilities will have a clear advantage when participating in a sport such as basketball that requires explosive power[2, 5]. Yet being able to measure players' anaerobic abilities consistently and accurately requires uniform and relevant measurement tests. The aim of this thesis, therefore, was also to review the existing anaerobic alactic measurement tests that can be specifically used in relation to basketball, as a means for providing basketball trainers, researchers, and physiologists with important information about optimal testing.

1.2. EXPLOSIVE POWER AND ANAEROBIC ALACTIC DEMANDS IN BASKETBALL

Analysis of the physiological requirements of basketball players over the past few decades indicates great reliance on the body’s anaerobic metabolism to perform sprints and jumps throughout a game[33]. Moreover, the relatively high blood lactate concentration values recorded during games indicate the central involvement of the player’s anaerobic capacity[2, 5, 34, 35]. As evaluating these factors during basketball practices and games is important, researchers and coaches have developed a range of tests for assessing anaerobic alactic system, and the effectiveness of the players’ physical conditioning. For example, Abdelkrim et al.[3] found that in elite male basketball players under 19, the new rules of basketball meant longer time periods performing high-intensity activities and an in-creased number of actions per game. Despite this, blood lactate concentration values were found to be slightly lower than those reported in earlier studies[1, 4, 5]. Such changes to the players’ metabolic load during basketball games must be addressed when developing and applying suitable physical conditioning programs and tests.

In a review that assessed the most important and relevant measurement tests for basketball players, researchers found that following the introduction of the new rules of the game, basketball playing is mainly dependent on anaerobic power rather than on an-aerobic capacity[5, 15]. To assess the effectiveness of basketball training programs, tests should therefore specifically address players’ lower limbs, through tests such as vertical jump (VJ), agility T tests, and short distance sprints (5-meter), rather than tests like the suicide run that lasts about 30 seconds[5]. These tests all assess anaerobic alactic capabilities and explosive power of the players' lower limbs - as seen in basketball training and games.

1.2.1. Specific movements in basketball

As explained, basketball players' successful performance depends greatly on their anaerobic alactic systems, with shorter, more intense actions that require greater explosive power[1, 2]. As such, training and tests should be developed in line with this important factor. However, it is also important to understand the more frequent movements required of basketball players in each situation[1, 5]. During practices and games, key actions include vertical movements (rebounds and jump shots), horizontal actions (change of direction and sprints), and a combination of the two (usually during shot blocking or when penetrating the basket)[2, 14, 33, 36]. As these high-intensity actions are continuously performed throughout the game[1–3, 9] professionals in the field seek optimal training methods for developing these physical capabilities among basketball players, especially their explosive power[2].

In order to maximize performance and minimize the risk of injuries, a comprehensive understanding of biomechanics is crucial when designing training programs for basketball players[1, 37]. Biomechanics, the study of the mechanical principles that govern human movement, plays a vital role in optimizing athletic performance and reducing the likelihood of musculoskeletal imbalances or flaws in technique[3, 12]. By analyzing the specific movement patterns in basketball, such as the mechanics of jumping, pivoting, and rapid changes of direction, trainers and coaches can identify areas for improvement and tailor training exercises accordingly[1, 2]. For instance, jump training programs can be designed to enhance vertical jump height and power, while agility drills can focus on improving lateral quickness and quick acceleration-deceleration capabilities[16, 26, 38].

Moreover, incorporating sport-specific drills that mimic game-like situations can further enhance basketball players' performance. These drills not only train the physical attributes required but also help develop decision-making skills, spatial awareness, and anticipation abilities[2, 5, 16, 39, 40]. By simulating realistic scenarios, players can improve their reaction time, adaptability, and overall basketball IQ[12, 16]. Additionally, integrating strength and conditioning exercises into the training program can enhance muscular power, endurance, and resilience, which are vital for sustaining optimal performance throughout a game[1, 2, 26].

Overall, by taking a holistic approach to training, considering both the anaerobic alactic systems and the specific movement patterns inherent to basketball, coaches and trainers can effectively prepare players for the physical demands of the sport. By focusing on explosive power development, optimizing biomechanics, and incorporating sport-specific drills, basketball players can enhance their overall performance, elevate their game, and excel on the court[1, 5, 41–43].

1.2.2. **Differences in explosive power by age and gender**

Research has shown that there are differences in explosive power among basketball players based on age, gender, and playing positions[44–49]. Regarding age, explosive power typically increases with age during childhood and adolescence, with the greatest gains occurring during the growth spurt that occurs in early adolescence[50–55]. Boys tend to have greater explosive power than girls due to their greater muscle mass, and this difference is most pronounced during adolescence. However, both boys and girls can improve their explosive power through appropriate training programs[28, 29, 44, 56–66].

Explosive power is highly valued by coaches in basketball and they focus on improving this skill in players of all ages, experience, and levels of performance. To effectively develop players' explosive power and tailor training programs and game plans, coaches require consistent and accurate tools for assessing players' explosive power development. These tools must be tailored to the specific needs of basketball[1, 2, 20, 23, 67–70].

Previous studies have found that men generally have a higher number of type II muscle fibers, greater muscle mass, strength, and quality compared to women[71]. These individual characteristics affect their ability to perform explosive movements that require higher contractile force and speed. Furthermore, age also plays a role in these differences as athletes develop and mature over time.

A research study carried out on young basketball players revealed that age and sex were important factors in determining the strength produced by the lower body. The study found that there were no significant differences in 11-13-year-olds, but in the 15-17 years age group, differences were observed in the force generated by the lower body, with female players exhibiting lower values in relative strength when compared to their body weight[27, 44, 51, 71].

Regarding the differences related to age[44, 56, 57, 72], it was confirmed that, the period of puberty can limit the development of skills in young basketball players, particularly in women's basketball players, due to the changes in physical abilities that occur during this physiological process. This can result in significant differences between the performance of male and female players. In the field of sports, it is common to present information through profiles[10, 33, 45, 73–76].

A literature review reveals the existence of a relationship between horizontal and vertical force production and their combination in explosive strength for basketball players. However, it is important to verify that these abilities in the field of explosive strength and the combination of specific movement demands in these planes also apply to basketball players in different age categories (U14, U16, and U18) and to consider differences between male and female players in these age groups[44, 56, 57, 71].

1.2.3. **Differences in explosive power by playing positions**

Explosive power can vary significantly among basketball players based on their playing positions[45, 71, 77, 78]. Forwards and centers tend to have greater explosive power than guards due to their greater size and strength, which is advantageous in activities such as jumping and pushing off the ground[41, 71, 79–82]. On the other hand, guards tend to be faster and more agile, which may be advantageous in activities such as dribbling and driving to the basket. Coaches and trainers should tailor their training programs to match the demands of each playing position and the specific needs of each player[45, 77, 83–86].

Basketball requires the execution of specific skills, movements, and physiological demands that vary depending on the player's position. Previous studies have shown that different positions in basketball have different physiological requirements, which may also vary by age and gender[44, 56, 67]. One aspect that has been frequently investigated is the anaerobic power and explosive power, especially in vertical jump performance[13, 71, 87].

Coaches should take into account the unique physical characteristics of players based on their playing position when designing training programs[1, 45, 77]. Research has shown that forwards tend to have smaller and lighter body frames compared to centers, but larger and heavier body frames compared to guards. Additionally, guards generally exhibit higher levels of aerobic fitness compared to other positions when measured by field tests such as the YoYoIR1 and multistage 20m shuttle run[2, 20, 71].

Compared to centers, guards possess greater vertical jumping ability, while centers are marked by their heightened levels of muscular strength and power. The bulk of studies exploring player characteristics based on position have been constrained by a limited number of participants (n < 60) or restricted to the preseason training period. Only a few studies have assessed these attributes using a sizable group of players or during the regular season[45, 71, 77].

Recent studies have revealed that there are variations in explosive power among different positions in professional basketball, namely guards, forwards, and centers. The results showed that guards have significantly greater explosive power compared to forwards and centers.

In addition, - Ziv and Lidor (2009) study yielded mixed findings with regards to the differences in vertical jump and jumping power among basketball players playing different positions[71]. On one hand, they reported no significant variances in these attributes across positions. On the other hand, they found that guards and forwards displayed significantly greater vertical jump heights compared to centers.

The demands of playing positions in basketball vary in terms of anaerobic power and explosive power, especially in vertical jump performance[45, 71]. Moreover, age and gender differences also play a role in these physiological demands, as older and male players tend to have higher anaerobic power and explosive power[56, 57, 71]. However, further research is needed to fully understand the differences in physiological demands among young basketball players of different positions, ages, and genders[71, 77].

1.3. EXPLOSIVE CAPABILITY ASSESSMENTS

The ability to produce great power in short periods of time is of the utmost importance in basketball. As such, an emphasis is placed on enhancing explosive power among players of all levels and ages[5, 33, 88]. Doing so is not solely a theoretical exercise in fitness training and physiological principles; it requires the developing of reliable and valid measuring techniques that offer accurate and consistent outcomes[89, 90]. Moreover, to provide coaches with applicable rather than theoretical outcomes, measurement protocols must accurately replicate movements that athletes perform in practices and games, while also offering consistent tools to enable comparisons and generalizations[91, 92]. Doing so will ensure that differences in results over time are attributed to changes in the athlete's performance rather than to differences in measuring systems. In addition, when applying measurement protocols, external factors should be controlled (such as time of day, the surface on which the test is conducted, and pre-test requirements), to avoid these environmental conditions and timeframes from impacting the test results[3, 93]. For example, in basketball, tests for explosive power should be conducted at three different points-in-time (immediately prior to the training program, about halfway through the program, and immediately after the training program), to gather maximum relevant data about the efficacy of the training program and its outcomes[1, 2, 5].

Basketball is unique in that it requires players to perform both horizontal and VJ. As such, the literature offers a range of tests for measuring horizontal, vertical, and combined explosive power in basketball players[1, 33, 77]. This thesis addresses those tests that specifically examine players' lower limb explosive power, which plays a central role in most basketball actions (Table 2).

Table 2. Specific Anaerobic Alactic Tests for Basketball Players

Horizontal	Vertical	Combined
5/10-meter sprint (speed test)	Countermovement jump	Bounding power
Standing broad jump	Squat jump	Spike jump
Horizontal drop jump	Vertical drop jump	
2 x 5-meter change of direction ability		

Following are details of these eight basketball-specific tests.

1.3.1. **5/10-meter sprint speed test**

The 5/10-meter sprint speed test is used to evaluate players' horizontal explosive power through cyclical movement (i.e., sprinting from a standing starting point). The athlete is asked to perform two sprints from a standing starting point, with 3-5 minutes' rest between the two sprints. The best time out of the two is recorded. The advantage of using photo-electric cells is threefold, as it provides athletes with an external "start" signal, automatically stops the measurement upon sprint completion, and if required, can record intermediate times during the sprint with modular systems[2, 94–96].

The test serves as a valuable tool for evaluating the explosive power of basketball players, a crucial attribute in their performance. By periodically conducting this assessment, coaches and trainers can monitor the progress and development of players over time. It allows for the identification of individual strengths and weaknesses, enabling targeted training interventions to enhance explosive power[2, 38, 97, 98]. The test results also facilitate player comparisons within a team, aiding in the selection of suitable roles and positions[45, 84].

Moreover, the 5/10-meter sprint speed test contributes to injury prevention. By closely examining athletes' sprinting mechanics during the test, coaches and medical staff can identify any deviations or compensatory movements that may increase the risk of injuries. This information guides the implementation of corrective exercises and injury prevention strategies, ensuring the athletes' safety and well-being during intense gameplay[2, 11, 72].

Furthermore, the test provides valuable information for the professional staff involved in basketball training. Sports scientists, strength and conditioning specialists, and medical professionals can utilize the data collected from the test to gain insights into the athletes' capabilities[19, 26]. This data-driven approach enables evidence-based decision-making in designing training programs, individualized interventions, and monitoring progress over time. Additionally, the simplicity and accessibility of the 5/10-meter sprint speed test make it a useful tool for clubs that may not have access to advanced equipment, allowing them to evaluate and monitor explosive power effectively[1, 2, 5].

Overall, the 5/10-meter sprint speed test plays a crucial role in assessing horizontal explosive power in ball games, particularly in basketball. Its periodic implementation aids in monitoring player development, enhancing performance, preventing injuries, and providing valuable information for professional staff to optimize training strategies and maximize players' potential[1, 11, 28].

Explanation of the 5/10- meter sprint speed test is presented in Figure 3.

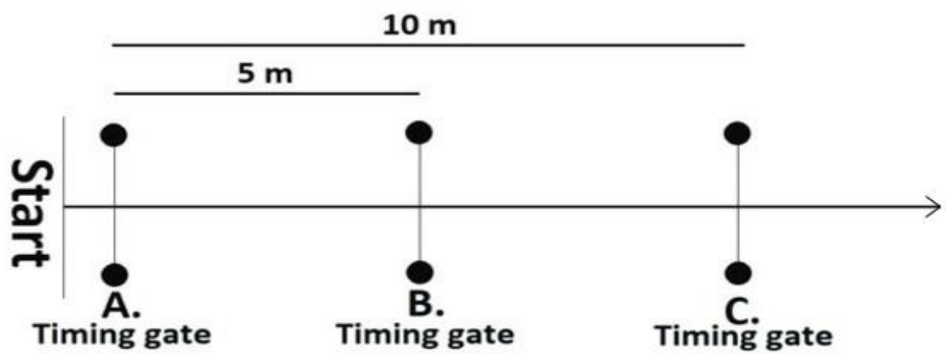


Figure 3. 5/10- meter sprint speed test

1.3.2. **Standing broad jump test**

The standing broad jump assessment is also used to assess basketball players' an-aerobic alactic capabilities. For this test, the athletes are instructed to stand with both feet together by the starting line[99–101]. They then create momentum for the jump by bending their knees and moving their arms forward. The recorded measurement is the best jump out of three, measured with a standard measuring tape. If the athlete falls backwards during any of the jumps, the jump is disqualified, and the athlete is asked to repeat the jump[102, 103]. From 1900 to 1912, the standing broad jump was part of the Olympic competitions. However, it has not been part of regular global competitions for over a century. In most cases, this test is used for assessing explosive power among basketball players in clubs that do not have access to advanced equipment[2, 99].

Performance of standing board jump test is presented in Figure 4.

Figure 4. Standing broad jump test

The standing broad jump test allows for the evaluation of anaerobic alactic capabilities, which are crucial for quick bursts of explosive movements on the basketball court. It provides valuable information about the athletes' explosive power, leg strength, and coordination. This data is essential for coaches and trainers to design targeted training programs that focus on enhancing these attributes to improve overall performance[99–101].

Furthermore, the standing broad jump test can be utilized as a cost-effective and accessible assessment tool in various basketball settings. It does not require advanced equipment, making it suitable for clubs with limited resources. By incorporating this test into training programs, coaches can monitor the progress and development of players' explosive power over time. Additionally, the test can aid in injury prevention by identifying any movement imbalances or technique flaws that may increase the risk of injuries during explosive actions[2, 99].

In summary, the standing broad jump test is a valuable assessment tool for evaluating athletes' explosive power and anaerobic alactic capabilities in ball games, including basketball. It provides valuable data for coaches and trainers to tailor training programs, monitor progress, and improve performance. Its accessibility makes it particularly useful for basketball clubs with limited resources, while its emphasis on explosive power aligns with the demands of the sport[2, 19, 25, 81].

1.3.3. **Drop jump test**

The drop jump test, which can be conducted as a horizontal drop jump (HDJ) or as a vertical drop jump (VDJ) test, is used for measuring and developing athletes' stretch-shortening cycle ability[63, 104, 105]. The athletes are instructed to stand on a pre-set box (at a height of 0.30-0.40 meters). The athletes then drop down to the ground, quickly bend their knees, and immediately perform a rebound jump as quickly as possible (< 0.25 seconds), minimizing their contact time with the ground. For the HDJ, they must jump as far forward as possible, while for the VDJ, they must jump up as high as possible. The test ends with their controlled landing on the ground[106–108]. Performance of drop jump test is presented in Figure 5.

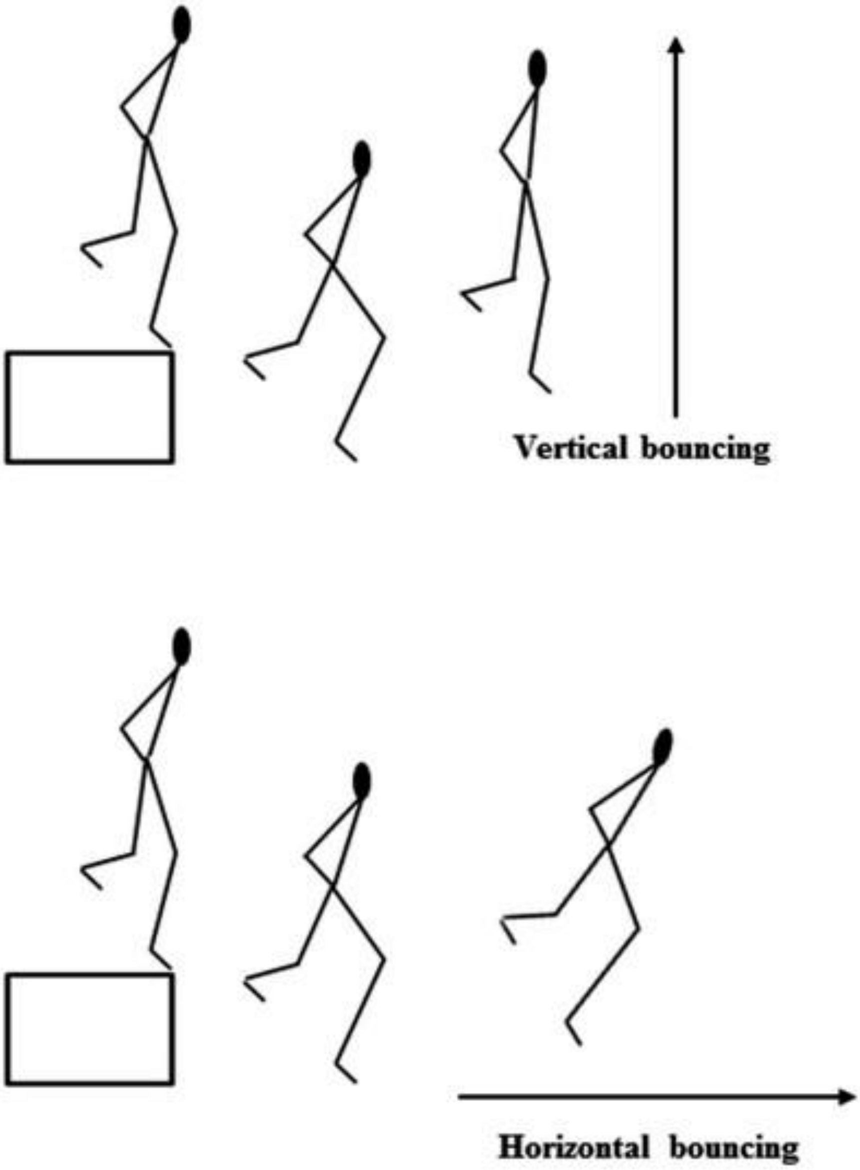


Figure 5. Drop jump test

The drop jump test focuses on evaluating the athletes' stretch-shortening cycle ability, which is crucial for the rapid and powerful movements required in ball games, including basketball. The stretch-shortening cycle involves the rapid stretching (eccentric phase) and subsequent shortening (concentric phase) of muscles, resulting in increased power production during explosive movements. By measuring and assessing the athletes' performance in the drop jump test, coaches and trainers gain insights into their ability to efficiently utilize the stretch-shortening cycle[104, 105, 107].

Moreover, the drop jump test serves as a valuable tool for developing athletes' stretch-shortening cycle ability. By incorporating specific training protocols, such as plyometric exercises, coaches can enhance the athletes' neuromuscular coordination and muscular power, improving their ability to generate explosive movements. This can directly translate to improved performance in ball games, where quick and powerful actions are essential[63, 105–107].

Additionally, the drop jump test provides valuable information for individualized training programs. By evaluating athletes' performance in both the HDJ and VDJ variations, coaches can identify specific areas of strength and weakness. For example, athletes who excel in the HDJ may possess exceptional horizontal power and could be suitable for roles requiring quick bursts of speed and agility. On the other hand, athletes who demonstrate superior performance in the VDJ may possess remarkable vertical power and could be well-suited for roles that involve jumping, rebounding, and shot blocking[104–107].

In summary, the drop jump test is a valuable assessment tool for evaluating and developing athletes' stretch-shortening cycle ability in ball games, including basketball. It provides valuable data for coaches and trainers to assess performance, design targeted training programs, and improve overall athletic performance. By focusing on the stretch-shortening cycle, coaches can enhance athletes' power production and explosiveness, leading to improved performance on the basketball court[63, 104, 105].

1.3.4. 2x5-meter change of direction ability test

The 2x5-meter change of direction ability (CODA) test is especially suitable for measuring basketball players' anaerobic alactic capabilities. The test measures sprinting time, turning, and changing direction. The athletes are instructed to perform a 5-meter run in one direction, turning around as quickly as possible, and then perform the same 5-meter run back to the starting point (a 10-meter run in total). Basketball players must possess strong agility capabilities to cope with the multiple stimuli and instantaneous decision making involved in the dynamic environment in which the game is played. In most cases, the T-test and pro-agility test are the gold standard for assessing agility among athletes[1, 16, 78]. However, in light of this review of the anaerobic alactic tests that are most suitable and specific for basketball players, the 2 x 5-meter CODA test should be conducted when examining the players' anaerobic alactic and change of direction capabilities[38, 39, 109–111]. Performance of 2X5-m change of direction ability test test is presented in Figure 6.

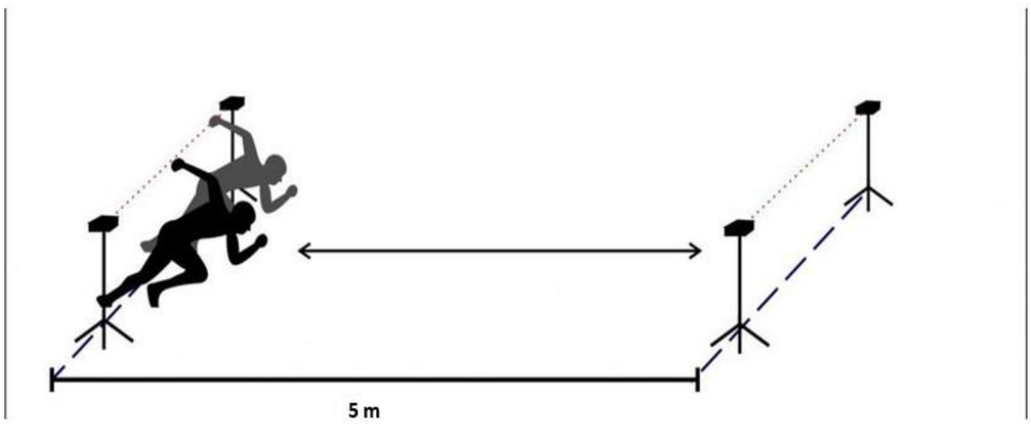


Figure 6. 2x5-meter change of direction ability test

By conducting the 2x5-meter CODA test, coaches and trainers can gather data on players' anaerobic alactic capacity and change of direction abilities. This information guides the design of targeted training programs to enhance these skills, ultimately improving overall performance on the basketball court. The test can also aid in identifying areas for improvement and developing strategies to optimize players' agility and quickness[1, 2].

In summary, the 2x5-meter CODA test is a valuable assessment tool for measuring anaerobic alactic capabilities and change of direction ability in ball games, with specific relevance to basketball. It provides valuable information on players' agility and quickness, enabling coaches and trainers to tailor training programs and strategies to enhance performance. The test's focus on sprinting, turning, and changing direction aligns with the demands of basketball gameplay, making it a suitable and specific evaluation method for basketball players' anaerobic alactic and change of direction capabilities[1, 2, 5, 16, 86].

1.3.5. **Countermovement jump test**

The countermovement jump (CMJ) test assesses explosive power in a VJ, with athletes standing up straight, then bending their knees and quickly extending them to leave the ground and rise up as high as possible. The athletes are usually instructed to place their hands on their hips during the jump, to minimize upper limb momentum. Players per-form up to three jumps in total, with about two minutes' rest between jumps. Jumps can be performed using one or both legs and a transmitting and receiving bar is employed that enables the accurate measurement of flight and contact times during jumps[2, 42, 90, 112–115].

The CMJ test plays a vital role in assessing explosive power, a critical attribute in ball games, including basketball. By measuring the height achieved during the vertical jump, coaches and trainers gain valuable insights into the athletes' ability to generate force and power through their lower body. This information allows for the evaluation of performance, identification of areas for improvement, and the design of targeted training programs to enhance explosive power[37, 42, 114]. Performance of countermovement jump test is presented in Figure 7.

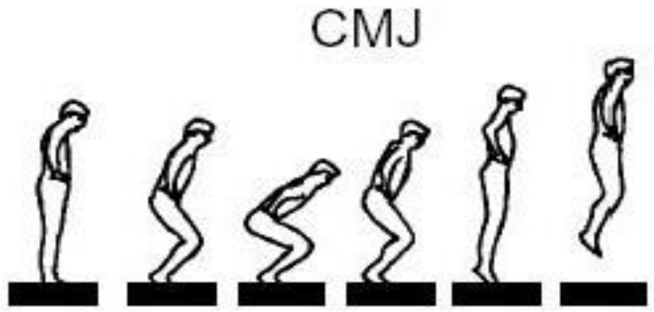


Figure 7. Countermovement jump test

Performing the CMJ test with one or both legs enables the assessment and comparison of bilateral and unilateral explosive power, providing valuable data on athletes' leg strength and coordination. This assessment can assist coaches in identifying potential asymmetries or imbalances that may impact performance or increase the risk of injuries. By addressing these imbalances through targeted training, athletes can improve their overall explosiveness and reduce the likelihood of injury[1, 2, 90, 114].

Moreover, the use of transmitting and receiving bars in the CMJ test ensures accurate measurement of flight and contact times, offering detailed information on athletes' jumping technique and efficiency[2, 116]. This data can be analyzed by coaches and trainers to refine jumping mechanics, optimize power production, and minimize energy loss during explosive movements. The insights gained from the CMJ test can guide the development of individualized training programs, targeting specific areas for improvement and enhancing overall athletic performance on the basketball court[1, 5, 114].

In summary, the countermovement jump (CMJ) test is a crucial assessment tool for evaluating athletes' explosive power in ball games, with specific relevance to basketball. By measuring the height achieved during the vertical jump, coaches and trainers can assess performance, identify areas for improvement, and design training programs to enhance explosive power[2]. The test allows for the assessment of bilateral and unilateral explosive power, aiding in the detection of imbalances[1, 2]. The use of transmitting and receiving bars ensures accurate measurement, enabling the analysis and refinement of jumping technique. Ultimately, the CMJ test plays a significant role in optimizing athletic performance and enhancing explosiveness in the game of basketball[2, 19, 25].

1.3.6. **Squat jump test**

The sixth test reviewed in this article is the squat jump test, which also offers a tool for specifically measuring basketball players' vertical explosive power. For this measurement assessment, the athletes assume a low squat position, refrain from any movement, then jump as up as high as possible. During the test, the players are usually asked to place their hands on their hips or behind their back, to prevent momentum from their upper limbs that could impact this assessment[1, 19, 90]. Performance of squat jump test is presented in Figure 8.

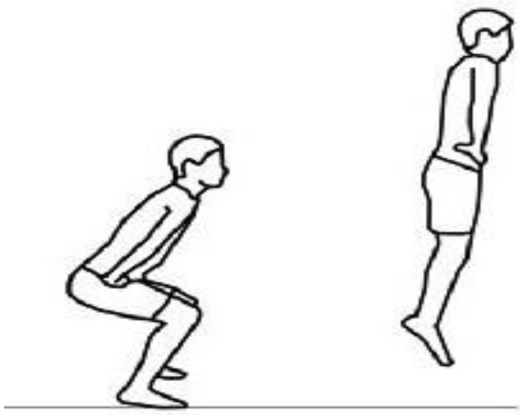


Figure 8. Squat jump test

The squat jump test serves as a valuable tool for evaluating basketball players' vertical explosive power, a critical attribute in the sport. By assessing the height achieved during the jump, coaches and trainers gain insights into the athletes' ability to generate force and power through their lower body. This information facilitates the evaluation of performance and enables targeted training interventions to enhance vertical explosive power[2, 90, 117].

Placing the hands on the hips or behind the back during the squat jump test eliminates the involvement of upper limb momentum, ensuring that the measurement accurately reflects the lower body's power generation. This focused assessment allows coaches and trainers to isolate and assess the athletes' lower body strength and power, specifically in relation to vertical jumping ability[26, 90].

Furthermore, the squat jump test provides valuable information for designing individualized training programs. By evaluating performance in this test, coaches can identify areas for improvement and tailor training strategies to enhance athletes' vertical explosive power. The test allows for ongoing monitoring of progress and the effectiveness of training interventions, facilitating evidence-based decision-making in optimizing performance[2, 90, 117].

In summary, the squat jump test plays a crucial role in assessing basketball players' vertical explosive power in ball games, particularly in basketball. By measuring the height achieved during the jump and ensuring minimal upper limb involvement, coaches and trainers can evaluate performance, identify areas for improvement, and design targeted training programs to enhance vertical explosive power. The test's focus on isolating lower body strength and power aids in the development of specific training interventions[17, 19, 41, 67]. Ultimately, the squat jump test contributes to optimizing athletic performance and enhancing vertical jumping ability in the game of basketball.[2, 90]

1.3.7. **Bounding power test**

The bounding power test also examines basketball players' anaerobic alactic abilities. The athletes are asked to stand on one leg and jump horizontally as far forward as they can, six consecutive times. Alternating the jumping legs after each jump means that a total of three jumps are performed with each leg. This test combines both horizontal and vertical capability assessments. In most tests, the athlete performs the final jump using both legs, into a sand box. This test is performed twice, with the longer distance being recorded. Results are measured manually using a tape measure[1, 118]. Performance of bounding power test is presented in Figure 9.

Figure 9. Bounding power test

In most bounding power tests, the final jump is performed using both legs, and athletes land into a sand box or within the specific sports field. By incorporating both single-leg and double-leg jumps, the test captures different aspects of power production and coordination, which are essential in basketball. The specific sports field landing further enhances the specificity of the test, simulating game-like conditions and requiring athletes to execute controlled landings[1, 5, 41].

The bounding power test serves as a valuable tool for evaluating basketball players' power and explosiveness, which are crucial attributes for success on the court. By measuring the distance covered in the horizontal jumps, coaches and trainers gain insights into the athletes' ability to generate force and power in both horizontal and vertical directions[2]. This information aids in assessing performance, identifying areas for improvement, and designing targeted training programs to enhance bounding power[1, 2, 118].

Moreover, the bounding power test assesses athletes' anaerobic alactic capacity, which is particularly relevant in basketball. Anaerobic alactic abilities enable athletes to produce quick and explosive movements without relying on oxygen consumption[2, 6]. These abilities are vital for actions such as rapid accelerations, decelerations, and changes of direction on the basketball court. By evaluating anaerobic alactic capacity through the bounding power test, coaches can gain specific information about athletes' power production during high-intensity actions[1, 5, 6, 118].

In summary, the bounding power test holds substantial importance for ball games, athletes, and basketball. By evaluating both horizontal and vertical capabilities, as well as assessing anaerobic alactic capacity, the test provides a comprehensive evaluation of basketball players' power and explosiveness[1, 118]. It aids in evaluating performance, identifying areas for improvement, and designing targeted training programs[1, 119]. The specificity of the test, including the landing and alternating leg jumps, ensures its relevance to basketball-specific movements. Ultimately, the bounding power test contributes to optimizing athletic performance and enhancing power production in the game of basketball[1, 2, 118].

1.3.8. **Spike jump test**

Finally, the eighth test presented in this thesis is the spike jump test, which examines the horizontal and vertical explosive power of basketball players, using what is considered a specific volleyball jump. First, upstretched arm length is measured. Next, they are asked to jump up as high as possible (after taking three or four steps forward, or not). Their upstretched arm length is then measured at the height of their jump. Their static up-stretched arm length is then subtracted from their jump arm length, to achieve the relative height of the jump. A standing jump test can also be conducted for this assessment test[37, 120, 121]. These tests are specific for assessing explosive power in ball games and especially for professional basketball players who are required to manifest high levels of explosive power. Elite players will exhibit significantly higher levels in these tests than amateurs or players from lower leagues[5, 121]. Performance of spike jump test is presented in Figure 10.

Figure 10. Spike jump test

Notably, the spike jump test is particularly relevant for professional basketball players who are expected to manifest high levels of explosive power. Elite players are expected to exhibit significantly higher levels of performance in these tests compared to amateurs or players from lower leagues. The test serves as a discriminative measure that distinguishes between different skill levels, enabling the identification of athletes with exceptional explosive power[37, 121].

In summary, the spike jump test is of considerable importance for ball games, athletes, and the game of basketball. By assessing both horizontal and vertical explosive power, the test provides a comprehensive evaluation of basketball players' power generation capabilities. It aids in evaluating performance, distinguishing skill levels, and identifying areas for improvement. The specificity of the test to the game of basketball ensures its relevance to the sport's demands. Ultimately, the spike jump test contributes to optimizing athletic performance and enhancing explosive power in basketball players[37, 120, 121].

1.4. THE MOST COMMON EQUIPMENT FOR MEASURING EXPLOSIVE ABILITY

There are several common measuring tools used on the court to measure the explosive strength ability of basketball players, including Optojump system, force plates, photoelectric cells, and the My Jump 2 app.

1.4.1. **Optojump system**

The Optojump system is a frequently used tool to measure explosive power and vertical jump performance in athletes. It comprises two horizontal bars with 32 infrared diodes and sensors each, which are placed on the ground. The photoelectric cells of the system measure the athlete's flight time and contact time during a jump, which helps in calculating various performance parameters like power, speed, and jump height[98, 116, 122, 123].

Numerous studies have examined the reliability and validity of the Optojump system for measuring explosive power and vertical jump[1, 116]. One study revealed that the Optojump system had high intra-rater reliability, which means that the same researcher could obtain consistent results over multiple trialsjump[13, 91, 116]. Another study compared the Optojump system's measurements to force plate measurements, considered the gold standard for measuring vertical jump performance, and found that the Optojump system produced results that were highly correlated with force plate measurements, demonstrating high concurrent validity[116].

Apart from research, coaches and trainers frequently use the Optojump system to monitor an athlete's performance and progress over time. The system identifies an athlete's strengths and weaknesses in explosive power and can track progress resulting from training interventions[1, 91, 124].

Overall, the Optojump system is a reliable and valid tool to measure explosive power and vertical jump performance in athletes. Its portability and ease of use make it a popular choice among researchers and practitioners in the field of sports science[91, 98, 116].

1.4.2. **Force plates**

Force plates are devices used to measure the force applied to a surface, such as the ground, by an object or person. They are commonly used in sports science and biomechanics research to measure a variety of parameters related to movement, including explosive power and vertical jump[125, 126].

To measure explosive power using a force plate, an athlete will typically perform a maximal effort jump or movement, such as a squat jump or a countermovement jump. The force plate measures the force applied to the ground during the movement, as well as the time taken to reach peak force and the rate of force development. These parameters can be used to calculate measures of explosive power, such as the rate of force development (RFD) and the explosive strength index (ESI)[125–127].

The vertical jump is a commonly used test of explosive power, and force plates are often used to measure the height of the jump, as well as the force and power generated during the movement. To measure vertical jump height using a force plate, the athlete stands on the force plate and jumps as high as possible, while the force plate measures the ground reaction force (GRF) and the time taken to reach peak GRF. The height of the jump can then be calculated using the flight time of the athlete[127].

The Force plates can also be used to measure other parameters related to explosive power and vertical jump, such as the velocity and power of the takeoff phase of the jump. These parameters could be used to provide a more detailed analysis of the athlete's performance and to identify areas for improvement.

The Force plates are a valuable tool for measuring explosive power and vertical jump in sports science and biomechanics research. They provide a detailed analysis of an athlete's performance and can be used to identify areas for improvement in training and conditioning programs[103, 125–127].

1.4.3. **Photoelectric cells**

Photoelectric cells are sensors that emit a beam of light and are used to measure explosive power and vertical jump performance in athletes[116, 128]. They work by detecting changes in the amount of light that is reflected back to the sensor. During jump measurement, photoelectric cells are placed at a fixed distance above the ground and emit a beam of light that is interrupted when the athlete jumps. The sensors then measure the flight time and contact time of the athlete's jump, which can be used to calculate various performance parameters such as jump height, power, and speed[122, 128].

Studies have investigated the validity and reliability of photoelectric cells in measuring explosive power and vertical jump. It has been found that they have high intra-rater reliability, meaning that consistent results can be obtained over multiple trials by the same researcher. Additionally, photoelectric cells have high concurrent validity when compared to other tools such as force plates, which are considered the gold standard for measuring vertical jump performance[1, 122, 128].

One of the benefits of using photoelectric cells is their ease of use and portability. They can be quickly set up and transported, making them a convenient tool for coaches and trainers to use for monitoring athletes' performance and progress over time. However, photoelectric cells also have some limitations. They are sensitive to ambient light, which can affect their accuracy. Additionally, factors such as athlete technique and body position can impact their measurements[128].

Despite these limitations, photoelectric cells remain a valuable tool for measuring explosive power and vertical jump performance in athletes. Their ease of use and portability make them a popular choice for coaches and trainers in the field of sports science. While they may not be as accurate as force plates, photoelectric cells provide a useful and convenient alternative for measuring athletic performance[122, 128].

1.4.4. **My Jump 2 App**

My Jump 2 App is a mobile phone application that has been developed to measure vertical jump height and estimate lower body power. The app is becoming increasingly popular among athletes, coaches, and trainers as a low-cost and easy-to-use tool for assessing explosive power[129–132].

The app uses the accelerometer and gyroscope sensors in a smartphone to detect the athlete's movement and calculate the jump height using the formula of gravity and displacement. In addition to measuring jump height, the app provides a power index score that combines the jump height with the athlete's body mass to estimate lower body power[132].

Several studies have examined the validity and reliability of My Jump 2 App in measuring explosive power and vertical jump. One study compared the measurements obtained from My Jump 2 App to those obtained from a force plate, which is considered the gold standard for jump measurement. The study found that My Jump 2 App had high concurrent validity with force plates, indicating that the app produced results that were highly correlated with those obtained from the force plate[129, 131, 133].

One advantage of My Jump 2 App is its low cost and ease of use. The app can be downloaded onto a smartphone, making it a convenient tool for athletes, coaches, and trainers to use for monitoring performance and progress over time. Additionally, the app provides immediate feedback, which can be useful for athletes to adjust their technique and improve their performance[129, 130, 132].

However, like other jump measurement tools, My Jump 2 App also has limitations. The app's accuracy may be affected by factors such as athlete technique, body position, and landing surface. Additionally, the app's measurements may not be as accurate as those obtained from more sophisticated and expensive tools such as force plates[129].

Despite these limitations, My Jump 2 App remains a popular and valuable tool for measuring explosive power and vertical jump performance in athletes. Its low cost, ease of use, and immediate feedback make it a convenient option for athletes, coaches, and trainers to use in their training programs[129, 131].

My Jump 2 App is a reliable and valid tool for measuring explosive power and vertical jump height in athletes. Its convenience and low cost make it a popular option for athletes, coaches, and trainers to use in their training programs. However, its accuracy may be affected by certain factors and should be considered when interpreting the results obtained from the app[129, 132].

II – JUSTIFICATION

II - JUSTIFICATION

The game of basketball is far from new, yet over time certain rules have been added, removed, or altered[2]. In today's era of the more modern basketball, players must develop and apply lower limb explosive power, to ensure optimal performance throughout the game[19, 26]. The ability to produce such intense actions within extremely short periods of time is largely dependent on the players' anaerobic alactic system[8]. In general, the basketball game is comprised of many anaerobic actions – short forceful moves that are frequently carried out throughout practices and games, such as short sprints, jumps, and change of direction[2, 5]. The capability to perform anaerobic activities, such as those that require lower limb explosive power, is based on the players' anaerobic alactic energy resources[2, 16], the adenosine tri-phosphate – creatine phosphate system (ATP-CP) that is easily accessible through stores in the muscles. The players' glycolysis system also contributes to such anaerobic activities, especially those that last more than just a number of seconds. In addition to employing the anaerobic system, the players' aerobic energy system also plays a key role, as it enables fast recovery from, and repetition of, high intensity anaerobic actions[3, 15, 134–136].

Many key actions that are performed during a basketball practice or game are based on vertical movements (e.g., rebounds and jump shots), horizontal movements (e.g., change of direction and sprints), or a combination of the two (e.g., layups) – all of which are intermittently performed throughout the game while employing lower limb explosive power[2, 9, 12]. Due to its important, coaches place an emphasis on improving players' explosive power for players of all ages, level of performance, and years of experience in the game of basketball[73, 124]. To examine and assess the players' development and improvement of their explosive power – as a means for creating and adjusting training programs and game plans – measurement tools are needed for assessing these abilities in a consistent, accurate, and reliable manner, and in a form that suits the specific field of basketball[8].

The main aim of such fitness tests is to assess the condition of athletes in terms of the relevant fitness component that is being tracked, to determine what needs to be improved and worked on during training programs[26]. These tests are especially important among children and teenagers so that coaches can see whether players are developing in terms of physical fitness as they get older[32, 77]. However, to the best of our knowledge, no test has been developed and validated specifically for assessing lower limb explosive power among basketball players. While existing tests are often applied to players from a variety of sports[2], they entail certain limitations when employing them in basketball players[8].

The scientific literature offers several protocols for measuring players' explosive power, yet different protocols may lead to different results, rendering comparisons between outcomes of different tests inaccurate or incomplete[8, 19]. As such, coaches from different clubs who wish to confer with one another on explosive power training issues must ensure they have employed the same protocol in order to compare notes. Similarly, when comparing the performance of the same basketball players over time, the same test must be used consistently[137], despite changes such as different professional staff members (trainers, coaches and sports scientists) and other different team members[32]. Without a consistent testing protocol, differences in results cannot necessarily be attributed to changes in performance, as they may simply stem from differences in the measurement systems or from the person who is conducting the test[2, 32].

Measurement protocols should be as similar as possible to the actual movements that athletes perform when playing, and should take into account a range of environmental and other factors[2, 8, 19, 32]. Tests for measuring explosive power should be administered at the onset of the training program, halfway through, and then again at the end – to maximize the relevance and accuracy of the data received with regards to the efficacy of the training program and its contribution to the seen achievements[8, 77]. In some cases, existing tests do not provide necessary field tests for assessing specific basketball movements. To the best of our knowledge, no relevant test currently exists for actions that combine both vertical and horizontal movements, coordination, and using only one leg – all of which are specific to the game of basketball.

Thus, it is a challenge to construct a reliable and valid test that mediates between test and performance limitations and provides a means for coaches to test unique basketball abilities.

III – OBJECTIVES

III - OBJECTIVES

The main objective of this thesis, was to develop and assess the reliability and validity of a unique new test that optimally measures lower limb explosive power (i.e., alactic anaerobic capability) in basketball players, through a combination of specific vertical and horizontal movements that replicate actions performed during the game of basketball, similar to penetration to the basket and layups.

Another objective of this thesis was, to examine differences in age, gender and specific position in the game. According to the results we will try to determine specific standards for this new and unique test.

Here are tables presented with a question, hypothesis, and objective regarding the main goals of the three major stages in this thesis:

Table 3. The first stage- objective 1

QUESTION	HYPOTHESIS	OBJECTIVE
Is it possible using the field tests that presented in the literature to assess specific physical abilities of basketball players?	Yes, but more specific tests are required. Such are tests that examine physiological requirements and movements that are more specific and relevant to what is happening in the game.	To review the field tests in the literature and examine in depth the need for an explosive power test, unique ones with very specific requirements for the game of basketball.

Table 4. The second stage- objective 2

QUESTION	HYPOTHESIS	OBJECTIVE
Does the unique specific jumping test will be more efficient for basketball players?	The test is very specific and combines horizontal and vertical movement together as in penetrating a basket in a lay-up. For this goal, we need to do research that will include a lot of relevant tests and to examine the reliability and validity of the new test.	To develop a unique test that can optimally predict explosive power for basketball players in specific actions in penetration to the basket and layups.

Table 5. The third stage- objective 3

QUESTION	HYPOTHESIS	OBJECTIVE
Are there differences when using the new test in age, gender and position for basketball players?	Yes. we will see differences in performance in age, gender and position.	To examine differences in age, gender and specific position in the game. According to the results we will try to determine specific standards for this new and unique test.

Specific objectives:

- To compare the new unique test to 9 relevant standardized tests.

- To compare the new test using both the dominant and non-dominant foot.

- To compare and repeat the new test again after 72 hours.

- To compare and examine differences in the new test among 3 different age groups (Under 14, Under 16, and Under 18).

- To compare and examine differences in the new test between both genders at different ages.

To compare and examine differences in specific positions in basketball for groups in age Under 18.

IV – MATERIAL AND METHODS

IV -MATERIAL AND METHODS

4.1. STUDY 1- THE UNIQUE SPECIFIC JUMPING TEST: VALIDITY AND RELIABILITY

4.1.1. Participants

The study included 22 male basketball players, ages 16-18, members of an elite youth league team in Israel (mean age 16.8 ± 0.5 years; body mass 78.2 ± 5.9 kg; height 185.3 ± 4.0 cm; and body fat 11.1 ± 3.1%). The participants had been members of the club and had participated in professional training and competitions for at least eight consecutive years. Their weekly routine included five basketball practices, two fitness practices, and one league game. Four inclusion criteria were applied in this study, whereby each participant had: (a) participated in at least 90% of the weekly trainings during the season (10-months) prior to the research: (b) regularly participated in the previous season; (c) not incurred any injuries, were not in any pain, and were not taking any medication; and (d) a clean bill of health.

To reduce interference in the research outcomes, the participants were instructed to refrain from consuming depressants (such as alcohol) or stimulants (such as caffeine) for 24 hours following up to the testing; they were asked not to eat for about three hours as well; and were instructed not to conduct strenuous physical activity for at least 24 hours leading up to the testing. The parents of the participants (who were minors) signed and submitted an informed written consent form. Anonymity could not be assured, in light of the nature of the research, yet all obtained data were treated with scientific rigor and maximum confidentiality, and the data obtained were used solely for this research project. The research study was approved by the Ethics Committee at the authors' affiliated academic institution and was performed in line with the December 13 Organic Law 15/1999 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza[138].

4.1.2. **Procedure**

To examine lower limb explosive power among basketball players, we developed a unique jumping test specifically for examining lower limb explosive power in basketball players. This capability was measured through the jump movement of the layup following the penetration to the basket, which combines both horizontal and vertical movements that replicate real time basketball movements on the court. Flight time was used as the measurement indicator of this test – before and after contact with the ground. This was measured using the Optojump system by MicroGate® (Italy), an optical measurement system that is comprised of a receiving and transmitting bar. This system offers high accuracy compared to alternative measuring methods and enables tests and measurements in real sports environments, such as basketball courts and soccer fields[1, 95, 98, 116, 122, 123]. Each jump was also recorded on two separate video recordings. Using the Optojump system enabled the real time documenting of numerical and graphic measures, thereby providing an objective tool. The gathered data was then transmitted directly onto an Excel file®, enabling fast and simple documentation and access[116, 122]. The complementary video recordings allowed us to examine and verify the recorded data as needed.

The participants performed the tests assessed in this study at 4 pm, with indoor temperatures of about 20.4 ±0.5°C and humidity of about 60.3% ±3.5%. The participants wore basketball shoes and appropriate sportswear. Prior to the tests, the participants warmed up for about 20 minutes on their home basketball court. The warmup included 6 minutes of layups (right/left), 8 minutes of mobility movements and dynamic stretches, and 6 minutes of accelerations and deceleration.

After warmups, each participant performed the unique test twice, which included two layups and penetrations of the basket, once for their dominant leg (U1D) and once for their non-dominant leg (U1ND). In this study, the dominant leg was defined as their preferred hopping leg. These were repeated 72 hours later, for their dominant leg (U2D) and for their non-dominant leg (U2ND). The test/retest results were then compared to assess the reliability of the new test. During Day 1 of the testing, after performing the U1D and U1ND tests, the participants also performed nine additional standardized tests. A recovery period of at least 5 minutes between each test was provided[1, 2, 31, 139]. All tests were carried out on the basketball court where the participants regularly practiced and played, to ensure familiarity with the testing environment. The unique test/standardized test results were then compared to the assess the validity of the new test.

In addition to the new test, the participants also completed a 5 and 10 m sprint, the bounding power test (BP), and the following 6 versions of the countermovement jump (CMJ): countermovement jump both legs, hands free (CMJF); countermovement jump both legs, with hands on hips (CMJWH); countermovement jump dominant leg, hands free (CMJDF); countermovement jump dominant leg, with hands on hips (CMJDWH); countermovement jump non-dominant leg, hands free (CMJNDF); and countermovement jump non-dominant leg, with hands on hips (CMJNDWH). The results of these tests were compared to those of the unique new test to assess validity. The participants were able to achieve complete recovery following a 5-minute rest among tests, allowing the participants to perform a number of tests on the same day. However, the unique test was performed first, for both the dominant and the non-dominant leg, we chose to conduct this test first, prior to performing the additional nine standardized tests – to ensure similar conditions 72-hours later during the retest.

4.1.3. **Stage 1: The New Unique Test for Basketball Players**

As seen in Figures 11-13, the novel test requires players to perform a penetration and layout, once using their dominant leg and once using their non-dominant leg. The test incorporates running, jumping, and landing, as well as shooting the ball into the basket, and is performed on the regular basketball court.

Two pictures of the new and unique test presented in this thesis were taken on the day of the research, in order to best illustrate the new test that was developed.

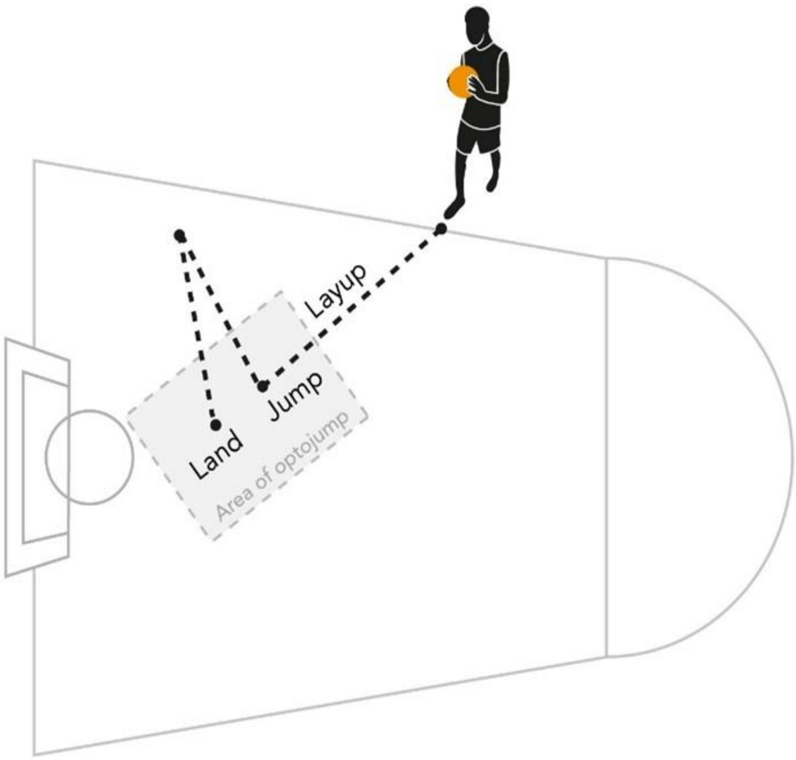


Figure 11. Performance of the novel jumping test for basketball players

Figure 12. Performance new test on Research Day at the moment of the beginning of the jump

Figure 13. Performance new test on Research Day during the jump

More specifically, the participants began the test outside the detection area of the Optojump system, which was placed on the floor in the painted area. They began in the standing position, while holding the ball in both hands, followed by a layup into the testing zone, and then a combined horizontal-vertical jump as they threw the ball towards the basket using only one hand. They released the ball at the zenith of their jump, shooting towards the basket with the one hand. They then landed within the measuring area no more than 1.5 m from their last point of contact prior to their flight. Figure 14, provides a detailed explanation of the flow chart of the test.

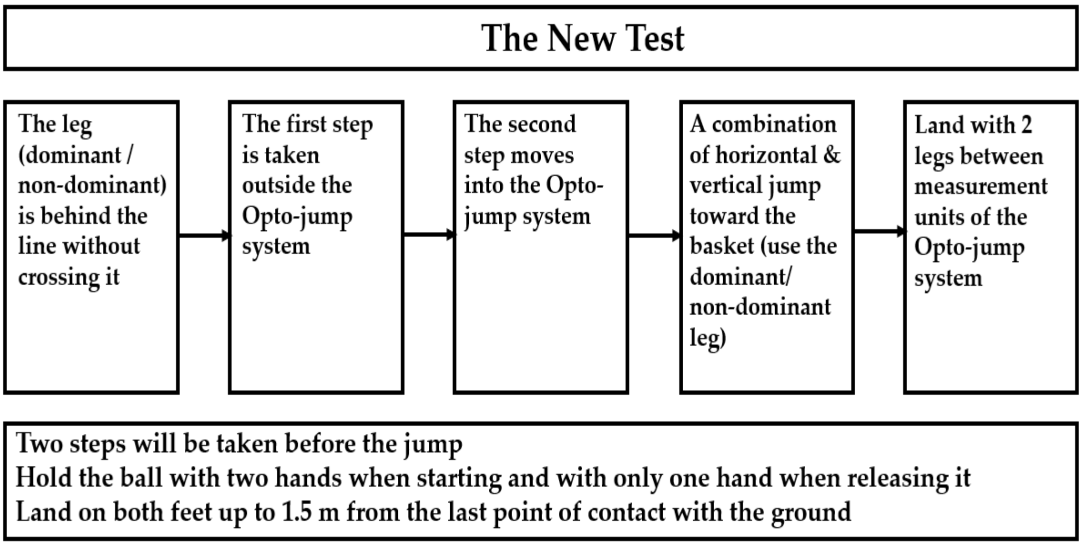


Figure 14. Flow chart of the novel jumping test for basketball players

In this study, two basketball coaches and two fitness coaches conducted the test while ensuring the following: (1) The leg (dominant / non-dominant) was behind the foul line without crossing it; (2) Two steps were taken before the jump; (3) Push off was performed with one leg (dominant / non-dominant); (4) The ball was held with both hands when starting and with only one hand when releasing it; (5) The ball entered the basket, or at least touch the rim, after the ball was released from the player's hand;

(6) Players landed on the balls of their feet without excessive bending of the knees, and landed only on their feet; (7) Players landed with both feet within the measurement zone; (8) Players did not touch the basket rim or net with the hand during the jump, either before or after releasing the ball; and (9) The ball did not fall onto the measurement units of the Optojump system before the player landed. Players who did not meet all of these guidelines were asked to repeat the jump.

In summary, when performing the layup for the test, the players were asked to jump as high as they can, i.e., a horizontal run followed by a vertical jump that also comprises horizontal elements. They were also instructed to land on both feet up to 1.5 m from the last point of contact with the ground after holding the ball in just one hand, to replicate a real time penetration of the basket.

4.1.4. **Stage 2: Comparison of the Unique Test to Standardized Tests**

To assess and validate this new field tool, the data achieved from the novel test were compared to results from nine standardized tests, as detailed in the following section.

The 5/10-Meter Sprint Speed Test. This speed test was used to evaluate players' horizontal explosive power through cyclical movement (i.e., sprinting from a standing starting point). The participants were asked to perform two 10 m sprints from a high starting point, with 3-5 minutes' rest between the two sprints. The best result of the two was recorded[1, 2, 26]. In this study, the participants only completed two 10 m sprints, as the measuring tool recorded their results after completing both 5 m and 10 m in the same sprint.

BP Test. This test was used to evaluate players' horizontal and vertical explosive power. In the study, the participants were instructed to stand on one leg and jump as far forward as they can, six consecutive times, each time landing on the alternating leg[1, 118]. The recorded results were the final distance reached by the participants after bounding forward six times. This test was also performed twice, with the greater distance being recorded. Distances were measured manually using a tape measure[1].

CMJ Tests. In the study, the participants completed 6 types of CMJ tests, to assess their vertical explosive power in a single jump. The participants began in the straight standing position, then bent their knees and quickly extended their legs to leave the ground into a flight movement, rising up as high as possible[90, 140]. This was performed once using both legs, once using the dominant leg, and once using the non-dominant leg – all with hands on hips to neutralize upper limb momentum. These 3 jumps were then repeated while hands were in a free position – resulting in a total of 6 tests. Recovery time was about 2 minutes between jumps[1, 2, 90]. The jump heights were also recorded using the Optojump which converts flight time to jump height[1, 2, 116, 122].

4.2. STUDY 2- THE UNIQUE SPECIFIC JUMPING TEST: DIFFERENCES IN AGE, GENDER AND PLAYING POSITION

4.2.1. **Participants**

This research included 232 young basketball players, both male and female, from 4 clubs in Israel. The study began by taking various physical measurements of each participant, such as their height (in meters), body mass (in kilograms), and body fat (%). The height measurement was taken using a stadiometer (SECA®, Germany) with a precision of 1 cm, while the body weight and fat percentage were measured using electronic scales (Tanita BC® 418, Japan) with a precision of 0.1 kg[141]. All participants had been playing basketball for a period ranging from three to eight years. Additionally, they were required to attend at least two fitness practices, participate in 3-5 basketball practices, and one league game each week. Finally, it was necessary for the players to have no current injuries, aches, or medication usage to be included in the study.

Table 6, presents the participants' physical characteristics, including body mass, height, and body fat by age group and gender.

Table 6 . Participants' Physical Characteristics by Mean (SD)

		N	Body Mass (kg)	Height (m)	FAT%
Males	U-18	42	76.4±7.53	1.86±5.38	10.83±1.31
	U-16	37	65.9±8	1.78±6.7	10.62±1.29
	U-14	36	58.1±7.9	1.73±6.9	11.01±1.27
Females	U-18	42	59.8±5.8	1.66±5.07	25.33±4.56
	U-16	37	56.9±5.73	1.63±4.79	23.451±3.37
	U-14	38	48.2±4.37	1.58±4.76	22.95±5.56

4.2.2. Procedure

Once the basketball clubs and coaches were contacted to participate in the study, the players and their parents were requested to provide informed consent. It was made clear that participation was optional for all participants. Although complete anonymity could not be guaranteed due to the study's nature, all participants and parents were guaranteed the highest level of confidentiality and scientific precision throughout the study. It was emphasized that the data collected would only be used for the research project. Dates for conducting the study at each club were scheduled to avoid disrupting their training and competitions.

To avoid any variations caused by the time of day, all participants completed the test at 6 pm under standard ambient conditions, with a temperature of 23.1 ±0.5°C and relative humidity of 70.5% ±3.5%. The assessments were conducted by the researchers and the team's coach inside the official indoor basketball courts, and the players were instructed to wear their regular sportswear and basketball shoes. Before the assessments, the players were advised to avoid consuming caffeine, other stimulants, alcohol, and other depressants, and to refrain from strenuous physical activities for at least 24 hours. They were also instructed to fast for approximately three hours prior to the testing. The research study was approved by the Ethics Committee at the authors' affiliated academic institution and was performed in line with the December 13 Organic Law 15/1999 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza[138].

4.2.3. **Tools**

The New Unique Test for Basketball Players

Using their preferred hopping leg, players are required to perform a penetration and layup as can be seen in the figures presented in Study 1. The test entails a combination of activities such as running, jumping, and landing, in addition to shooting the ball into the basket. It should be noted that the test is conducted on a standard basketball court.

4.2.4. **Variables**

The following three independent variables were addressed in this study, including (1) gender (male/female), (2) three age groups (according to their affiliated basketball team): Under-14 (U14), Under-16 (U16), and Under-18 (U18), and (3) three positions groups: guards, forwards and centers (all from the group of Under-18).

4.3. OPTOJUMP SYSTEM FOR THE NEW TEST

The measurement device chosen for the development of the new test is the OptoJump system, which is displayed in Figure 15.

Figure 15. Optojump system

4.3.1. The advantages of Optojump in field tests

Many methods are used today to measure and assess explosive power. These methods include contact exercise mats, standing high jump and various types of optical systems. While these methods are commonly used and simple to operate, they have a number of limitations. For example: standing high jump results can be affected by shoulder flexibility and arm length. In addition, when using contact mats the athlete's feet work on a surface that differs from the one the athlete plays on, thus reducing test validity [116, 122, 123].

These methods require the use of various measurement instruments which produce different results due to measurement errors[116]. Thus in addition to the differences created by different measurement protocols, the use of the same protocol but with different measurement equipment may complicate comparisons of results. For example, a difference of 2.9% was found in jumping height between two different systems that measure time in air. In another study which measured vertical jump using four different measurement methods, different values were reported for each measurement, while test reliability for each method by itself was high[98, 116]. In other words, as long as the same instrument is used over time, differences in performance can be attributed to changes in performance and not to errors in repeat measurements[116].

It should be noted that explosive power performance can also be affected by environmental conditions such as external temperature, wakefulness, time of day when the test is conducted and whether the test is conducted before or after training[116, 122, 123]. Thus such data should be documented and further tests should be administered in conditions as similar as possible to the first test in order to maintain uniformity. Some measurement systems for explosive power are expensive and require professional staff for operation[91, 116, 117, 122].

In contrast, simple systems are available for measuring jump height but these systems are not suitable for all jumping protocols. When selecting the most suitable test for the needs of the coach/athlete, measurement protocol and instruments should be considered. Because of the great importance of performing tests in a manner as close as possible to actual actions during games/competitions and in order to avoid limiting athletes' movements during the jump, more advanced measurement instruments are probably preferable[116, 122].

In order to overcome the limitations of the most commonly used methods today, the innovative Optojump system was developed to analyze, assess and measure sport performance and abilities. Central to the system architecture are a pair of measurement units, comprising a transmitting device and a receiving apparatus, strategically positioned upon the performance surface. This is different from other systems such as the contact exercise mats. Each of the measurement units is about a meter long and a number of measurement units can be connected together. Each unit contains from 33 to 100 electronic "eyes", depending on the measurement resolution desired. The eyes in the transmitting measurement unit are in constant contact with the receiver, and the system can record every movement performed between the measurement units as well as duration. In addition, all the tests performed with the system are documented by two video cameras. The advantages of the system over others in use are the level of accuracy, mobility and ease of operation – the test can be conducted on a soccer field, a basketball or volleyball court, the athletics stadium and even on the run-up surface for broad jumps, high jumps or pole vaulting[116, 122, 123].

With the system it is possible to gather numerical and graphic measures in real time as well as visual feedback from the video cameras. Test results are received in real time so that the instrument can be used not only to assess performance but also as an objective tool for feedback during training or periodic monitoring of performance. After edited data were transmitted directly to an Excel file where they can be accessed and processed simply and easily[116].

The system can be used to compare the functioning between right and left legs – to reveal any lack of balance and adapt an intervention program if necessary. The visual documentation provided by the cameras can be retrieved later to verify data against actual test performance[116, 122, 123].

Optojump is suitable for many sports and preparatory meetings are usually held with the training staff to coordinate expectations and build individualized series of tests[116, 123].

In short, the Optojump system utilizes innovative technology for accurate and consistent measurement of physical abilities. With these measurements coaches and athletes can identify weaknesses and improve the training program so as to improve athletic abilities and reach athletic goals[98, 116, 122, 123].

4.4. STATISTICS

4.4.1. **Statistics of study 1**

Internal consistency (α Cronbach) was used to assess the validity and reliability of the new proposed test. Mean ±SD were calculated and presented for describing a range of participant characteristics as well as the results of their physical tests. Normality was tested using Shapiro-Wilk W statistics. Reliability of the new test was measured via Intra-class Correlation (ICC) and Bland Altman plot[20, 140, 142]. Correlations between the standardized jump tests and the unique test were calculated using Hopkins et al.[143, 144] to consider their strength: trivial ($r < 0.1$; small ($0.1 < r < 0.3$); moderate ($0.3 < r < 0.5$), high ($0.5 < r < 0.7$); very high ($0.7 < r < 0.9$), nearly perfect ($r > 0.9$), and perfect ($r=1$)). Significance levels were set at $p < 0.05$. SPSS v.26.0 (IBM) was used for conducting statistical analyses.

4.4.2. **Statistics of study 2**

In this quantitative study, means and standard deviations (SD) were calculated for body mass, height, and body fat; independent T-tests were conducted for age and gender, and 2-way ANOVA tests were conducted to compare mean differences between the age groups, genders, and positions groups. Statistical analyses were performed using the SPSS v.21 software (Inc, Chicago, IL, USA); statistical significance was set at $p<.05$.

V – RESULTS

V - RESULTS

5.1. RESULTS OF THE TWO ORIGINAL RESEARCH STUDIES IN THE THESIS PROJECT

In this chapter, the results of the original research conducted in this thesis are presented.

5.1.1. Results of study 1

In order to assess the validity and reliability of the new proposed test, measurements were conducted twice, with a 72-hour gap between the two. For the dominant leg, internal consistency (α Cronbach) was 0.992 and ICC was 0.984 ($p<0.001$). For the non-dominant leg, internal consistency was 0.994 and ICC was 0.978 ($p<0.001$).

For the dominant leg, Figure 16 presents the Bland-Altman plot [mean = -0.354, 95% CI (-3.577, 2.868)]. Only one point was outside the CI, thereby enhancing the validity and reliability of the new test for the dominant leg.

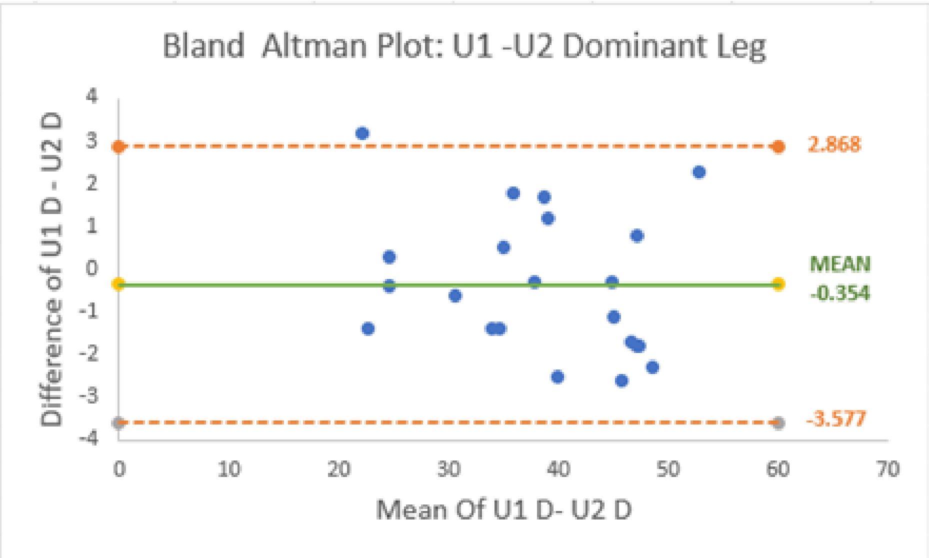


Figure 16. Bland Altman Plot U1D, U2D

For the non-dominant leg, Figure 17 presents the Bland-Altman plot [mean = -1.268, 95% CI (-3.959, 1.423)]. Again, only one point was outside the CI, thereby enhancing the validity and reliability of the new test for the non-dominant leg. In addition, test/retest correlations were calculated, indicating a very high correlation for both the dominant and non-dominant leg [R = 0.985 (P < 0.001); R = 0.988 (P < 0.001), respectively]. Moreover, differences between U1D and U2D mean scores, examined through t-tests, were not found to be significant [t21=-0.101, p=0.323], while differences between U1ND and U2ND were found to be significant [t21=-4.331, p<0.001].

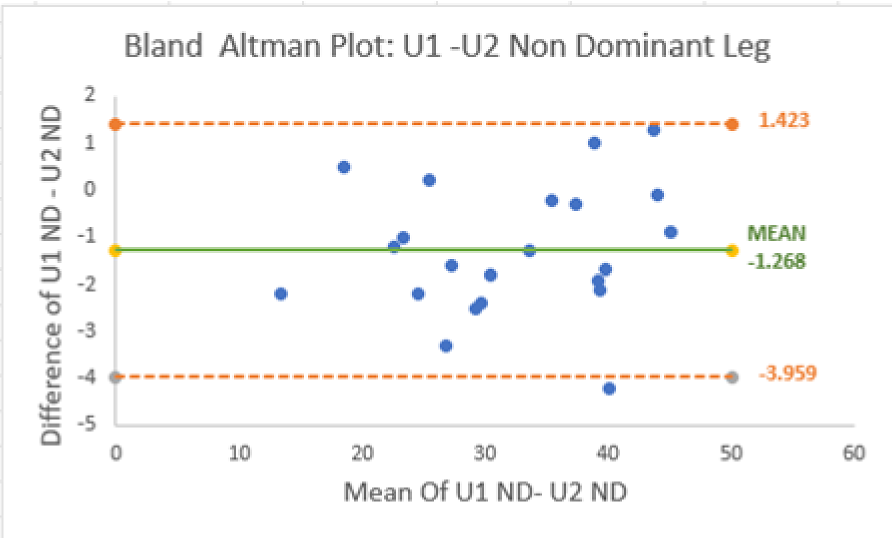


Figure 17. Bland Altman Plot U1ND, U2ND

Table 7 presents mean ± SD of the new and standardized explosive power tests conducted in this study. The highest scores achieved in the novel test were U1D = 53.90 cm and U2ND = 45.50 cm.

Table 8 presents strong correlations between results of the novel test and the standardized tests. The results indicate a high magnitude of correlations (Hopkins) for the new test with all standardized tests was high (0.5 < r < 0.7), very high (0.7 < r < 0.9), and nearly perfect (r > 0.9). Correlations between U1D/U1ND and both horizontal tests (5 / 10 m sprint) were high; correlations between U1D/U1ND and all CMJ vertical tests was very high. Finally, especially high correlations were seen between the U1D/U1ND scores and the BP test ($r > 0.9$) [R = 0.956 and R = 0.933, respectively].

Table 7. Results of Lower Limb Explosive Power Tests

Basketball Players (N=22)	M±SD
5 m Sprint (s)	1.08 ± 0.07
10m Sprint (s)	1.84 ± 0.09
BP (m)	13.2 ± 1.73
CMJF (cm)	43.8 ± 8.6
CMJWH (cm)	35.8 ± 7.6
CMJDF (cm)	24.40 ± 5.45
CMJDWH (cm)	19.90± 4.20
CMJNDF (cm)	23.20 ± 5.51
CMJNDWH (cm)	19.72 ± 4.72
U1D (cm)	38.21 ± 9.00
U2D (cm)	38.56 ± 9.41
U1ND (cm)	31.55 ± 8.95
U2ND (cm)	32.82 ± 8.73

Table 8. Correlations between Novel Test and Standardized Tests

Basketball Players (N=22)				
	U1D (CI 95%)		**U1ND (CI 95%)**	
5m Sprint (s)	-0.571*	(-1.099, -0.199)	-0.535*	(-1.047, -0.147)
10m Sprint (s)	-0.670*	(-1.260, -0.361)	-0.637*	(-1.203, -0.303)
BP (m)	0.956***	(1.448, 2.347)	0.933***	(1.231, 2.131)
CMJF (cm)	0.848**	(0.799, 1.699)	0.851**	(0.810, 1.709)
CMJWH (cm)	0.856**	(0.829, 1.728)	0.827**	(0.729, 1.628)
CMJDF (cm)	0.859**	(0.840, 1.739)	0.888**	(0.963, 1.862)
CMJDWH (cm)	0.811**	(0.680, 1.580)	0.780**	(0.596, 1.495)
CMJNDF (cm)	0.775**	(0.583, 1.482)	0.860**	(0.844, 1.743)
CMJNDWH (cm)	0.706**	(0.430, 1.329)	0.775**	(0.583, 1.482)

Magnitude of correlation: *high, **very high, ***nearly perfect

5.1.2. **Results of study 2**

Table 9 presents, the participants' descriptive data by gender (including age and average of jump height achievement of the unique specific jumping test), and optimal results of this unique test. Significant differences were seen between the genders in their mean jump height achievement, regardless of age, whereby the mean jump height achievement for males (40.82±8.03) was significantly greater than for females (32.76±5.54), ($p<0.05$). Moreover, improvement in these results in line with increased age was also evident, whereby older players jumped higher.

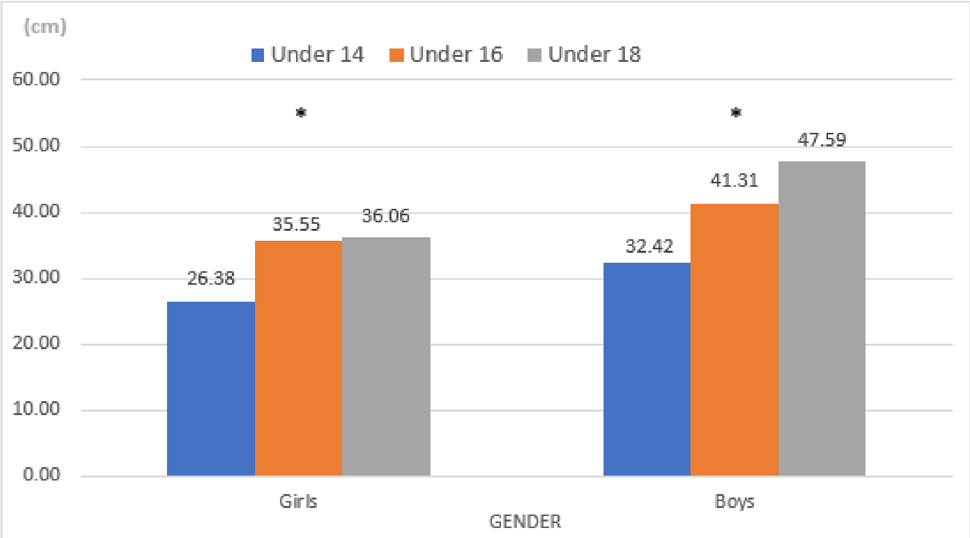
As seen in Figure 18, there are significant differences between males and females also in relation to age. In the male group there are significant differences between the age groups, U-18-U-14 and U-18-U-16 and U-16-U-14 ($p<0.05$). In the female group there are also significant differences between the age groups, U14-U-18 and U-14-U-16 ($p<0.05$).

Table 9 . Participants' Descriptive Statistics

Gender	Age	N	USJT (cm)	Optimal Results (cm)
Males	U-14	36	32.42±3.83	41.21±2.57
	U-16	37	41.31±6.72*	51.21±0.73
	U-18	42	47.59±4.24*	56.11±1.09
Females	U-14	38	26.38±3.42*	31.48±0.55
	U-16	37	35.55±3.29	41.36±1.03
	U-18	42	36.06±3.30	41.77±0.40

USJT= unique specific jumping test (the new test), USJT (cm) = The average of each group, Optimal Results = The average of the 3 best results for each group.

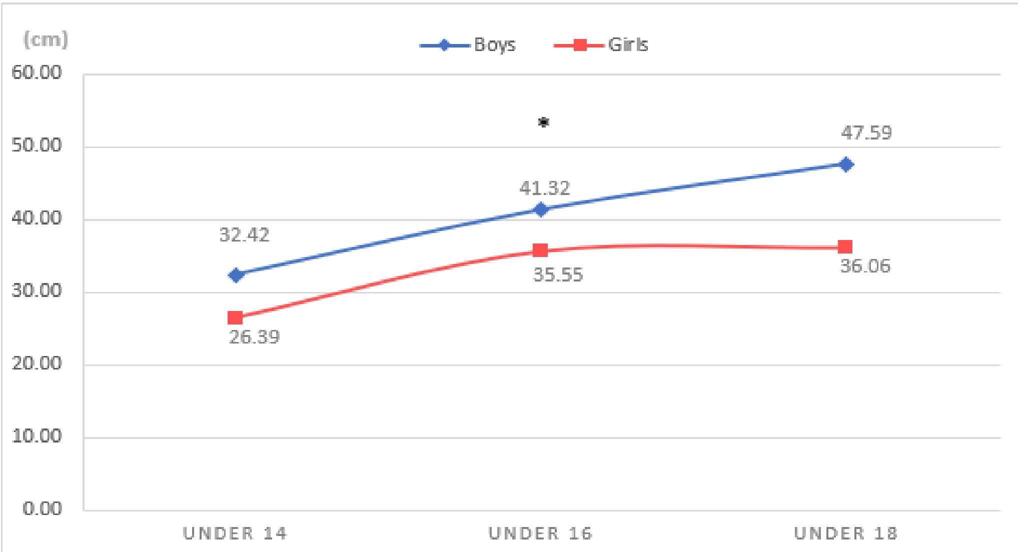
In addition, interactions were also seen between age and gender, whereby improved jump height in the female participants began to decrease after the age of 16, unlike the continued increase seen in males at the same ages (Figure 19)



* Boys U-18-U-14 and U-18-U-16 and U-16-U-14 (p<0.05)

* Girls U-14-U-18 and U-14-U-16 (p<0.05)

Figure 18. Average Jump Achievement by Age and Gender

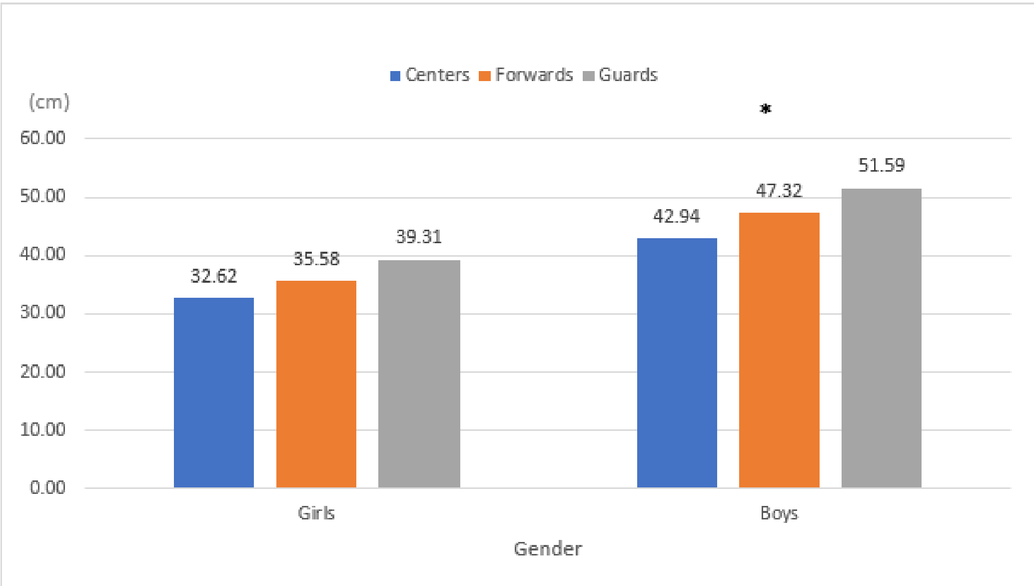


* Between boys-girls in U-14 and U-16 and U-18 (p<0.05).

Figure 19. Differences in Average Jump Achievement by Age and Gender Interactions

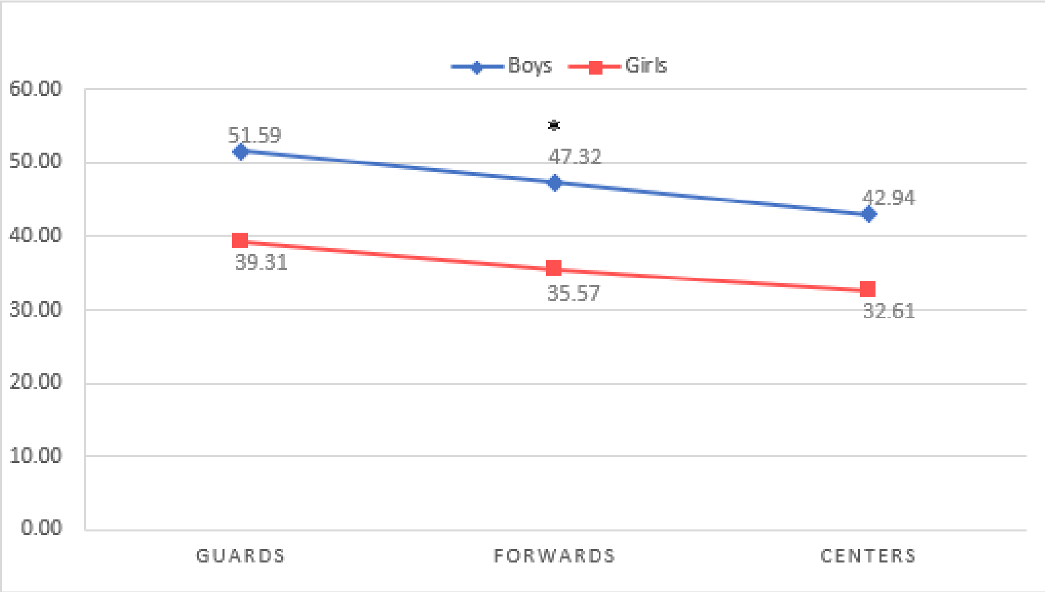
The male participants showed consistent significant improvement in the mean jump achievement by age, with a significant increase from U-14 (32.42±3.83) to U-16 (41.31±6.72), and from U-16 to U-18 (47.59±4.24). With the female participants, on the other hand, no such consistency was seen, in light of an increase from U-14 (26.38±3.42) to U-16 (35.55±3.29), yet with no significant change from U-16 to U-18 (36.06±3.30), as depicted in Figure 4. In addition, significant differences were seen in gender at all age groups, between boys-girls in U-14 and U-16 and U-18 ($p<0.05$). When the jumping performance of the males was significantly higher.

When examining differences in gender and playing positions among the age groups U-18, Only the males groups showed significant differences between the playing position groups, as depicted in Figure 20. The guards jumped significantly higher than the centers. In addition, as seen in Figure 21, there were significant differences in gender in all positions of the game.



* Boys: Guards-Centers ($p<0.05$).

Figure 20. Average Jump Achievement by Gender and Playing Position in Age U18.



* Between boys-girls in Guards and Forwards and Centers ($p<0.05$).

Figure 21. Differences in Average Jump Achievement by Gender and Playing Position Interactions

The findings from this thesis have led to the creation of an Estimated Achievement Table (Table 10) that can be utilized by coaches and trainers of young basketball players. This customized scale accounts for the age and gender of the players and provides an estimated jump performance score using the Unique Specific Jumping Test for Basketball Players. With this tool, coaches and trainers will be able to rank their players' jump performance on a scale from unprepared to excellent.

Table 10. Achievements Table (Unique Specific Jumping Test for Basketball Players)

Achievement table (USJT)

GIRLS			BOYS		
Assessment	**High (cm)**	**Age**	**Assessment**	**High (cm)**	**Age**
Excellent	38.87>		Excellent	49.87>	
Very good	(35.70-38.87)		Very good	(46.66-49.87)	
Good	(32.97-35.70)	**U18**	Good	(43.10-46.66)	**U18**
Poor	(31.44-32.97)		Poor	(41.54-43.10)	
unprepared	31.44<		unprepared	41.54<	
Assessment	**High (cm)**	**Age**	**Assessment**	**High (cm)**	**Age**
Excellent	36.77>		Excellent	47.33>	
Very good	(33.34-36.77)		Very good	(43.33-47.33)	
Good	(31.34-33.34)	**U16**	Good	(36.34-43.33)	**U16**
Poor	(26.88-31.34)		Poor	(32.89-36.34)	
unprepared	26.88<		unprepared	32.89<	
Assessment	**High (cm)**	**Age**	**Assessment**	**High (cm)**	**Age**
Excellent	32.12>		Excellent	37.77>	
Very good	(26.88-32.12)		Very good	(31.88-37.77)	
Good	(24.27-26.88)	**U14**	Good	(27.81-31.88)	**U14**
Poor	(18.22-24.27)		Poor	(23.22-27.81)	
unprepared	18.22<		unprepared	23.22<	

VI – DISCUSSION

VI -DISCUSSION

This chapter will examine, validate, and compare the results of the current doctoral thesis with previous research. The chapter is divided into two sections: a discussion of the literature review findings that shed light on the need for a more specific field tests in basketball, the second study (an original experimental study), and the third study (a larger original experimental study).

This thesis reviews the existing lower-limb anaerobic alactic tests that are suitable for measuring basketball players' abilities, a total of eight assessment tests. The modern game of basketball has become more intensive following the introduction of new rules in 2000. As such, basketball players' agility and anaerobic alactic[3, 5] abilities, rather than aerobic capabilities, play a more central role in their performance. Basketball players today are highly conditioned athletes, which is necessary for achieving consistent high-level performance throughout the season[12, 145, 146]. Moreover, the game is unique as it requires players to perform horizontal movements, vertical ones, and a combination of the two[2, 124]. These high-intensity movements are intermittently performed throughout the game, at different time intervals and from different positions on the court[5, 77]. As such, sports re-searchers, trainers, and strength and conditioning coaches continue to strive to identify optimal measurements tests that are specific to basketball[19, 33].

Trainers and researchers often use 20 or 27-meter tests for assessing players' abilities, as this is similar to the length of a basketball court[6]. However, video analysis indicates that basketball players rarely have to sprint across the entire court. Rather, they mainly perform high intensity runs lasting 1.7-2.1 seconds, which is more similar to the 5/10-meter run[3, 33]. To the best of our knowledge, both theoretical and practical field tests are lacking that examine both horizontal and vertical capabilities specifically for basketball players. Moreover, a number of tests assess athletes' upper body explosive strength (such as the 1-RM bench press test). These were not reviewed in this thesis as these skills are less frequently used in basketball.

Efforts have been made to create tests that specifically assess lower limb explosive power among basketball players[2, 5, 19, 43, 147]. Although studies indicate correlations between vertical and horizontal power[120, 148], the scientific literature lacks specific tests for examining this power in combined vertical and horizontal movements[1, 38, 149]. In a study on handball players[124], no association was observed between the CMJ tests and the players' time in the air – an action that entails both horizontal and vertical movements. As such, CMJ may not be a reliable tool for predicting jumping ability specific to handball players. On the other hand, a different study revealed a strong connection between CMJ outcomes and the volleyball jump serve, which also combines both horizontal and vertical components, similar to the spike jump in basketball[120]. As such, connections among these variables seem to differ from sport to sport, and perhaps even among athletes with different levels of development. Moreover, it is unclear as to whether CMJ test protocols and others can reliably predict specific basketball jumping abilities (e.g., jumping time when leaping up towards the basket on one leg while holding the ball).

Additional examples of inadequate tests can be seen in a number of intervention studies relating to ball games. While the outcomes of these studies indicate improvements in maximal sprint, strength, plyometric, and complex training, as seen in CMJ performance assessments[1, 25, 119, 140, 150, 151], it is unclear whether these improvements can be transferred to additional game situations, such basket penetrating and layups. Indeed, transferring physical improvements seen in training to actual ball games is not easy to assess – as additional factors must be addressed, such as players' technical abilities and complex inter-actions.

Since the main factor for assessing basketball players' capabilities is their anaerobic alactic system, tests that examine their anaerobic glycolytic energy system are less relevant[5]. Tests should specifically focus on players' lower limb explosive power, such as the 5/10-meter sprint test rather than the 20-meter test. Moreover, it seems that while multiple tests exist, there is no standardization of these assessment tools – national or international. For example, while the horizontal and vertical drop jump tests may offer important tools for assessing basketball players' plyometric and jump height abilities, drop height and jump height are not always identical and as such, could result in different measurements[104, 106]. Additional limitations of the existing tests can be seen in tests such as the spike jump that combines both horizontal and VJ capabilities, as differences in players' shoulder joint flexibility may impact the outcomes of the test and hinder the ability to reliably compare athletes' measurements[120].

Finally, the issue of upper-limb momentum should be addressed, as biomechanical and physiological tools used to study the VJ often attempt to neutralize the athletes' arm movement (by performing the test with their hands on their hips or behind their back). This is done in an attempt to isolate the effect of leg muscle power as a means for seeking causal relationships between improved lower body muscular power and jump height. However, this does not replicate the exact jump movements that athletes in general and basketball players in particular perform during practice and games – especially as jumping without arm momentum is not an action that is performed in competitive sports[2, 19, 152].

Regarding study 1, the aim of the current study was to develop a unique test for assessing lower limb explosive power in basketball players in the field, and assess its reliability and validity. Indeed, the game of basketball requires players to use lower limb explosive power for performing horizontal and vertical movements, as well as complex jumps that require a combination of the two[2, 116]. Players also need to have strong coordination capabilities between their upper and lower limbs, for performing actions such as penetration to the basket through layups, while continuously maintaining control of the ball[2, 26].

In 2017, Rodríguez-Rosell et al.[153] examined the reliability and validity of two standardized tests for vertical jumps (CMJ and the Abalakov jump) and two specific jump tests that combine both horizontal and vertical abilities (run-up and 2-LEGS or 1-LEG take-off jump). The researchers examined these tests as predictors of sprint and strength performance among soccer and basketball players. All four tests presented high intraclass correlation coefficients, regardless of the players' age or sport. The 1-LEG test presented slightly greater variability than the other three tests, as well as the least validity. The researchers explained these findings as the result of the more complex motor structure of this jump. Indeed, assessing the 1-LEG test among both soccer and basketball players may have created a limitation, as these two ball games require different physical abilities[5, 153]. Rodríguez-Rosell et al.'s[153] findings, combined with a range of additional reasons, led us to create a more unique 1-LEG test specifically for basketball players, assessing a basic movement that is learned and acquired when first embarking on basketball, yet one that is constantly repeated during practice and games at all levels and ages while holding a ball. As such, the use of the ball during tests should not perceived as a limitation and may even be advantageous when assessing the jump specifically among basketball players[2, 12].

The skills exhibited in the novel test are relatively complex, requiring explosive power on two plains (horizontal and vertical) while holding a ball. However, for professional basketball players, these are basic, frequently used skills in both warmups, practice, and games[9]. For this reason, we chose to only assess highly experienced basketball players from professional clubs – to ensure that they possess very good control of the examined movement, and as a means for decreasing the limitation of a learning curve (i.e., learning a new skill specifically for the test) between the test and the retest. Moreover, unlike previous studies, we assessed a combination of a horizontal jump of up to 1.5 m forward – as the jump in the test was performed after a horizontal run with the ball and as a natural continuation of this action[12, 153].

The main findings of the study indicate a high correlation between the test/retesting results for both legs, with mean scores remaining very similar. The magnitude of correlation of the new test was nearly perfect ($r > 0.9$) for both legs. Moreover, as only one point was found to be outside the confidence interval (CI), our findings enhance the reliability and validity of the new test for both legs.

Although the new test was found to be valid for both legs, differences were seen in the mean scores when comparing between the test/retest results. For the dominant leg, better scores were seen in the test (U1D), while for the non-dominant leg, better scores were seen in the retest, conducted 72 hours after the initial test (U2ND). This finding could stem from the ongoing need for strong coordination skills with the dominant leg when playing basketball – as no differences were seen in the test-retest scores for this leg. Although the test was performed on one leg, it was performed after a layup – which could explain the large differences in means scores compared to the CMJ tests that were performed on one leg without accelerating beforehand.

According to the Bland-Altman plot, accuracy is higher for the dominant (preferred) leg, as compared to the non-dominant leg where variability is higher. This is apparently due to the fact that the participants are more used to using the dominant leg in games and practice so there is more consistency.

For the horizontal tests, the highest correlation was seen for the 10 m sprint test (R > 0.670), which required greater acceleration than the 5 m sprint, as well as greater combination of horizontal and vertical movements. In the vertical tests, the CMJ presented very high correlations for all assessments, with the highest correlation being between the CMJF and the CMJDF (R > 0.8). As in these tests the participants were required to jump with their hands free, not on their hips, this could explain the higher significance of the results.

The highest correlation was seen for the BP test (R > 0.9), where both horizontal and vertical skills were combined. As this is a typical requirement when playing basketball, this finding enhances the importance and relevance of the newly developed test. As with the novel testing protocol, the BP test requires strong capabilities of both vertical and horizontal lower limb explosive power[118]. The participants possessed a strong foundation for doing so, based on their training in plyometrics and in explosive power – which is why we compared between the BP test and our newly proposed test. Yet despite the combination of movements, the BP test is not as specific as the new test in replicating and assessing basketball players' explosive power. As such, our findings indicate the significance of the newly proposed test for assessing lower limb explosive power among basketball players in the field.

The findings of this research are in line with those of previous studies that assessed standardized tests for measuring lower limb explosive power and complex coordination (that require both horizontal and vertical capabilities) for a range of ball games[18, 120, 124, 153]. Yet to the best of our knowledge, this is the first research study to examine a unique test for the game of basketball, compared to other standardized tests that could be relevant to a number of fields of sport.

The second study in this thesis was conducted on a large group of basketball players with diverse ages and genders, and the analysis of these data is also highly important and interesting.

High-level explosiveness is crucial to the performance of young basketball players[2]. This component is dependent on genetics but can also be developed through various training programs[1]. In order to compete at high levels in basketball, players require specific and unique abilities for the game[1, 2, 20]. The game demands a combination of horizontal and vertical explosiveness[1, 2, 26]. Young players who are able to express their explosiveness in specific movements of the game will have a significant competitive advantage over players with lower explosiveness[2, 5, 19, 51, 141, 154].

The new test we developed measures a basic basketball movement that is first learned when starting basketball, but is constantly practiced and used in games at all ages and levels while holding a ball. It is important to note that using the ball during the test is not a limitation and may even be beneficial in assessing the jump specifically among basketball players. The skills required for the test are relatively complex, involving explosive power on both horizontal and vertical planes while holding a ball (as presented in study 1)[155]. However, for professional basketball players, these skills are basic and frequently used in warmups, practice, and games[1, 2, 153]. That's why we only tested highly experienced basketball players from professional clubs to ensure that they have excellent control over the movement being examined[153].

The first objective of this research was to examine differences in specific explosiveness based on gender and age groups, using a unique and innovative test for basketball players presented in this study. The test simulates a specific movement of penetration to the basket with a ball. Significant differences were found between genders, as male players had higher average vertical jump heights compared to female players in each age group. Significant differences were found in the effects of age on performance among genders and within groups of female players. Male players exhibited consistent improvement with age, while female player groups displayed a different pattern. Although female players showed similar improvement between ages U14 to U16 as male players, no significant improvement was observed between ages U16 to U18 in female player groups. This findings is in line with the previous study by Ramos et al. (2019), which reported different effects of gender on the adolescent age and their implications on sports performance[156].

The second objective of this study was to examine differences in specific explosive power ability using a unique test based on gender and playing positions. Since younger basketball players typically play in all positions and not in specific playing positions, this study examined differences in playing positions only in male and female U18 groups. Significant differences were found between genders, as male players had higher average vertical jump heights than female players in all playing positions. These findings are also in line with previous studies that investigated the effect on playing positions in basketball[41, 45, 71, 77, 80, 81].

The observed differences in vertical jump heights between male and female players could be attributed to inherent biological factors. Generally, males tend to have higher levels of testosterone, which can contribute to increased muscle mass, strength, and power. These physiological differences may give male players an advantage in generating vertical jump height compared to female players[7, 30, 33, 49].

Additionally, significant differences were found between playing positions only in the male participant group, where guards achieved significantly higher results in the specific unique jumping test compared to centers.

Guards and centers in basketball may have different physiological characteristics that affect their jumping ability. Guards, who tend to be smaller and lighter, may have better agility and explosive power, which can contribute to higher results in jumping tests compared to centers, who are typically taller and heavier[79, 84]. In addition the specific role and responsibilities of guards and centers within the basketball game may influence their jumping abilities. Guards often need to make quick vertical jumps for shooting or defending against taller opponents, while centers might rely more on their standing reach and strength near the basket. These role-specific demands could explain the discrepancies in jumping performance between the two positions[41, 45, 85].

The unique jumping test may involve specific skills that are more relevant to the playing style and responsibilities of guards. Guards often rely on quick explosive of speed and leaping ability to navigate through defenders and finish plays at the basket. Centers, on the other hand, may focus more on strength and post positioning rather than explosive jumping[27].

VII – CONCLUSIONS

VII - CONCLUSIONS

Based on the results obtained, as well as the hypotheses and objectives proposed by the present doctoral thesis, the conclusions are made below.

7.1. GENERAL CONCLUSIONS

Regarding the scientific literature review presented in this thesis, it seems that specific tests for basketball players are lacking, especially tests for examining agility[16, 39] a skill that requires lower-limb explosive power. The literature also lacks measurement tests for examining lower limb explosive power that requires both horizontal and vertical movements combined, as required in penetration of the basket[5, 19]. It is especially difficult to replicate the dynamic, constantly changing environment that is typical of basketball games – an environment filled with simultaneous multiple stimuli in which players must make split-second decisions that could impact the outcome of the game. Future studies could benefit from developing and researching basketball specific tools for assessing players' anaerobic alactic energy systems in relation to their lower-limb explosive power. Developing such tools could significantly enhance research and performance in basket-ball.

Assessment tests must provide useful input and insights that trainers and coaches can utilize in the field. As such, it is important to comply with the principle of specificity in training, whereby a given motor skill is improved (and tested) as it is performed during actual games[2, 5, 10, 157]. Indeed, with specific respect to basketball, developing an applicable, reliable, and valid field-specific test for assessing players' anaerobic capabilities is im-portant. As such, this thesis helps to make order regarding the specific demands made on the players' physiological energy systems – especially the alactic anaerobic system – and the role they play during a basketball game, as well as the specific patterns of movements. Despite the fact that much of the information in this review thesis is familiar to coaches and trainers, highlighting the specific needs of basketball may help them to choose the most suitable tools, and may also shed light on new directions for developing basket-ball-specific assessment tests.

7.2. SPECIFIC CONCLUSIONS

Regarding study 1, the game of basketball is unique as it requires lower limb explosive power combined with high coordination capabilities. Professional basketball teams of all ages are committed to a tight and strenuous schedule. As a result, trainers and coaches may encounter difficulties in assessing the players' physical abilities, especially during the game's season[2, 11, 93, 146, 158, 159]. In addition, although a number of validated tests assess explosive power and players of ball games, none are specifically suited to the game of basketball, thereby making the assessment task more difficult[2].

The novel test that we developed, which is specific for the game of basketball, could provide trainers and coaches with a unique and applicable field tool for assessing players' lower limb explosive power – especially during congasted schedules[93]. Doing so will save time, as only the one test will be needed, rather than having to employ a range of tests[2, 20, 153]. In addition to saving resources, using this novel test could enhance results, assessments, and comparisons as it is suited to the game of basketball with its unique and specific movements. Moreover, as the new test is performed on one leg, it can be used to assess players' dominant and non-dominant leg individually – offering insights into symmetry and differences between both legs, as well as the ability to return to playing after an injury. As such, the test could also be helpful for strength and conditioning coaches and physiotherapists.

It is important to note that the standardized tests that assess explosive power, as presented in this study, remain relevant and important – and may offer additional insights and conclusions. However, when seeking a more focused and specific test for the game of basketball, the unique test presented in this article offers added value to the field of basketball and its assessments.

In conclusion of study 2, our research sheds light on the differences in performance on a novel specific jumping test among young basketball players, with age, gender, and playing position all affecting results. Our findings highlight the importance of including sport-unique specific tests in talent identification and selection processes, as these tests can provide valuable information about a players skill set and potential for success in the sport and basketball in particular. Furthermore, coaches and trainers should consider these factors when designing training programs to improve jumping ability, as individualized approaches may be necessary for optimal development. Future research should continue to explore the effects of other factors, such as training history and physical fitness, on performance regarding specific jumping tests in young basketball players. Ultimately, a better understanding of the unique characteristics of young basketball players can help optimize their athletic development and enhance their potential to success.

VIII – LIMITATIONS AND FUTURE WORK

VIII - LIMITATIONS AND FUTURE WORK

There were some limitations in the presented studies, which may affect the interpretation of the reported results.

Regarding study 1, the current study has important value for research and assessments in sports in general, and in basketball in particular. However, the research does entail a number of limitations. First, the participants only included male basketball players from an elite youth league team in Israel. As such, future studies could benefit from employing the test on a more varied sample, to include a larger range of positions and ages, as well as both male and female players. In addition, it would be interesting to examine the new test for jumps using both legs, such as penetration to the basket, as well as assessing the test on non-professional basketball players who have not been trained to develop the necessary coordination and control.

In study 2, although its practical and theoretical contributions to the field, this study has some limitation that should be addressed. This study was initially conducted during the competition season when the players were at their peak fitness, therefore the findings may be less relevant to other periods. Additionally, the study was conducted only on young basketball players, and it is important to verify the data presented in this study on adult players, particularly regarding game positions. It would also be interesting to examine the impact of the new and unique test on non-professional basketball players, as this test only examined professional basketball players.

IX – BIBLIOGRAPHICAL REFERENCES

IX - BIBLIOGRAPHICAL REFERENCES

1. Gottlieb R, Eliakim A, Shalom A, Iacono A, Meckel Y. Improving Anaerobic Fitness in Young Basketball Players: Plyometric vs. Specific Sprint Training. Journal of Athletic Enhancementer. 2014;03.

2. Gottlieb R, Shalom A, Calleja-Gonzalez J. Physiology of Basketball – Field Tests. Review Article. J Hum Kinet. 2021;77:159–67.

3. Abdelkrim N, El Fazaa S, El Ati J, Tabka Z. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition * Commentary. Br J Sports Med. 2007;41:69–75.

4. Stojanović E, Stojiljković N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanović Z. The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. Sports Medicine. 2018;48:111–35.

5. Delextrat A, Cohen D. Physiological Testing of Basketball Players: Toward a Standard Evaluation of Anaerobic Fitness. J Strength Cond Res. 2008;22:1066–72.

6. Burke EJ. Physiological considerations and suggestions for the training of elite basketball players. In: Toward an Understanding of Human Performance. Ithaca, NY: Movement; 1980.

7. Fox EL, Mathews DK. The Physiological Basis of Physical Education and Athletics. Philadelphia: WB Saunders; 1996.

8. Aksović N, Bjelica B, Milanović F, Milanovic L, Jovanović N. Development of Explosive Power in Basketball Players. Turkish Journal of Kinesiology. 2021. https://doi.org/10.31459/turkjkin.861920.

9. Stojanovic MD, Ostojic SM, Calleja-González J, Milosevic Z, Mikic M. Correlation between explosive strength, aerobic power and repeated sprint ability in elite basketball players. J Sports Med Phys Fitness. 2012;52:375–81.

10. Mancha-Triguero D, García-Rubio J, Antúnez A, Ibáñez SJ. Physical and Physiological Profiles of Aerobic and Anaerobic Capacities in Young Basketball Players. Int J Environ Res Public Health. 2020;17:1409.

11. Edwards T, Spiteri T, Piggott B, Bonhotal J, Haff GG, Joyce C. Monitoring and Managing Fatigue in Basketball. Sports (Basel). 2018;6.

12. Apostolidis N, Nassis GP, Bolatoglou T, Geladas ND. Physiological and technical characteristics of elite young basketball players. J Sports Med Phys Fitness. 2004;44:157–63.

13. Alemdaroğlu U. The Relationship Between Muscle Strength, Anaerobic Performance, Agility, Sprint Ability and Vertical Jump Performance in Professional Basketball Players. J Hum Kinet. 2012;31:149–58.

14. Balčiūnas M, Stonkus S, Abrantes C, Sampaio J. Long term effects of different training modalities on power, speed, skill and anaerobic capacity in young male basketball players. J Sports Sci Med. 2006;5:163–70.

15. McInnes SE, Carlson JS, Jones CJ, McKenna MJ. The physiological load imposed on basketball players during competition. J Sports Sci. 1995;13:387–97.

16. Sheppard JM, Young WB. Agility literature review: Classifications, training and testing. J Sports Sci. 2006;24:919–32.

17. Schwesig R, Hermassi S, Lauenroth A, Laudner K, Koke A, Bartels T, et al. Validity of a basketball-specific complex test in female professional players. Sportverletzung · Sportschaden. 2018;32:125–33.

18. Shalfawi SAI, Sabbah A, Kailani G, Tønnessen E, Enoksen E. The relationship between running speed and measures of vertical jump in professional basketball players: a field-test approach. J Strength Cond Res. 2011;25:3088–92.

19. Mancha-Triguero D, García-Rubio J, Calleja-González J, Ibáñez SJ. Physical fitness in basketball players: a systematic review. J Sports Med Phys Fitness. 2019;59:1513–25.

20. Gottlieb R, Shalom A, Alcaraz PE, Calleja-González J. Validity and reliability of a unique aerobic field test for estimating VO2max among basketball players. Scientific Journal of Sport and Performance. 2022;1:112–23.

21. Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, Ati J El. Activity Profile and Physiological Requirements of Junior Elite Basketball Players in Relation to Aerobic-Anaerobic Fitness. J Strength Cond Res. 2010;24:2330–42.

22. Vaquera A, Mielgo-Ayuso J, Calleja-González J, Leicht AS. Match intensity and heart rate predictors in top level basketball referees during men's Eurobasket. J Sports Med Phys Fitness. 2016;56:1034–40.

23. Scanlan AT, Wen N, Spiteri T, Milanović Z, Conte D, Guy JH, et al. Dribble Deficit: A novel method to measure dribbling speed independent of sprinting speed in basketball players. J Sports Sci. 2018;36:2596–602.

24. Santos FG dos, Pacheco MM, Basso L, Bastos FH, Tani G. Development and Validation of a Checklist to Assess Proficient Performance of Basketball Straight Speed Dribbling Skill. J Hum Kinet. 2020;71:21–31.

25. Drinkwater EJ, Pyne DB, McKenna MJ. Design and Interpretation of Anthropometric and Fitness Testing of Basketball Players. Sports Medicine. 2008;38:565–78.

26. Gál-Pottyondy A, Petró B, Czétényi A, Négyesi J, Nagatomi R, Kiss RM. Collection and Advice on Basketball Field Tests—A Literature Review. Applied Sciences. 2021;11:8855.

27. Ziv G, Lidor R. Vertical jump in female and male basketball players—A review of observational and experimental studies. J Sci Med Sport. 2010;13:332–9.

28. Arede J, Vaz R, Franceschi A, Gonzalo-Skok O, Leite N. Effects of a combined strength and conditioning training program on physical abilities in adolescent male basketball players. J Sports Med Phys Fitness. 2019;59.

29. Ciacci S, Bartolomei S. The effects of two different explosive strength training programs on vertical jump performance in basketball. J Sports Med Phys Fitness. 2018;58.

30. Fox E, Bowers R, Foss M. The Physiological Basis of Physical Education and Athletics . Philadelphia: WB Saunders; 1988.

31. Gillam GM. Basketball energetics: physiological basis. Nat Strength Cond Assoc. J 6; 1985.

32. Hoare DG. Predicting success in junior elite basketball players--the contribution of anthropometic and physiological attributes. J Sci Med Sport. 2000;3:391–405.

33. Ostojic SM, Mazic S, Dikic N. Profiling in Basketball: Physical and Physiological Characteristics of Elite Players. The Journal of Strength and Conditioning Research. 2006;20:740.

34. Wen N, Dalbo VJ, Burgos B, Pyne DB, Scanlan AT. Power Testing in Basketball: Current Practice and Future Recommendations. J Strength Cond Res. 2018;32:2677–91.

35. Boone J, Bourgois J. Morphological and Physiological Profile of Elite Basketball Players in Belgium. Int J Sports Physiol Perform. 2013;8:630–8.

36. Kraska JM, Ramsey MW, Haff GG, Fethke N, Sands WA, Stone ME, et al. Relationship Between Strength Characteristics and Unweighted and Weighted Vertical Jump Height. Int J Sports Physiol Perform. 2009;4:461–73.

37. Kipp K, Krzyszkowski J, Smith T, Geiser C, Kim H. Comparison of Countermovement and Preferred-Style Jump Biomechanics in Male Basketball Players. Applied Sciences. 2021;11:6092.

38. Vescovi JD, Mcguigan MR. Relationships between sprinting, agility, and jump ability in female athletes. J Sports Sci. 2008;26:97–107.

39. Young WB, McDowell MH, Scarlett BJ. Specificity of sprint and agility training methods. J Strength Cond Res. 2001;15:315–9.

40. Raya MA, Gailey RS, Gaunaurd IA, Jayne DM, Campbell SM, Gagne E, et al. Comparison of three agility tests with male servicemembers: Edgren Side Step Test, T-Test, and Illinois Agility Test. J Rehabil Res Dev. 2013;50:951–60.

41. Ivanović J, Kukić F, Greco G, Koropanovski N, Jakovljević S, Dopsaj M. Specific Physical Ability Prediction in Youth Basketball Players According to Playing Position. Int J Environ Res Public Health. 2022;19:977.

42. Kipp K, Kiely M, Giordanelli M, Malloy P, Geiser C. Joint- and subject-specific strategies in male basketball players across a range of countermovement jump heights. J Sports Sci. 2020;38:652–7.

43. Battaglia G, Paoli A, Bellafiore M, Bianco A, Palma A. Influence of a sport-specific training background on vertical jumping and throwing performance in young female basketball and volleyball players. J Sports Med Phys Fitness. 2014;54:581–7.

44. Mancha-Triguero D, García-Rubio J, Gamonales JM, Ibáñez SJ. Strength and Speed Profiles Based on Age and Sex Differences in Young Basketball Players. Int J Environ Res Public Health. 2021;18:643.

45. Ferioli D, Rampinini E, Bosio A, La Torre A, Azzolini M, Coutts AJ. The physical profile of adult male basketball players: Differences between competitive levels and playing positions. J Sports Sci. 2018;36:2567–74.

46. Lucia S, Aydin M, Di Russo F. Sex Differences in Cognitive-Motor Dual-Task Training Effects and in Brain Processing of Semi-Elite Basketball Players. Brain Sci. 2023;13:443.

47. Thomas C, Kyriakidou I, Dos'Santos T, Jones P. Differences in Vertical Jump Force-Time Characteristics between Stronger and Weaker Adolescent Basketball Players. Sports. 2017;5:63.

48. Trninić S, Marković G, Heimer S. Effects of developmental training of basketball cadets realised in the competitive period. Coll Antropol. 2001;25:591–604.

49. Hinkle AJ, Brown SM, Mulcahey MK. Gender disparity among NBA and WNBA team physicians. Phys Sportsmed. 2021;49:219–22.

50. Anton MM, Spirduso WW, Tanaka H. Age-Related Declines in Anaerobic Muscular Performance: Weightlifting and Powerlifting. Med Sci Sports Exerc. 2004;36:143–7.

51. Sartorio A, Agosti F, De Col A, Lafortuna CL. Age-and gender-related variations of leg power output and body composition in severely obese children and adolescents. J Endocrinol Invest. 2006;29:48–54.

52. Jakovljevic ST, Karalejic MS, Pajic ZB, Macura MM, Erculj FF. Speed and Agility of 12- and 14-Year-Old Elite Male Basketball Players. J Strength Cond Res. 2012;26:2453–9.

53. Nikolaidis Pantelis T. Relationship of body mass status with running and jumping performances in young basketball players. Muscles Ligaments Tendons J. 2015. https://doi.org/10.11138/mltj/2015.5.3.187.

54. Ponce-González JG, Olmedillas H, Calleja-González J, Guerra B, Sanchis-Moysi J. Physical fitness, adiposity and testosterone concentrations are associated to playing position in professional basketballers. Nutr Hosp. 2015;31:2624–32.

55. Cañadas M, Gómez M-Á, García-Rubio J, Ibáñez SJ. Analysis of Training Plans in Basketball: Gender and Formation Stage Differences. J Hum Kinet. 2018;62:123–34.

56. Garcia-Gil M, Torres-Unda J, Esain I, Duñabeitia I, Gil SM, Gil J, et al. Anthropometric Parameters, Age, and Agility as Performance Predictors in Elite Female Basketball Players. J Strength Cond Res. 2018;32:1723–30.

57. Buchanan PA, Vardaxis VG. Lower-Extremity Strength Profiles and Gender-Based Classification of Basketball Players Ages 9-22 Years. J Strength Cond Res. 2009;23:406–19.

58. Haizlip KM, Harrison BC, Leinwand LA. Sex-Based Differences in Skeletal Muscle Kinetics and Fiber-Type Composition. Physiology. 2015;30:30–9.

59. Oh S-L, Yoon SH, Lim J-Y. Age- and sex-related differences in myosin heavy chain isoforms and muscle strength, function, and quality: a cross sectional study. J Exerc Nutrition Biochem. 2018;22:43–50.

60. Wu R, Delahunt E, Ditroilo M, Lowery M, De Vito G. Effects of age and sex on neuromuscular-mechanical determinants of muscle strength. Age (Omaha). 2016;38:57.

61. Mihalik JP, Libby JJ, Battaglini CL, McMurray RG. Comparing Short-Term Complex and Compound Training Programs on Vertical Jump Height and Power Output. J Strength Cond Res. 2008;22:47–53.

62. Vaquera A, Mielgo-Ayuso J, Calleja-González J, Leicht AS. Sex differences in cardiovascular demands of refereeing during international basketball competition. Phys Sportsmed. 2016;44:164–9.

63. Brini S, Boullosa D, Calleja-González J, Ramirez-Campillo R, Nobari H, Castagna C, et al. Neuromuscular and balance adaptations following basketball-specific training programs based on combined drop jump and multidirectional repeated sprint versus multidirectional plyometric training. PLoS One. 2023;18:e0283026.

64. Santos EJ, Janeira MA. The Effects of Plyometric Training Followed by Detraining and Reduced Training Periods on Explosive Strength in Adolescent Male Basketball Players. J Strength Cond Res. 2011;25:441–52.

65. Santos EJAM, Janeira MAAS. Effects of Complex Training on Explosive Strength in Adolescent Male Basketball Players. J Strength Cond Res. 2008;22:903–9.

66. Santos EJAM, Janeira MAAS. The Effects of Resistance Training on Explosive Strength Indicators in Adolescent Basketball Players. J Strength Cond Res. 2012;26:2641–7.

67. Scanlan AT, Dascombe BJ, Kidcaff AP, Peucker JL, Dalbo VJ. Gender-Specific Activity Demands Experienced During Semiprofessional Basketball Game Play. Int J Sports Physiol Perform. 2015;10:618–25.

68. Spiteri T, Binetti M, Scanlan AT, Dalbo VJ, Dolci F, Specos C. Physical Determinants of Division 1 Collegiate Basketball, Women's National Basketball League, and Women's National Basketball Association Athletes: With Reference to Lower-Body Sidedness. J Strength Cond Res. 2019;33:159–66.

69. Ferioli D, Conte D, Rucco D, Alcaraz PE, Vaquera A, Romagnoli M, et al. Physical Demands of Elite Male and Female 3 × 3 International Basketball Matches. J Strength Cond Res. 2023;37:e289–96.

70. Espasa-Labrador J, Fort-Vanmeerhaeghe A, Montalvo AM, Carrasco-Marginet M, Irurtia A, Calleja-González J. Monitoring Internal Load in Women's Basketball via Subjective and Device-Based Methods: A Systematic Review. Sensors. 2023;23:4447.

71. Ziv G, Lidor R. Physical Attributes, Physiological Characteristics, On-Court Performances and Nutritional Strategies of Female and Male Basketball Players. Sports Medicine. 2009;39:547–68.

72. Allen AN, Wasserman EB, Williams RM, Simon JE, Dompier TP, Kerr ZY, et al. Epidemiology of Secondary School Boys' and Girls' Basketball Injuries: National Athletic Treatment, Injury and Outcomes Network. J Athl Train. 2019;54:1179–86.

73. Gómez-Carmona CD, Feu S, Pino-Ortega J, Ibáñez SJ. Assessment of the Multi-Location External Workload Profile in the Most Common Movements in Basketball. Sensors. 2021;21:3441.

74. Ferioli D, Schelling X, Bosio A, La Torre A, Rucco D, Rampinini E. Match Activities in Basketball Games: Comparison Between Different Competitive Levels. J Strength Cond Res. 2020;34:172–82.

75. Cormery B, Marcil M, Bouvard M. Rule change incidence on physiological characteristics of elite basketball players: a 10-year-period investigation. Br J Sports Med. 2007;42:25–30.

76. Portes R, Navarro Barragán RM, Calleja-González J, Gómez-Ruano MÁ, Jiménez Sáiz SL. Physical Persistency across Game Quarters and during Consecutive Games in Elite Junior Basketball Players. Int J Environ Res Public Health. 2022;19:5658.

77. Ferioli D, Rampinini E, Martin M, Rucco D, la Torre A, Petway A, et al. Influence of ball possession and playing position on the physical demands encountered during professional basketball games. Biol Sport. 2020;37:269–76.

78. Freitas TT, Alcaraz PE, Bishop C, Calleja-González J, Arruda AFS, Guerriero A, et al. Change of Direction Deficit in National Team Rugby Union Players: Is There an Influence of Playing Position? Sports (Basel). 2018;7.

79. Pehar M, Sekulic D, Sisic N, Spasic M, Uljevic O, Krolo A, et al. Evaluation of different jumping tests in defining position-specific and performance-level differences in high level basketball players. Biol Sport. 2017;3:263–72.

80. Sekulic D, Pehar M, Krolo A, Spasic M, Uljevic O, Calleja-González J, et al. Evaluation of Basketball-Specific Agility: Applicability of Preplanned and Nonplanned Agility Performances for Differentiating Playing Positions and Playing Levels. J Strength Cond Res. 2017;31:2278–88.

81. Köklü Y, Alemdaroğlu U, Koçak F, Erol A, Fındıkoğlu G. Comparison of Chosen Physical Fitness Characteristics of Turkish Professional Basketball Players by Division and Playing Position. J Hum Kinet. 2011;30:99–106.

82. Svilar L, Castellano J, Jukic I, Casamichana D. Positional Differences in Elite Basketball: Selecting Appropriate Training-Load Measures. Int J Sports Physiol Perform. 2018;13:947–52.

83. Ben Abdelkrim N, Chaouachi A, Chamari K, Chtara M, Castagna C. Positional Role and Competitive-Level Differences in Elite-Level Men's Basketball Players. J Strength Cond Res. 2010;24:1346–55.

84. Reina Román M, García-Rubio J, Feu S, Ibáñez SJ. Training and Competition Load Monitoring and Analysis of Women's Amateur Basketball by Playing Position: Approach Study. Front Psychol. 2019;9.

85. Štrumbelj B, Vučković G, Jakovljević S, Milanović Z, James N, Erčulj F. Graded Shuttle Run Performance by Playing Positions in Elite Female Basketball. J Strength Cond Res. 2015;29:793–9.

86. Sekulic D, Pehar M, Krolo A, Spasic M, Uljevic O, Calleja-González J, et al. Evaluation of Basketball-Specific Agility: Applicability of Preplanned and Nonplanned Agility Performances for Differentiating Playing Positions and Playing Levels. J Strength Cond Res. 2017;31:2278–88.

87. Delextrat A, Cohen D. Strength, Power, Speed, and Agility of Women Basketball Players According to Playing Position. J Strength Cond Res. 2009;23:1974–81.

88. Calleja González J, Mielgo Ayuso J, Lekue JA, Leibar X, Erauzkin J, Jukic I, et al. Anthropometry and performance of top youth international male basketball players in Spanish national academy. Nutr Hosp. 2018;35:1331.

89. Wragg CB, Maxwell NS, Doust JH. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. Eur J Appl Physiol. 2000;83:77–83.

90. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and Factorial Validity of Squat and Countermovement Jump Tests. The Journal of Strength and Conditioning Research. 2004;18:551.

91. García-López J, Peleteiro J, Rodgríguez-Marroyo JA, Morante JC, Herrero JA, Villa JG. The validation of a new method that measures contact and flight times during vertical jump. Int J Sports Med. 2005;26:294–302.

92. Bosco C, Luhtanen P, Komi P V. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol. 1983;50:273–82.

93. Huyghe T, Scanlan A, Dalbo V, Calleja-González J. The Negative Influence of Air Travel on Health and Performance in the National Basketball Association: A Narrative Review. Sports. 2018;6:89.

94. Meckel Y, Machnai O, Eliakim A. Relationship Among Repeated Sprint Tests, Aerobic Fitness, and Anaerobic Fitness in Elite Adolescent Soccer Players. J Strength Cond Res. 2009;23:163–9.

95. Mujika I, Santisteban J, Castagna C. In-season effect of short-term sprint and power training programs on elite junior soccer players. J Strength Cond Res. 2009;23:2581–7.

96. Haugen TA, Breitschädel F, Seiler S. Sprint Mechanical Properties in Handball and Basketball Players. Int J Sports Physiol Perform. 2019;14:1388–94.

97. Loturco I, D'Angelo RA, Fernandes V, Gil S, Kobal R, Cal Abad CC, et al. Relationship Between Sprint Ability and Loaded/Unloaded Jump Tests in Elite Sprinters. J Strength Cond Res. 2015;29:758–64.

98. van den Tillaar R. Comparison of Step-by-Step Kinematics of Elite Sprinters' Unresisted and Resisted 10-m Sprints Measured With Optojump or Musclelab. J Strength Cond Res. 2021;35:1419–24.

99. Hardy LL, Merom D, Thomas M, Peralta L. 30-year changes in Australian children's standing broad jump: 1985–2015. J Sci Med Sport. 2018;21:1057–61.

100. Tai W-H, Tang R-H, Huang C-F, Lo S-L, Sung Y-C, Peng H-T. Acute Effects of Handheld Loading on Standing Broad Jump in Youth Athletes. Int J Environ Res Public Health. 2021;18:5046.

101. Glencross DJ. The nature of the vertical jump test and the standing broad jump. Res Q. 1966;37:353–9.

102. Thomas E, Petrigna L, Tabacchi G, Teixeira E, Pajaujiene S, Sturm DJ, et al. Percentile values of the standing broad jump in children and adolescents aged 6-18 years old. Eur J Transl Myol. 2020;30:9050.

103. Krishnan A, Sharma D, Bhatt M, Dixit A, Pradeep P. Comparison between Standing Broad Jump test and Wingate test for assessing lower limb anaerobic power in elite sportsmen. Med J Armed Forces India. 2017;73:140–5.

104. Pedley JS, Lloyd RS, Read P, Moore IS, Oliver JL. Drop Jump: A Technical Model for Scientific Application. Strength Cond J. 2017;39:36–44.

105. Markwick WJ, Bird SP, Tufano JJ, Seitz LB, Haff GG. The Intraday Reliability of the Reactive Strength Index Calculated From a Drop Jump in Professional Men's Basketball. Int J Sports Physiol Perform. 2015;10:482–8.

106. Laffaye G, Bardy B, Taiar R. Upper-limb motion and drop jump: effect of expertise. J Sports Med Phys Fitness. 2006;46:238–47.

107. Baca A. A comparison of methods for analyzing drop jump performance. Med Sci Sports Exerc. 1999;31:437–42.

108. Brini S, Boullosa D, Calleja-González J, van den Hoek DJ, Nobari H, Clemente FM. Impact of combined versus single-mode training programs based on drop jump and specific multidirectional repeated sprint on bio-motor ability adaptations: a parallel study design in professional basketball players. BMC Sports Sci Med Rehabil. 2022;14:160.

109. Sayers M. Does the 5-0-5 test measure change of direction speed? J Sci Med Sport. 2014;18:e60.

110. Scanlan AT, Madueno MC, Guy JH, Giamarelos K, Spiteri T, Dalbo VJ. Measuring Decrement in Change-of-Direction Speed Across Repeated Sprints in Basketball: Novel vs. Traditional Approaches. J Strength Cond Res. 2021;35:841–5.

111. Banda DS, Beitzel MM, Kammerer JD, Salazar I, Lockie RG. Lower-Body Power Relationships to Linear Speed, Change-of-Direction Speed, and High-Intensity Running Performance in DI Collegiate Women's Basketball Players. J Hum Kinet. 2019;68:223–32.

112. Barker LA, Harry JR, Mercer JA. Relationships Between Countermovement Jump Ground Reaction Forces and Jump Height, Reactive Strength Index, and Jump Time. J Strength Cond Res. 2018;32:248–54.

113. Claudino JG, Cronin J, Mezêncio B, McMaster DT, McGuigan M, Tricoli V, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. J Sci Med Sport. 2017;20:397–402.

114. Claudino JG, Cronin J, Mezêncio B, McMaster DT, McGuigan M, Tricoli V, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. J Sci Med Sport. 2017;20:397–402.

115. Mandic R, Knezevic OM, Mirkov DM, Jaric S. Control strategy of maximum vertical jumps: The preferred countermovement depth may not be fully optimized for jump height. J Hum Kinet. 2016;52:85–94.

116. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA. Validity and Reliability of Optojump Photoelectric Cells for Estimating Vertical Jump Height. J Strength Cond Res. 2011;25:556–60.

117. López-Segovia M, Marques M, van den Tillaar R, González-Badillo J. Relationships Between Vertical Jump and Full Squat Power Outputs With Sprint Times in U21 Soccer Players. J Hum Kinet. 2011;30:135–44.

118. Chu DA. Jumping into plyometrics. Human Kinetics, Champaign, IL. 1998.

119. Ramirez-Campillo R, García-Hermoso A, Moran J, Chaabene H, Negra Y, Scanlan AT. The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. J Sport Health Sci. 2022;11:656–70.

120. Sheppard JM, Cronin JB, Gabbett TJ, McGuigan MR, Etxebarria N, Newton RU. Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. J Strength Cond Res. 2008;22:758–65.

121. Pehar M, Sekulic D, Sisic N, Spasic M, Uljevic O, Krolo A, et al. Evaluation of different jumping tests in defining position-specific and performance-level differences in high level basketball players. Biol Sport. 2017;3:263–72.

122. Attia A, Dhahbi W, Chaouachi A, Padulo J, Wong D, Chamari K. Measurement errors when estimating the vertical jump height with flight time using photocell devices: the example of Optojump. Biol Sport. 2017;1:63–70.

123. Healy R, Kenny IC, Harrison AJ. Assessing Reactive Strength Measures in Jumping and Hopping Using the Optojump™ System. J Hum Kinet. 2016;54:23–32.

124. Karcher C, Buchheit M. Shooting Performance and Fly Time in Highly Trained Wing Handball Players: Not Everything Is as It Seems. Int J Sports Physiol Perform. 2017;12:322–8.

125. Alsalaheen BA, Haines J, Yorke A, Stockdale K, P. Broglio S. Reliability and concurrent validity of instrumented balance error scoring system using a portable force plate system. Phys Sportsmed. 2015;43:221–6.

126. Bellicha A, Giroux C, Ciangura C, Menoux D, Thoumie P, Oppert J-M, et al. Vertical Jump on a Force Plate for Assessing Muscle Strength and Power in Women With Severe Obesity: Reliability, Validity, and Relations With Body Composition. J Strength Cond Res. 2022;36:75–81.

127. Bellicha A, Giroux C, Ciangura C, Menoux D, Thoumie P, Oppert J-M, et al. Vertical Jump on a Force Plate for Assessing Muscle Strength and Power in Women With Severe Obesity: Reliability, Validity, and Relations With Body Composition. J Strength Cond Res. 2022;36:75–81.

128. Condello G, Khemtong C, Lee Y-H, Chen C-H, Mandorino M, Santoro E, et al. Validity and Reliability of a Photoelectric Cells System for the Evaluation of Change of Direction and Lateral Jumping Abilities in Collegiate Basketball Athletes. J Funct Morphol Kinesiol. 2020;5:55.

129. Haynes T, Bishop C, Antrobus M, Brazier J. The validity and reliability of the My Jump 2 app for measuring the reactive strength index and drop jump performance. J Sports Med Phys Fitness. 2019;59.

130. Bogataj Š, Pajek M, Hadžić V, Andrašić S, Padulo J, Trajković N. Validity, Reliability, and Usefulness of My Jump 2 App for Measuring Vertical Jump in Primary School Children. Int J Environ Res Public Health. 2020;17:3708.

131. Barbalho M, Kleiner AFR, Callegari B, de Lima RC, da Silva Souza G, de Athayde Costa e Silva A, et al. Assessing Interlimb Jump Asymmetry in Young Soccer Players: The My Jump 2 App. Int J Sports Physiol Perform. 2021;16:19–27.

132. Gallardo-Fuentes F, Gallardo-Fuentes J, Ramírez-Campillo R, Balsalobre-Fernández C, Martínez C, Caniuqueo A, et al. Intersession and Intrasession Reliability and Validity of the My Jump App for Measuring Different Jump Actions in Trained Male and Female Athletes. J Strength Cond Res. 2016;30:2049–56.

133. Bogataj Š, Pajek M, Hadžić V, Andrašić S, Padulo J, Trajković N. Validity, Reliability, and Usefulness of My Jump 2 App for Measuring Vertical Jump in Primary School Children. Int J Environ Res Public Health. 2020;17:3708.

134. Chaouachi A, Brughelli M, Chamari K, Levin GT, Abdelkrim N ben, Laurencelle L, et al. Lower Limb Maximal Dynamic Strength and Agility Determinants in Elite Basketball Players. J Strength Cond Res. 2009;23:1570–7.

135. Ochoa-Lácar J, Singh M, Bird SP, Charest J, Huyghe T, Calleja-González J. How Sleep Affects Recovery and Performance in Basketball: A Systematic Review. Brain Sci. 2022;12:1570.

136. Escribano-Ott I, Calleja-González J, Mielgo-Ayuso J. Ergo-Nutritional Intervention in Basketball: A Systematic Review. Nutrients. 2022;14:638.

137. Fragoso I, Ramos S, Teles J, Volossovitch A, Ferreira AP, Massuça LM. The Study of Maturational Timing Effect in Elite Portuguese Adolescent Basketball Players: Anthropometric, Functional and Game Performance Implications. Applied Sciences. 2021;11:9894.

138. World Medical Association Declaration of Helsinki. JAMA. 2013;310:2191.

139. Narazaki K, Berg K, Stergiou N, Chen B. Physiological demands of competitive basketball. Scand J Med Sci Sports. 2009;19:425–32.

140. Freitas TT, Martinez-Rodriguez A, Calleja-González J, Alcaraz PE. Short-term adaptations following Complex Training in team-sports: A meta-analysis. PLoS One. 2017;12:e0180223.

141. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol. 1988;60:709–23.

142. Giavarina D. Understanding Bland Altman analysis. Biochem Med (Zagreb). 2015;25:141–51.

143. Hopkins WG. Measures of Reliability in Sports Medicine and Science. Sports Medicine. 2000;30:1–15.

144. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. Med Sci Sports Exerc. 2009;41:3–12.

145. Spencer M, Bishop D, Dawson B, Goodman C. Physiological and metabolic responses of repeated-sprint activities:specific to field-based team sports. Sports Med. 2005;35:1025–44.

146. Davis JK, Oikawa SY, Halson S, Stephens J, O'Riordan S, Luhrs K, et al. In-Season Nutrition Strategies and Recovery Modalities to Enhance Recovery for Basketball Players: A Narrative Review. Sports Medicine. 2022;52:971–93.

147. Calleja-González J, Mielgo-Ayuso J, Lekue JA, Leibar X, Erauzkin J, Jukic I, et al. The Spanish "Century XXI" academy for developing elite level basketballers: design, monitoring and training methodologies. Phys Sportsmed. 2016;44:148–57.

148. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, Nosaka K. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? J Strength Cond Res. 2008;22:412–8.

149. Meylan C, McMaster T, Cronin J, Mohammad NI, Rogers C, deKlerk M. Single-Leg Lateral, Horizontal, and Vertical Jump Assessment: Reliability, Interrelationships, and Ability to Predict Sprint and Change-of-Direction Performance. J Strength Cond Res. 2009;23:1140–7.

150. DiFiori JP, Güllich A, Brenner JS, Côté J, Hainline B, Ryan E, et al. The NBA and Youth Basketball: Recommendations for Promoting a Healthy and Positive Experience. Sports Med. 2018;48:2053–65.

151. Ramirez-Campillo R, Garcia-Hermoso A, Moran J, Chaabene H, Negra Y, Scanlan AT. The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. J Sport Health Sci. 2020. https://doi.org/10.1016/j.jshs.2020.12.005.

152. Bird SP, Markwick WJ. Musculoskeletal screening and functional testing: considerations for basketball athletes. Int J Sports Phys Ther. 2016;11:784–802.

153. Rodríguez-Rosell D, Mora-Custodio R, Franco-Márquez F, Yáñez-García JM, González-Badillo JJ. Traditional vs. Sport-Specific Vertical Jump Tests: Reliability, Validity, and Relationship With the Legs Strength and Sprint Performance in Adult and Teen Soccer and Basketball Players. J Strength Cond Res. 2017;31:196–206.

154. Petway AJ, Freitas TT, Calleja-González J, Medina Leal D, Alcaraz PE. Training load and match-play demands in basketball based on competition level: A systematic review. PLoS One. 2020;15:e0229212.

155. Shalom A, Gottlieb R, Alcaraz PE, Calleja-Gonzalez J. A Unique Specific Jumping Test for Measuring Explosive Power in Basketball Players: Validity and Reliability. Applied Sciences. 2023;13:7567.

156. Ramos S, Volossovitch A, Ferreira AP, Fragoso I, Massuça L. Differences in maturity, morphological and physical attributes between players selected to the primary and secondary teams of a Portuguese Basketball elite academy. J Sports Sci. 2019;37:1681–9.

157. Brini S, Boullosa D, Calleja-González J, Delextrat A. Construct Validity and Reliability of a New Basketball Multidirectional Reactive Repeated Sprint Test. Int J Environ Res Public Health. 2021;18:10695.

158. Huyghe T, Alcaraz PE, Calleja-González J, Bird SP. The underpinning factors of NBA game-play performance: a systematic review (2001–2020). Phys Sportsmed. 2022;50:94–122.

159. Delextrat A, Trochym E, Calleja-González J. Effect of a typical in-season week on strength jump and sprint performances in national-level female basketball players. J Sports Med Phys Fitness. 2012;52:128–36.

X – APPENDIXES

X - APPENDIXES

APPENDIX 1. Published Scientific Article (Review Article)

Reference:

Gottlieb R, Shalom A, Calleja-Gonzalez J. Physiology of Basketball – Field Tests. Review Article. J Hum Kinet. 2021;77:159–67.

-This paper is an important part of writing the introduction of the research proposal and also of the introduction of this thesis project.

Journal of Human Kinetics volume 77/2021, 159-167 DOI: 10.2478/hukin-2021-0018 159
Section III – Sports Training

sciendo

Physiology of Basketball – Field Tests. Review Article

by
Roni Gottlieb[1], Asaf Shalom[2], Julio Calleja-Gonzalez[3]

The game of basketball is characterized by short and intense bouts of activity at medium to high frequency. Basketball entails specific types of movements, physiological requirements and energy sources. The duration of physiological responses involving ATP, CP and glycolysis responses to this type of activity is 5-6 seconds for a single sprint, and a contribution of the aerobic system is of less than 10%. Recovery periods in basketball, as a rule, are not long enough to fill the gap for such high intensity activities. It is hard to achieve the same level of performance consistently over time in repeated sprints. This means that basketball players need great athletic ability in order to demonstrate speed, strength and power required to produce a successful performance most proficiently. Therefore, tests are needed to help coaches to monitor their players and ensure that they have the physiological capacity required for the game. The aim of fitness tests is to assess the condition of athletes in terms of each fitness component, in order to determine what needs to be improved through the training program and to conduct retests at set times to assess whether their condition has changed. The literature offers a number of widely used tests to measure aerobic and anaerobic fitness. This article reviews the physiological demands of basketball and analyzes the field tests commonly used at present. The article emphasizes the need for a specific test that will serve coaches and physical fitness trainers in monitoring their players.

***Key words**: aerobic, anaerobic, explosive.*

Introduction

The game of basketball is characterized by short and intense bouts of activity at medium to high frequency (Meckel and Gottlieb, 2009; Meckel et al., 2009). Such activity requires aerobic and anaerobic capabilities, both of which impact anaerobic performance (Gottlieb et al., 2014). The ability to continuously perform intermittent high-intensity actions throughout the game is crucial for basketball players (Ben Abdelkrim et al., 2007). Thus, higher aerobic capacity has been found to be essential for basketball players' performance in games and in practice (Castagna et al., 2008), in order to recover faster.

Basketball includes high-intensity movements lasting less than 6 s and moderate-intensity exercise of up to 60 s (Stolen et al., 2005). The duration of physiological responses involving ATP, CP and glycolysis responses to this type of activity is 5-6 s for a single sprint, and a contribution of the aerobic system is of less than 10%. During recovery from intense activity, when CP must be replenished, blood lactate concentration is used as a source of energy and phosphates accumulated in the cells are removed (Wragg et al., 2000). For example, in basketball short recovery periods do not last long enough to fill the gap for such high-intensity activities. The ability of basketball players to continue to play well over time depends on rebuilding CP storage and removing waste products – both of which are functions of the aerobic system (Glaister, 2005). Basketball is one of the fastest team sports, and is characterized by exceptional movements such as sprints, changes of direction, dunks, rebounds and blocked shots (Gottlieb et al., 2014). This means

1 - *The Academic College at Wingate, Wingate Institute, Netanya, Israel.*
2 - *The Matte Asher Basketball Club, Matte Asher, Israel.*
3 - *Physical Education and Sport Department, Faculty of Education and Sport University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Spain.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 77/2021 in January 2021.

that basketball players need great athletic ability in order to most proficiently demonstrate speed, strength and power required to produce a successful basketball performance (Delextrat and Cohen, 2008).

The game of basketball has undergone radical changes in the past decade. Coaches believe that the rule changes in May 2000 (Meckel and Gottlieb, 2009; Meckel et al., 2009) that shortened offensive attack time from 30 to 24 s and the time allowed to cross the median line from 10 to 8 s, as well as subdividing play time into four 10-min quarters instead of two 20-min halves, modified the tactical and physical demands of the game. Basketball players have been found to cover about 4500–5000 m during a 48–min game (Crisafulli et al., 2002), and spend only 34.1% of the time playing, 56.8% walking, and 9.0% standing (Narazaki et al., 2009). Thus, identifying the physiological requirements of modern basketball is essential in order to develop and prescribe an appropriate physical training program (Abdelkrim et al., 2007).

Many of the key actions performed by basketball players in a game are based on horizontal movements (sprints and changes of direction), vertical movements (jump shots and rebounds) and combinations of movements within both of these planes, mainly when penetrating to the basket and blocking a shot (Meckel and Gottlieb, 2009; Meckel et al., 2009). These high-intensity movements are usually performed intermittently throughout the game (Gottlieb et al., 2014).

The fitness component and energy system in basketball

Many coaches and players equate athleticism with physical fitness in this type of sport. Being physically fit is essential from a health standpoint, but the following fitness components are equally important for elite basketball players (Abdelkrim et al., 2007; Gottlieb et al., 2014; Shaher, 2011): cardiorespiratory fitness, muscular strength, muscular endurance, flexibility and body composition.

The first component, cardiorespiratory fitness, refers to the effective delivery of blood, oxygen and nutrients to the active body by the heart and lungs during physical work. Aerobic exercise improves cardiorespiratory function (Meckel et al., 2009) and also strengthens the heart muscle. Aerobic training can be done through any activity requiring continuous low-intensity effort for 20-60 min (Meckel and Gottlieb, 2009). In this sense basketball requires short and intense periods of activity, during which players expend a great deal of energy at a rapid rate. Anaerobic pathways are another aspect of cardiorespiratory fitness, and provide energy for high-intensity activities. Thus the anaerobic energy systems must also be well developed (Abdelkrim et al., 2007; Gottlieb et al., 2014; McInnes et al., 2008).

The physiology underlying the aerobic and anaerobic energy systems is complex, and especially so in basketball (Gottlieb et al., 2014; Meckel and Gottlieb, 2009). On the one hand, the aerobic system, which supplies long-term energy, depends on the presence of oxygen for the production of ATP. This is the preferred energy source for exercise lasting more than 3 min (Castagna et al., 2005; Meckel and Gottlieb, 2009; Meckel et al., 2009). When basketball players begin exercising, both the aerobic and anaerobic energy systems are involved. However, the relative contribution of each energy source varies according to the demands of the exercise, which in turn vary as functions of the intensity and duration of the activity (Table 1). Basketball is about 20% aerobic and 80% anaerobic, and therefore many factors influence the exact energy expenditure ratio for individual players (Abdelkrim et al., 2007).

Assigning exact ratios to fit all styles of play would be impossible. It is widely accepted that basketball is a game requiring a high level of anaerobic fitness. This is certainly the case when a 2-hour game is broken down into shorter segments. For example, if we monitor one player for the first quarter (10 min), we can observe a work-rest ratio of 1:1 or less (Abdelkrim et al., 2007; Meckel and Gottlieb, 2009; Meckel et al., 2009), but if we monitor the same player for the whole game, we see a work-rest ratio of 1:2-1:3, given that the game includes short breaks: time-outs, quarter breaks and halftime (Gottlieb et al., 2014). While the energy to perform high-intensity efforts is derived primarily from the anaerobic system during the basketball game, recovery for subsequent bouts of exercise is facilitated during the rest periods by the aerobic system (Meckel and Gottlieb, 2009).

It is important to develop a training program that specifically emphasizes the energy system required to play basketball. Within 20 s of rest, 50% of the muscle stores of ATP-CP is restored, and 87% is restored after 60 s. Heavy breathing after high intensity is the process through which the aerobic system metabolizes lactate in an effort to facilitate recovery. In addition, if basketball players have strong basic aerobic conditioning to tolerate high levels of accumulated blood lactate concentration, this will delay the onset of fatigue and enhance productivity on the court (Gottlieb et al., 2014; Meckel and Gottlieb, 2009; Meckel et al., 2009).

Table 1

Type of field tests

Endurance tests (Aerobic)	Neuromuscular tests (Anaerobic)
Cooper	5/10 m sprints from a standing start
Yo-Yo endurance	20/30 m sprint test from a standing start
Yo-Yo intermittent recovery	Countermovement jump (CMJ)
	Squat jump
	Standing broad jump
	2 x 5 m agility
	T test (5-10-5 shuttle)
	Repeat sprint ability (RSA)
	Change of direction ability (CODA)

The physical requirements of a basketball game (intermittent exercise)

The last two decades have yielded a significant accumulation of specific data related to modern methods of coaching basketball (Shelling and Torres, 2016). The body structure and impressive athletic ability of basketball players may account for some of the rapid development of the sport in recent years (Delextrat and Cohen, 2008).

As noted, since the introduction of the 24-s shot clock, the game has become much faster and the concept of fast playing has become crucial in basketball. This change has led to high physical demands on the players, both defensive and offensive, raising the importance of their explosive strength (Stojanovic et al., 2012). For this reason, strength and conditioning coaches and other professionals in the field seek more effective training methods for nurturing and developing players' physical abilities, as well as better methods to monitor and assess the fitness components required for the sport of basketball (Delextrat and Cohen, 2008; Meckel and Gottlieb, 2009).

Another important component required for repeated sprints is aerobic capacity for overall performance in the game. Nevertheless, most of the actions during the game are characterized as anaerobic, e.g. jumping, changing direction and footwork (Abdelkrim et al., 2007; Gottlieb et al., 2014). A basketball game is considered anaerobic-dominated and requires repetitive short and intense sprints from the players. Such activities take a high toll on the players (Castanga et al., 2005, 2008). In a basketball game a player averages 105 intense movements lasting between 2 to 6 s, which occur on average every 21 s on the game clock (not including time-outs). Intensity during these movements shows values of 60 to 75% of VO_{2max}, and 70-90% of the maximum heart rate (Meckel and Gottlieb, 2009; Meckel et al., 2009). The overall distance a player sprints during the game is less than 10% of the total distance a player moves throughout a full game. Overall, the intermittent activity pattern in basketball demands aerobic capabilities sufficient to sustain repeated short bouts of high-intensity exercise (Bishop, 2004).

Despite the infrequency of these sprints, they have a great impact on the outcome of the game (Wragg et al., 2000). It should be noted that time-outs last for 2 min, the halftime period for 15 min, and foul calls from 20 s to 1 min. The assessment of RSA as a training and research tool is also discussed (Spencer et al., 2005).

To repeat these activities without fatigue two main processes are required: 1) faster renewal of CP stores, and 2) faster removal of blood lactate concentration from the muscles (Gottlieb et al., 2014). Sport intensities and movement patterns during men's basketball were investigated by videoing the movements of eight elite players and monitoring their heart rate and blood lactate responses during competition (Gottlieb et al., 2014; Meckel and Gottlieb, 2009). The results are expressed in "live time", which means actual playing time and "total time" which includes live time as well as all stoppages in play. The mean ± SD frequency of all activities was 997 ± 183, with a change in the movement category every 2.0 s (Ostojic et al., 2006). A mean total of 105 ± 52 high-intensity runs (mean duration of 1.7 s) was recorded for each basketball game, resulting in one high-intensity run every 21 s in live time. Sixty percent of live time was spent engaged in low-intensity activity, while 15% was spent in high-intensity activity. The mean heart rate during live time was 169 ± 9 beats/min^{-1} (89 ± 2% peak HR attained during laboratory testing); 75% of live time was spent with an HR response greater than 85% of the peak heart rate. Mean blood lactate concentration was 6.8 ± 2.8 mM/L, indicating the involvement of glycolysis in the energy demands of basketball. It was concluded in these studies that physiological requirements of men's basketball are high, placing considerable demands on the cardiovascular and metabolic capacities of players (Abdelkrim et al., 2007; Ostojic et al., 2006).

Physical fitness is a performance factor that is characterized by its ability to be assessed using closed tests. Among the existing tests today, there are no data on which are the most optimal ones for the sport to which they are applied (Mancha-Triguero et al., 2019).

Tests for assessing aerobic and neuromuscular capacity

The aim of fitness tests is to assess the condition of athletes in terms of each fitness component, in order to determine what needs to be improved through the training program and to conduct retests at set times to assess whether their condition has changed. These tests are especially important among children and teenagers, so that coaches can see whether players are developing in terms of physical fitness as they get older (Chiu et al., 2003; Gottlieb et al., 2014; Hoffman, 1996; Mujika et al., 2009).

The ability to produce great power in a short period of time is an important measure in many sports, such as basketball, soccer and volleyball. For this reason, these team sports place great emphasis on improving strength at every age and every level of performance (Gottlieb et al., 2014). Optimal development and improvement of this ability, as well as of speed, agility and coordination, is not merely a theoretical exercise in comprehending the principles of physiology and training underlying these fitness components. It is also connected to the need for valid and reliable measurement techniques that make it possible to assess different abilities accurately and consistently (Delextrat and Cohen, 2008).

The most commonly used field tests in the basketball literature

The literature offers a number of widely used tests to measure aerobic and anaerobic fitness (Abdelkrim et al., 2007; Delextrat and Cohen, 2008; Gottlieb et al., 2014). The following are examples of field tests that can provide fitness coaches with relevant information for basketball:

Endurance tests (aerobic):

Yo-Yo endurance test – a maximum aerobic capacity test that includes running back and forth for 20 m with increasing effort until the participant becomes exhausted. The test has a high correlation with VO_{2max} (r = 0.92). This test is reliable and valid for predicting aerobic capacity in different populations (Clair et al., 1998). The test was chosen to evaluate aerobic fitness every few months, due to its suitability to the activity patterns routinely performed by athletes. The pace starts at 8 km/h and increases by 0.5 km/h every minute. The pace is dictated and made audible by an audio disc. Test results are determined by the number of times the athlete performs the sprints before reaching exhaustion (Castagna et al., 2005; Delextrat and Cohen, 2008; Ostojic et al., 2006).

Yo-Yo recovery test (Level 1) – this version of *Yo-Yo* has a correlation of r = 0.77 with maximum VO_{2max}. Assessment includes a 40-m run, divided into 20 m up and 20 m back to the starting point, and 10 s recovery after each full cycle (40 m). The test starts at 10 km/h and increases by 0.5 km/h after each cycle. This version was developed for sports that require intense physical efforts followed by periods of incomplete recovery, such as basketball (Bangsbo, 2006; Castagna et al., 2005; Delextrat and Cohen, 2008).

Cooper test – in this test the player needs to run as far as he/she can in 12 minutes. Its predictive ability of VO_{2max} is very good r = 0.89 (Cooper, 1968), but does not reflect the character of all ball games (Castagna et al., 2005).

Neuromuscular tests (anaerobic):

5/10-m sprints from a standing start – Starting Speed test: this test evaluates horizontal power while performing a cyclical movement – sprints from a standing start. The first step is decisive in the examinee's achievement. Times are usually measured by photo-electric cells or Optojump (Microgate, Italy). Each player performs 2 sprints from a high start, with 3-5 min of rest between runs. The best time is recorded (Balciunas, 2006; Gottlieb et al., 2014; Hoffman, 1996; Shaher, 2011).

20/30-m sprint test from a standing start – Absolute Speed test: this test also evaluates horizontal power while performing a cyclical movement – sprints from a standing start. The ability to accelerate is decisive for good results. Times are usually measured by photo-electric cells or Optojump). Each player performs two sprints from a standing start, with 3-5 min of rest between runs. The best time is recorded (Delextrat and Cohen, 2008; Gottlieb et al., 2014; Hoffman, 1996; Mujika et al., 2009; Shaher, 2011).

Repeat Sprint Ability (RSA)Test - field-based team sports present some fitness components which are poorly understood. In particular, repeated-sprint ability (RSA) is one area that has received relatively little research attention until recent times. However, with improvements in technology, time-motion analysis has allowed researchers to document the detailed movement patterns of team-sport athletes. This type of practice involves the metabolic changes occurring during this type of exercise, such as energy system contribution, adenosine triphosphate depletion and resynthesis, phosphocreatine degradation and resynthesis, glycolysis and glycogenolysis, and purine nucleotide loss. Assessment of RSA, as a training and research tool, is also discussed (Spencer et al., 2015). The recognition of the important role of RSA for performance in basketball has led to the wide use of RSA-based tests among basketball players as part of routine fitness testing (Caprino et al., 2012; Meckel et al., 2009), as well as for training session strategy (Attene et al., 2015).

Countermovement jump (CMJ) test – this test assesses vertical power in a single jump. Jumps begin while standing straight, then knees are bent and quickly extended while leaving the ground and rising to the maximal height. Hands are usually placed on the hips in order to neutralize momentum from the arms. Each athlete performs 3 maximal jumps with about 2 min of rest between jumps. Jumps are usually performed using Optojump, which is connected to a digital timer that converts time in air to the jump height, or a force plate which contains sensors that measure the strength exerted by the feet (Gottlieb et al., 2014; Hoffman, 1996; Shaher, 2011).

Squat jump test – in the same way, it is possible to perform a squat jump as a test. Players assume a low squat position. Movement is stopped and then the athlete jumps as high as they can from this position, with hands on hips or behind their back (García-López et al., 2005).

Standing broad jump – athletes stand with both legs together. They bend their knees and use arm momentum in order to jump. The longest jump of 3 attempts is recorded as the result. If an athlete falls backward the jump must be repeated. Although the standing broad jump was part of the Olympic Game athletics competitions from 1900 to 1912, it has not been part of regular competitions worldwide for more than a century. In addition, no extensive statistics are available about achievements and progress in this event. If this test is used for assessing power, it is only by basketball clubs which do not have advanced equipment.

Also available are agility tests that assess changes of direction which require, among other things, great explosive strenght. Players need starting speed, a fast takeoff, stopping, acceleration, change of direction and at times sideways running. In addition, it is important to mention that the ability to change direction requires high technical skills combined with unique leg work (Sheppard and Young, 2006; Wragg et al., 2000). Many agility tests can be found in the literature. The two mentioned here are among the most accepted for assessing the explosive strength of basketball players (Delextrat and Cohen, 2008):

2 x 5-m agility test: this test measures sprinting time, turning, and changing direction. The test is performed by running 5 m in one direction, turning quickly, and returning 5 m to the starting point, a total of 10 m of running. The test can use photoelectric cells or an Optojump system to assess performance (Delextrat and Cohen, 2008; Sheppard and Young, 2006; Wragg et al., 2000).

T-test (5-10-5 Shuttle): this is an agility test that measures how quickly athletes can accurately change direction. The T-test is designed to measure lateral speed as well as forward and backward speed (Sheppard and Young, 2006; Wragg et al., 2000; Young et al., 2001).

Conclusions

The new generation of basketball players consists of highly conditioned athletes who ultimately elevate the level of the game (Spencer et al., 2005). For consistency in season-long, high-level performance, conditioning is the key. Participation in youth sports such as basketball offers many potential benefits for children and adolescents (DeFiori et al., 2018). However, there is also a concern that an excessive focus on sport-specific intensive training and competition at a young age may impede an athlete's ability to develop transferable athletic skills, and possibly increase the risk of burnout and overuse injury (DeFiori et al., 2014).

Based on the literature review of field tests presented above, the impression is that sports researchers still seek specific tests to reflect as closely as possible abilities of athletes required in the game itself.

The activity of basketball players is based on a combination of horizontal movements (sprints and changes of direction), vertical movements (jump shots and rebounds), and movements that combine the two movement planes, mainly when penetrating to the basket and blocking shots. These are high-intensity movements that are usually performed intermittently throughout the game and at different intervals, by players in the various positions on the court (Gottlieb et al., 2014).

This combined type of movement has caused fitness coaches, physiologists, and other professionals in the field to seek the most effective training methods for promoting and developing physical abilities in basketball players (Delextrat and Cohen, 2008; Gottlieb et al., 2014). Today, as fitness coaches deliberate long and hard about which training method is most effective for developing explosive strenght, they encounter many limitations in choosing the most effective tests for assessing this component. A number of efforts have been made to develop specific tests for assessing power among players (Delextrat and Cohen, 2008; Ostojic et al., 2006; Sheppard and Young, 2006; Wragg et al., 2000). Studies show a correlation between horizontal and vertical power (Hori et al., 2008; Sheppard et al., 2008). However, the literature does not offer a sufficient number of specific tests in ball sports to enable examining power where horizontal and vertical movements are combined (Gottlieb et al., 2014).

Karcher and Buchheit (2016) conducted a study in team handball which examined the benefit of conducting CMJ tests to predict specific jumping ability in handball. The results showed no clear correlation between time in the air in jump shots and the CMJ, indicating that the use of the CMJ for predicting specific jumping ability in handball, with its combination of horizontal and vertical movement, is questionable. Thus, specific tests are needed that reflect jumping ability and power for team handball. In contrast, a volleyball study by Sheppard et al. (2008) revealed a strong connection between CMJ performance and the jump serve which combines both horizontal and vertical components as does the spike jump. This seems to indicate that specific connections among these variables may differ from one sport to another and between the various developmental levels of athletes. However, it is still not known whether the protocols of tests like the CMJ can actually predict specific jumping abilities in basketball (such as the actual jumping time when penetrating to the basket while holding the ball and pushing off from one leg). As for improvement in performance, several intervention studies in ball games have shown that maximal strength training, plyometric training, sprint training, complex training, and other types of training all significantly improved CMJ performance (DeFiori et al., 2014; Gottlieb et al., 2014; Mujika et al., 2009). At the same time, it is still not clear whether these improvements can be transferred to game situations, such as lay-ups and penetrating to the basket, and therefore there is a need for future studies.

There is no doubt that aerobic capacity is significant in basketball for rapid recovery from sprints and repeated jumps (Meckel et al., 2009). The competition demands encountered by basketball players suggest that both anaerobic and aerobic energy pathways contribute to energy sources (Edwards et al., 2018), which cause fatigue and lower the rate of activity, thus impinging on the quality of a player's game. Therefore, coaches and fitness coaches must correctly measure their players' aerobic capacity, mainly before the season begins. Today a number of tests for aerobic capacity are available, both laboratory and field tests (Gottlieb et al., 2014; Meckel and Gottlieb, 2009). The laboratory VO_{2max} test is accurate, but because of its high cost various field tests, such as the Cooper test (sequential 12-min running tests), have been developed (Cooper, 1968).

Various types of Level 1 *Yo-Yo* tests (Bangsbo, 2006; Delextrat and Cohen, 2008) yield good predictions of VO_{2max} (aerobic ability) in ball games defined as sports with intermittent activities – in other words, many intense activities with short recovery periods. However, the tests are not adapted specifically to particular sports. In other words, the specific elements of the sport, as well as rest periods, changes of direction, typical movements, etc., must be taken into consideration when adapting the tests for particular sports. In general, the transfer of physical improvements from training to team ball games is difficult to predict, when technical abilities, complex interactions between players, and other factors must be considered.

Future lines of research

One of the problems with many of the physiological and biomechanical studies of the vertical jump is that they neutralize arm movement in an attempt to isolate the effect of leg muscle power in the action. In this way they hope to find a causal relationship between improved muscular power or muscle output, and jump height. Yet it must be kept in mind that few sports require athletes to jump without arm momentum (i.e., with arms on hips or behind the back). The result is that such tests are less useful for coaches in the field. In general, it is advisable to adhere to the principle of specificity in training – improving a given motor skill should entail practicing that skill as it is performed in games/competitions. To this end, specific tests for basketball should be developed and used.

One of the aspects to be considered is recovery time. Sports in general, and basketball in particular, involve intense but non-consistent body movement. Based on the observation and analysis of 15 basketball games in the Israel Premier League, it is apparent that basketball players experience incomplete recovery during rest periods that last from 10 s (for fouls with no free throws) and 30 s (for fouls with two free throws) to time-outs of about one minute in duration, and timeouts of somewhat more than two minutes between quarters. Importantly, the frequency of recovery (10-30 s) was observed on average every three possessions.

To the best of our knowledge, no specific test has yet been developed to assess the unique features of basketball. Thus, it would be both important and interesting to build a reliable and valid test of which results will provide coaches with tools for testing the specific abilities required in basketball, even if certain compromises must be made to accommodate field-based limitations.

The reviewed aerobic tests demonstrate a good correlation with VO_{2max} (Meckel and Gottlieb, 2009; Meckel et al., 2009) which is very important for recovery from short, intense bouts of movements of a few seconds. However, they do not offer elements similar enough to basketball movements which require leg muscle exertion. A basketball-oriented test should take this into consideration as well. The analyzed bibliography reveals the lack of the design and use of specific tests to highlight the qualities involved in the targeted sport (Mancha-Triguero et al., 2019).

References

Abdelkrim N, Fazaa S, Ati J. Time motion analysis and physiological data of elite under 19 year old basketball players during competition. *J Strength Cond Res*, 2007; 24: 2330-2342

Alemdaroğlu U. The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. *J Hum Kinet*, 2012; 31: 149-158

Attene G, Pizzolato F, Calcagno G, Ibba G, Pinna M, Salernitano G, et al. Sprint vs. intermittent training in young female basketball players. *J Sports Med Phys Fitness*, 2014; 54: 154–161

Balciunas M, Stonkus S, Abrantes C, Sampaio J. Long term of different training modalities on power, speed, skill and anaerobic capacity in young male basketball players. *J Sport Sci Med*, 2006; 5: 163-170

Bangsbo J. *Fitness Testing in Football*: 1-200; 2006

Ben Abdelkrim N, El Fazaa S, and El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*, *2007*: 41: 69–75. 10.1136/bjsm.2006.032318

Bishop D. The effects of travel on team performance in the Australian national netball competition. *J Sci Med Sport*, 2004; 7:118-122.

Caprino D, Clarke ND, and Delextrat A. The effect of an official match on repeated sprint ability in junior basketball players. *J. Sports Sci*, 2012; 30: 165–1173

Castagna C, Grant A, Stefano D. Competitive-level differences in yo-yo intermittent recovery and 12-minute run test performance in soccer referees. *J Strength Con Res*, 2005; 19: 805-809

Castanga C, Grant A, Vincenzo M, Giueseppe A, Evira P, Stefano D. Effect of recovery mode on repeated sprint ability in young basketball players. *J Strength Cond Res*, 2008; 22: 1-7

Chiu L, Fry L, Weiss B, Schilling L, Brown S. Post activation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res*, 2003; 17: 671-677

Clair G, Broomhead S, Lambert M, Prediction of maximal oxygen uptake from 20 m shuttle run as measured directly in runners and squash players. *J Sport Sci*, 1998; 16: 331-335

Cooper M. A means of assessing maximal oxygen intake correlation between field test and treadmill testing. *JAMA*, 1968; 203: 201-204

Crisafulli A, Melis F, Tocco, P. Laconi, P Lai, and Concu . External mechanical work versus oxidative energy consumption ratio during a basketball field test. *J Sports Med Phy Fit*, 2002; 42:409–417

DeFiori JP, Benjamin HJ, Brenner J, Gregory A, Jayanthi N, Landry GL, Luke A. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Clin J Sport Med*, 2014; 24:3-20

DeFiori JP, Gülich A, Brenner JS, Côté J, Hainline B, Ryan E 3rd, Malina RM. The NBA and youth basketball: Recommendations for promoting a healthy and positive experience. *Sports Med*, 2018; 48: 2053-2065

Delextrat A, Cohen D. Physiological testing of basketball players: towards standard evaluation of anaerobic fitness. *J Strength Cond Res* 2008; 22: 1066-1072

Edwards T, Spiten T, Piggott B, Bonhotal J, Haff G, Gregory JC. Monitoring and managing fatigue in basketball. *Sports (Basel)*, 2018; 6: 19

Garcia-Lopez J, Peleteiro J, Rodriguez-Marroyo JA, Morante JC, Herrero JA, Villa JG. The validation of a new method that measures contact and flight times during vertical jump. *Int J Sports Med*, 2005; 26: 294-302

Glaister M. Multiple sprint work. *Sport Med*, 2005; 35: 757-777

Gottlieb R, Eliakim A, Shalom A, Iacono AD, Meckel Y. Improving anaerobic fitness in young basketball players: Plyometric vs. specific sprint training. *J Ath Enhance*, 2014; 3: 3. doi:10.4172/2324-9080.1000148

Hoffman JR. Relationship between athletic performance tests and playing time in elite college basketball players. *J Strength Cond Res*, 1996; 10: 67-71

Hori N, Newton, RU, Andrews WA, Kawamori N, McGuigan, MR, Nosaka, K. Does performance of hang power clean differentiate performance of jumping, sprinting and changing of direction. *J Strength Cond Res*, 2008; 22: 412-418

Karcher C, Buchheit M. Shooting performance and fly time in highly trained wing handball players: Not everything is as it seems. *J Sports Physio Perform*, 2016; 24: 1-20

Mancha-Triguero D, García-Rubio J, Calleja-González J, Ibáñez SJ. Physical fitness in basketball players: a systematic review. *J Sports Med Phys Fitness*, 2019 Sep; 59(9): 1513-1525.

McInnes SE, Carlson JS, Jones CJ, McKenna MJ. The physiological load imposed on basketball players during competition, *J Sports Sci*, 2008; 13: 387-397

Meckel Y, Gottlieb R. Repeated sprint tests in young basketball players at different game stages. *Eur J App Physiol*, 2009; 107: 273-279

Meckel Y, Machnai O, Eliakim A. Relationship among repeated sprint test, aerobic fitness and anaerobic fitness in elite adolescent soccer players. *J Strength Cond Res*, 2009; 23: 163-169

Mujika I, Santisteban J, Castagna C. In-season effect of short-term sprint and power training programs on elite junior soccer players. *J Strength Cond Res*, 2009; 23: 2581-2587

Narazaki K, Berg KE, Stergiou N, Chen B. Physiological demands of competitive basketball. *Scand. J Med Sci Sport*, 2009; 19: 425-432

Ostojic SM, Mazic S, Dikic N. Profiling in basketball: Physical and physiological characteristics of elite players. *J Strength Cond Res*, 2006; 20: 740-744

Shalfawi SA, Sabbah A, Kailani G, Tønnessen E, Enoksen E. The relationship between running speed and measures of vertical jump in professional basketball players: A field test approach. *J Strength Cond Res*, 2011; 25: 3088-3092

Shelling X, Torres L. Accelerometer load profiles for basketball-specific drill in elite players. *J Sports Sci Med*, 2016; 15: 585-591

Sheppard JM, Cronin JB, Gabbett TJ, McGuigan MR, Etxebarria N, Newton RU. Relative importance of strength, power and anthropometric measures to jump performance of elite volleyball players. *J Strength Cond Res*, 2008; 22: 758-765

Sheppard JM, Young WB. Agility literature review: classification, training and testing. *J Sports Sci Med*, 2006; 24: 919-932

Spencer M, Bishop D, Dawson B, Goodman C. Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. *Sport Med*, 2005; 35: 1025-1044

Stojanovic MD, Ostojic SM, Calleja- González J, Milosevic Z, Mikic M. Correlation between explosive strength, aerobic power and repeated spring ability in elite basketball players. *J Sports Med Phys Fit*, 2012; 52: 375-381

Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: An update. *J Sport Med*, 2005; 35: 501-536

Wragg CB, Maxwell NS, Doust JH. Evaluation of the reliability and validity of a soccer specific field test of repeated sprint ability. *Eur J App Physiol*, 2000; 83: 77-83

Young WB, McDowell MH, Scralett NJ. Specificity of sprint and agility training methods. *J Strength Cond Res*, 2001; 15: 315-319

Corresponding author:

Roni Gottlieb M.P.E,
The Academic College at Wingate,
Wingate Institute, Netanya, Israel;
Phone: +972 (0) 9 7417844;
Cellular: +972 54 4822425
E-mail: ronigot23@gmail.com

APPENDIX 2. Published Scientific Article (Original Research)

Reference:

Shalom A, Gottlieb R, Alcaraz PE, Calleja-Gonzalez J. A Unique Specific Jumping Test for Measuring Explosive Power in Basketball Players: Validity and Reliability. Applied Sciences. 2023;13:7567.

-This paper presents the first original research study of this thesis.

applied sciences

MDPI

Article

A Unique Specific Jumping Test for Measuring Explosive Power in Basketball Players: Validity and Reliability

Asaf Shalom [1,2,3], Roni Gottlieb [1,3], Pedro E. Alcaraz [4] and Julio Calleja-Gonzalez [5,*]

1 Department of Sports Science, Universidad Católica San Antonio de Murcia, 30107 Murcia, Spain; asaf.fitness@gmail.com (A.S.); ronigot23@gmail.com (R.G.)
2 Ort Science and Art High School, Nahariya 2240635, Israel
3 Wingate Institute, The Academic College Levinsky-Wingate, Wingate Campus, Netanya 4290200, Israel
4 Research Center for High Performance Sport, Faculty of Sport Sciences, Catholic University of Murcia, 30107 Murcia, Spain; palcaraz@ucam.edu
5 Department of Physical Education and Sports, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, 01007 Vitoria-Gasteiz, Spain
* Correspondence: julio.calleja.gonzalez@gmail.com

Abstract: The aim of this study was to develop and assess the reliability and validity of an innovative field test that measures lower limb explosive power in basketball players (i.e., alactic anaerobic capacity) for the dominant and non-dominant legs. The test examines the performance of vertical, horizontal, and combined movements while holding the ball—similar to penetration to the basket or layup. Such capabilities are required throughout basketball practice and games, combined with upper and lower body coordination. The study included 22 male basketball players, ages 16–18, members of an elite youth league team in Israel. To assess validity, the participants performed the test for each leg, followed by nine standardized tests that were developed for a range of ball games, including basketball. To assess reliability, the participants performed a retest of the unique test 72-h later. Our findings indicate the validity and reliability of the proposed anaerobic alactic field test for basketball players, for the dominant and non-dominant legs. Moreover, strong correlations were seen between the novel test and the standardized tests, with a high correlation for horizontal explosive power ($0.5 < r < 0.7$), a very high correlation for vertical explosive power ($0.7 < r < 0.9$), and a nearly perfect correlation for the two combined ($r > 0.9$). In conclusion, this unique field test for basketball players could assist coaches in developing and applying optimal training programs and game plans, for players individually, and for the team as a whole. As the test measures each leg separately, it could also offer an assessment tool following players' injuries.

Keywords: performance analysis of sport; fitness field test; explosive power; alactic anaerobic capacity; horizontal and vertical jumping; basketball

check for updates

Citation: Shalom, A.; Gottlieb, R.; Alcaraz, P.E.; Calleja-Gonzalez, J. A Unique Specific Jumping Test for Measuring Explosive Power in Basketball Players: Validity and Reliability. *Appl. Sci.* **2023**, *13*, 7567. https://doi.org/10.3390/app13137567

Academic Editor: Mark King

Received: 23 April 2023
Revised: 15 June 2023
Accepted: 25 June 2023
Published: 27 June 2023

1. Introduction

The game of basketball is far from new, yet, over time, certain rules have been added, removed, or altered [1,2]. For example, since the 24 s rule was introduced (limiting the total time a team can control the ball without shooting), the game has become much faster and more attractive [3,4]. This change in game rules also made greater physical demands and led to the development of advanced training methods with an emphasis on explosive power, which also improved the players' athletic abilities [5–7]. In today's era of the more modern game of basketball, players must develop and apply lower limb explosive power to ensure optimal performance throughout the game [8,9]. Many key actions that are performed during a basketball practice or game are based on vertical movements (e.g., rebounds and jump shots), horizontal movements (e.g., change of direction and sprints), or a combination of the two (e.g., layups)—all of which are performed intermittently throughout the game and employing lower limb explosive power [1,10–12]. Due to its importance, coaches place an emphasis on improving explosive power for players of all ages, levels of performance, and years of experience in basketball [13–15].

The ability to produce such intense actions within extremely short periods of time is largely dependent on the players' anaerobic alactic system [3]. In general, the game of basketball is comprised of many anaerobic actions—short forceful moves that are frequently carried out throughout practices and games, such as short sprints, jumps, and changes of direction [1,16]. The capacity to perform anaerobic activities, such as those that require lower limb explosive power, is based on the players' anaerobic alactic energy resources [1,17], such as the adenosine tri-phosphate–creatine phosphate system (ATP–CP) that is easily accessible through stores in the muscles. The players' glycolysis system also contributes to such anaerobic activities, especially those that last more than just a number of seconds. In addition to employing the anaerobic system, the players' aerobic energy system also plays an important role, as it enables fast recovery from, and repetition of, high intensity anaerobic actions [4,18,19].

To examine and assess the players' development and improvement of their explosive power—as a means for creating and adjusting training programs and game plans—measurement tools are needed for assessing these abilities in a consistent, accurate, and reliable manner, and in a form that suits the specific game of basketball [3].

The aim of such fitness tests is to assess the condition of athletes in terms of the relevant fitness component that is being tracked, as well as to determine what needs to be improved and worked on during training programs [8]. These tests are especially important among children and teenagers, so that coaches can see whether players are developing in terms of physical fitness as they get older [8,20]. However, to the best of our knowledge, no test has been developed and validated specifically for assessing lower limb explosive power among basketball players. While existing tests are often applied to players from a variety of sports [1,2], they entail certain limitations when employed for basketball players [3].

The literature offers several protocols for measuring players' explosive power, yet different protocols may lead to different results, rendering comparisons between outcomes of different tests inaccurate or incomplete [3,9]. As such, coaches from different clubs who wish to confer with one another on explosive power training issues must ensure they have employed the same protocol in order to compare notes. Similarly, when comparing the performance of the same basketball players over time, the same test must be used consistently [21], despite changes, such as different professional staff (trainers and coaches) and different team members [20]. Without a consistent testing protocol, differences in results cannot necessarily be attributed to changes in performance, as they may simply stem from differences in the measurement systems or from the person who is conducting the test [1,2,20]. In short, conditions must be kept as stable as possible in test/retest conditions to prevent errors unconnected with actual performance.

Measurement protocols should be as similar as possible to the actual movements that athletes perform when playing and should take into account a range of environmental and other factors [1,20]. Adherence to such protocols should give the tests an advantage over others. Tests for measuring explosive power should be administered at the onset of the training program, halfway through, and then again at the end—to maximize the relevance and accuracy of the data received with regard to the efficacy of the training program and its contribution to the observed achievements [3,8]. In some cases, existing tests do not provide necessary field tests for assessing specific basketball movements. To the best of our knowledge, no relevant test currently exists for actions that combine both vertical and horizontal movements, coordination, and using only one leg—all of which are specific to the game of basketball.

The main aim of this study, therefore, was to develop and assess the reliability and validity of a unique new test that optimally measures lower limb explosive power (i.e., alactic anaerobic capacity) in basketball players, through a combination of specific vertical and horizontal movements that replicate actions performed during the game of basketball, similar to penetration to the basket and layups.

2. Methodology

2.1. Participants

The study included 22 male basketball players, ages 16–18, members of an elite youth league team in Israel (mean age 16.8 ± 0.5 years; body mass 78.2 ± 5.9 kg; height 185.3 ± 4.0 cm; and body fat 11.1 ± 3.1%). The participants had been members of the club and had participated in professional training and competitions for at least eight consecutive years. Their weekly routine included five basketball practices, two fitness practices, and one league game. Four inclusion criteria were applied in this study, whereby each participant had: (a) participated in at least 90% of the weekly trainings during the season (10-months) prior to the research: (b) regularly participated in the previous season; (c) not incurred any injuries, were not in any pain, and were not taking any medication; and (d) a clean bill of health.

To reduce interference in the research outcomes, participants were instructed to refrain from consuming depressants (such as alcohol) or stimulants (such as caffeine) for 24 h leading up to the testing; they were asked not to eat for about three hours as well; and were instructed not to conduct strenuous physical activity for at least 24 h leading up to the testing. The parents of the participants (who were minors) signed and submitted informed written consent forms. Anonymity could not be assured, in light of the nature of the research, yet all obtained data were treated with scientific rigor and maximum confidentiality, and the data obtained were used solely for this research project. The research study was approved by the Ethics Committee at the authors' affiliated academic institution and was performed in line with the December 13 Organic Law 15/1999 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza [22].

2.2. Procedure

To examine lower limb explosive power among basketball players, we developed a unique jumping test specifically for examining lower limb explosive power in basketball players. This capability was measured through the jump movement of the layup following penetration to the basket, which combines both horizontal and vertical movements that replicate real time basketball movements on court. Flight time was used as the measurement indicator of this test—before and after contact with the ground. This was measured using the Optojump system by MicroGate (Bolzano, Italy), an optical measurement system that is comprised of a receiving and transmitting bar. This system offers high accuracy compared to alternative measuring methods and enables tests and measurements in real sports environments, such as basketball courts and soccer fields [21,23,24]. Each jump was also recorded on two separate video recorders. Using the Optojump system enabled real time documentation of numerical and graphic measures, thereby providing an objective tool. The gathered data were then transmitted directly onto an Excel file, enabling fast and simple documentation and access [24]. The complementary video recordings allowed us to examine and verify the recorded data as needed.

The participants performed the tests assessed in this study at about 4 p.m., with indoor temperatures of about 20.4 ± 0.5 °C and humidity of about 60.3 ± 3.5%. The participants wore basketball shoes and appropriate sportswear. Prior to the tests, the participants warmed up for about 20 min on their home basketball court. The warmup included six minutes of layups (right/left), eight minutes of mobility movements and dynamic stretches, and six minutes of accelerations.

After warmups, each participant performed the unique test twice, which included two layups and penetrations to the basket, once for their dominant leg (U1D) and once for their non-dominant leg (U1ND). In this study, the dominant leg was defined as their preferred hopping leg. These were repeated 72 h later, for their dominant leg (U2D) and for their non-dominant leg (U2ND). The test/retest results were then compared to assess the reliability of the new test. During Day 1 of the testing, after performing the U1D and U1ND tests, the participants also performed nine additional standardized tests. A recovery period of at least five minutes between each test was provided. All tests were carried out on the basketball court where the participants regularly practiced and played, to ensure familiarity with the testing environment. The unique test/standardized test results were then compared to assess the validity of the new test.

In addition to the new test, the participants also completed a 5 and 10 m sprint, the bounding power test (BP), and the following six versions of the countermovement jump (CMJ): countermovement jump both legs, hands free (CMJF); countermovement jump both legs, with hands on hips (CMJWH); countermovement jump, dominant leg, hands free (CMJDF); countermovement jump, dominant leg, with hands on hips (CMJDWH); countermovement jump, non-dominant leg, hands free (CMJNDF); and countermovement jump, non-dominant leg, with hands on hips (CMJNDWH). The results of these tests were compared to those of the unique new test to assess validity. The participants were able to achieve complete recovery following a five-minute rest between tests in all the tests, allowing the participants to perform a number of tests on the same day. However, the unique test was performed first, for both the dominant and the non-dominant leg. We chose to conduct this test first, prior to performing the additional nine standardized tests—to ensure similar conditions 72-h later during the retest.

2.2.1. Stage 1: The New Unique Test for Basketball Players

As seen in Figure 1, the novel test requires players to perform a penetration and layup, once using their dominant leg, and once using their non-dominant leg. The test incorporates running, jumping, and landing, as well as shooting the ball into the basket, and it is performed on a regular basketball court.

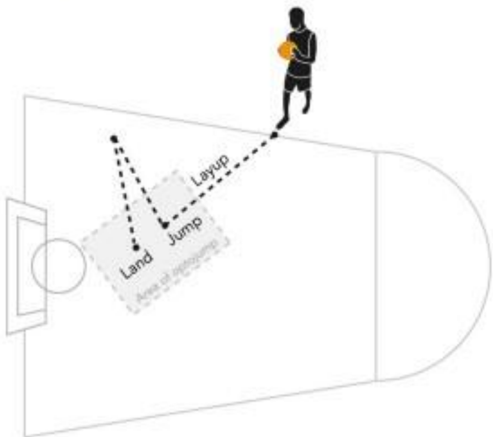


Figure 1. Performance of the novel jumping test for basketball players.

More specifically, the participants began the test outside the detection area of the Optojump system, which was placed on the floor in the painted area. They began in a standing position, while holding the ball in both hands, followed by a layup into the testing zone, and then they completed a combined horizontal–vertical jump as they threw the ball towards the basket using only one hand. They released the ball at the zenith of their jump, shooting towards the basket with the one hand. They then landed within the measuring area no more than 1.5 m from their last point of contact prior to their flight. Figure 2 provides a detailed explanation of the flow of the test.

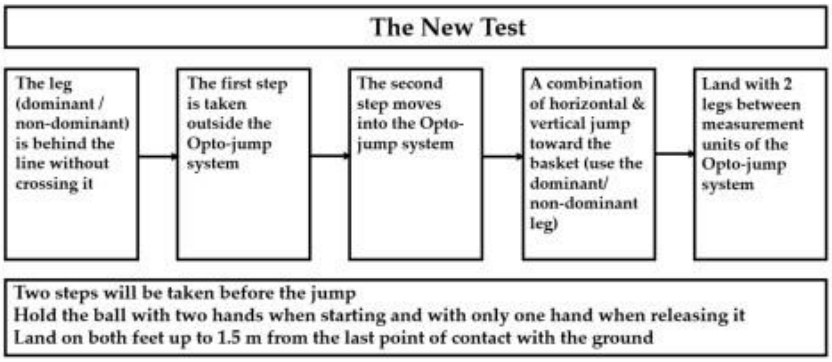


Figure 2. Flowchart of the novel jumping test for basketball players.

In this study, two basketball coaches and two fitness coaches conducted the test while ensuring the following: (1) the leg (dominant/non-dominant) was behind the foul line without crossing it; (2) two steps were taken before the jump; (3) push-off was performed with one leg (dominant/non-dominant); (4) the ball was held with both hands when starting and with only one hand when releasing it; (5) the ball entered the basket, or at least touched the rim, after the ball was released from the player's hand; (6) players landed on the balls of their feet without excessive bending of the knees; (7) players landed naturally where both feet had to be within the measurement zone; (8) players did not touch the basket rim or net with the hand during the jump, either before or after releasing the ball; and (9) the ball did not fall onto the measurement units of the Optojump before the player landed. Players who did not meet all of these guidelines were asked to repeat the jump. Participants were asked to perform the new test twice on each leg, with a rest period of 3–5 min between jumps.

In summary, when performing the layup for the test, the players were asked to jump as high as they can, i.e., a horizontal run followed by a vertical jump that also comprises horizontal elements. They were also instructed to land on both feet up to 1.5 m from the last point of contact with the ground after holding the ball in just one hand to replicate a real time penetration to the basket.

2.2.2. Stage 2: Comparison of the Unique Test to Standardized Tests

To assess and validate this new field tool, the data obtained from the novel test were compared to results from nine standardized tests, as detailed in the following section.

5/10-Meter Sprint Speed Test. This speed test was used to evaluate players' horizontal explosive power through cyclical movement (i.e., sprinting from a standing starting point). The participants were asked to perform two 10 m sprints from a high starting point, with 3–5 min rest between the two sprints. The best result of the two was recorded [1,8]. In this study, the participants only completed two 10 m sprints, as the measuring tool recorded their results after completing both 5 m and 10 m in the same sprint. These measurements were performed using a photoelectric cell system [5,25].

BP Test. This test was used to evaluate players' horizontal and vertical explosive power. In the study, the participants were instructed to stand on one leg and jump as far forward as they could, six consecutive times, alternating the leg they landed on each time [5,26]. The recorded results were the final distance reached by the participants after bounding forward six times. This test was also performed twice, with the greater distance being recorded. Distances were measured manually using a tape measure [5].

CMJ Tests. In the study, the participants completed six types of CMJ tests to assess their vertical explosive power in a single jump. The participants began in the straight standing position, then bent their knees and quickly extended their legs to leave the ground in a flight movement, rising up as high as possible [21,27]. This was performed once using both legs, once using the dominant leg, and once using the non-dominant leg—all with hands on hips to neutralize upper limb momentum. These three jumps were then repeated while hands were in a free position—resulting in a total of six tests. Recovery time was about two minutes between jumps [4]. The jump heights were also recorded using the Optojump, which converts flight time to jump height [1,3,8,28].

3. Statistical Analysis

Internal consistency (α Cronbach) was used to assess the validity and reliability of the new proposed test. Mean ± SD were calculated and presented for describing a range of participant characteristics, as well as the results of their physical tests. Normality was tested using Shapiro-Wilk W statistics. Reliability of the new test was measured via Intra-class Correlation (ICC) and a Bland Altman plot [29,30]. Correlations between the standardized jump tests and the unique test were calculated using Hopkins et al. [31] to consider their strength: trivial ($r < 0.1$; small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), high ($0.5 < r < 0.7$), very high ($0.7 < r < 0.9$), nearly perfect ($r > 0.9$), and perfect ($r = 1$)). Significance levels were set at $p < 0.05$. SPSS v.26.0 (IBM) was used for conducting statistical analyses.

4. Results

In order to assess the validity and reliability of the new proposed test, measurements were conducted twice, with a 72-h gap between the two. For the dominant leg, the internal consistency (α Cronbach) was 0.992, and the ICC was 0.984 ($p < 0.001$). For the non-dominant leg, the internal consistency was 0.994, and the ICC was 0.978 ($p < 0.001$).

For the dominant leg, Figure 3 presents the Bland-Altman plot [mean = −0.354, 95% CI (−3.577, 2.868)]. Only one point was outside the CI, thereby enhancing the validity and the reliability of the new test for the dominant leg.

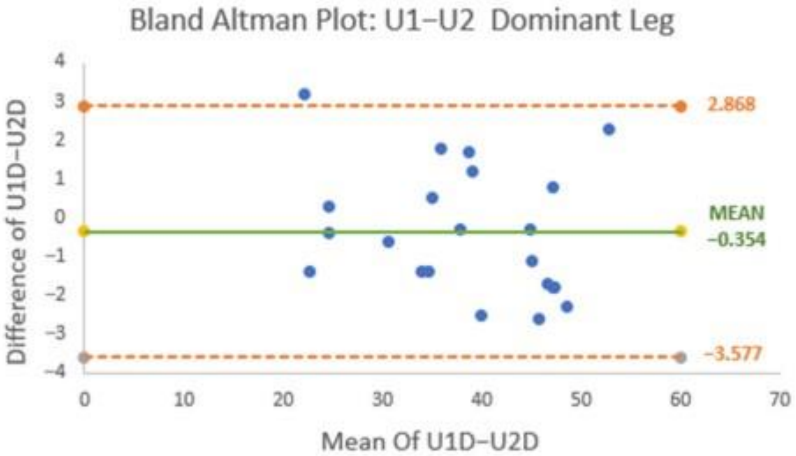


Figure 3. Bland-Altman plot—U1D, U2D.

For the non-dominant leg, Figure 4 presents the Bland-Altman plot [mean = −1.268, 95% CI (−3.959, 1.423)]. Again, only one point was outside the CI, thereby enhancing the validity and reliability of the new test for the non-dominant leg. In addition, test/retest correlations were calculated, indicating a very high correlation for both the dominant and non-dominant leg [$r = 0.985$ ($p < 0.001$); $r = 0.988$ ($p < 0.001$), respectively]. Moreover, differences between U1D and U2D mean scores, examined through *t*-tests, were not found to be significant [$t_{21} = -0.101$, $p = 0.323$], while differences between U1ND and U2ND were found to be significant [$t_{21} = -4.331$, $p < 0.001$].

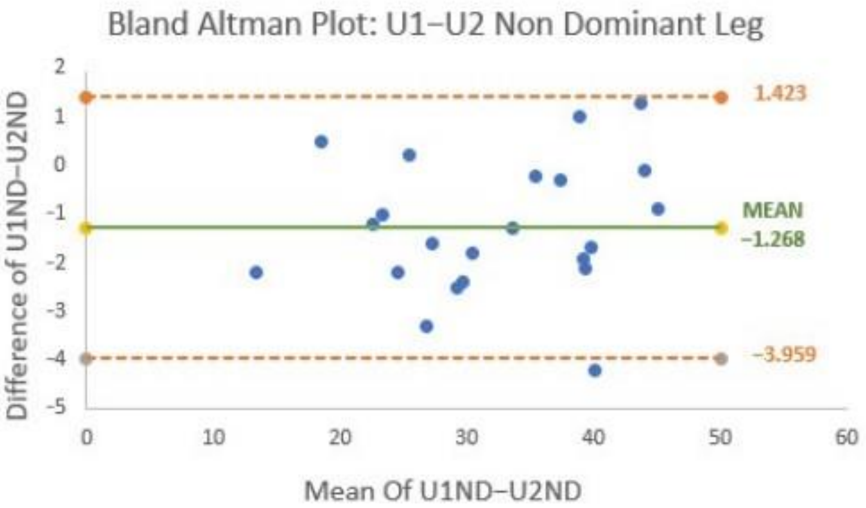


Figure 4. Bland-Altman plot—U1ND, U2ND.

Table 1 presents mean ± SD of the new and standardized explosive power tests conducted in this study. The highest scores achieved in the novel test were U1D = 53.90 cm and U2ND = 45.50 cm. Table 2 presents strong correlations between the results of the novel test and the standardized tests. The results indicate a high magnitude of correlations (Hopkins) for the new test, with all standardized tests being high ($0.5 < r < 0.7$), very high ($0.7 < r < 0.9$), and nearly perfect ($r > 0.9$). Correlations between U1D/U1ND and both horizontal tests (5/10 m sprint) were high; correlations between U1D/U1ND and all CMJ vertical tests were very high. Finally, especially high correlations were seen between the U1D/U1ND scores and the BP test ($r > 0.9$) ($r = 0.956$ and $r = 0.933$, respectively).

Table 1. Results of Lower Limb Explosive Power Tests.

Basketball Players (N = 22)	M ± SD
5 m Sprint (s)	1.08 ± 0.07
10 m Sprint (s)	1.84 ± 0.09
BP (m)	13.2 ± 1.73
CMJF (cm)	43.8 ± 8.6
CMJWH (cm)	35.8 ± 7.6
CMJDF (cm)	24.40 ± 5.45
CMJDWH (cm)	19.90± 4.20
CMJNDF (cm)	23.20 ± 5.51
CMJNDWH (cm)	19.72 ± 4.72
U1D (cm)	38.21 ± 9.00
U2D (cm)	38.56 ± 9.41
U1ND (cm)	31.55 ± 8.95
U2ND (cm)	32.82 ± 8.73

Table 2. Correlations between the Novel Test and Standardized Tests.

	Basketball Players (N = 22)			
	U1D (CI 95%)		U1ND (CI 95%)	
5 m Sprint (s)	−0.571 *	(−1.099, −0.199)	−0.535 *	(−1.047, −0.147)
10 m Sprint (s)	−0.670 *	(−1.260, −0.361)	−0.637 *	(−1.203, −0.303)
BP (m)	0.956 ***	(1.448, 2.347)	0.933 ***	(1.231, 2.131)
CMJF (cm)	0.848 **	(0.799, 1.699)	0.851 **	(0.810, 1.709)
CMJWH (cm)	0.856 **	(0.829, 1.728)	0.827 **	(0.729, 1.628)
CMJDF (cm)	0.859 **	(0.840, 1.739)	0.888 **	(0.963, 1.862)
CMJDWH (cm)	0.811 **	(0.680, 1.580)	0.780 **	(0.596, 1.495)
CMJNDF (cm)	0.775 **	(0.583, 1.482)	0.860 **	(0.844, 1.743)
CMJNDWH (cm)	0.706 **	(0.430, 1.329)	0.775 **	(0.583, 1.482)

Magnitude of correlation: * high, ** very high, *** nearly perfect.

5. Discussion

The aim of the current study was to develop a unique test for assessing lower limb explosive power in basketball players in the field and to assess its reliability and validity. Indeed, the game of basketball requires players to use lower limb explosive power for performing horizontal and vertical movements, as well as complex jumps that require a combination of the two [1,5]. Players also need to have strong coordination capabilities between their upper and lower limbs for performing actions, such as penetration to the basket through layups, while continuously maintaining control of the ball [1,8]. The main findings of the study indicate a high correlation between the test/retesting results for both legs. For the horizontal tests, the highest correlation was seen for the 10 m sprint test. The highest correlation was seen for the BP test (r > 0.9), where both horizontal and vertical skills were combined.

In 2017, Rodríguez-Rosell et al. [32] examined the reliability and validity of two standardized tests for vertical jumps (CMJ and the Abalakov jump) and two specific jump tests that combine both horizontal and vertical abilities (run-up and 2-LEGS or 1-LEG take-off jump). The researchers examined these tests as predictors of sprint and strength performance among soccer and basketball players. All four tests presented high intraclass correlation coefficients, regardless of the players' age or sport. The 1-LEG test presented slightly greater variability than the other three tests, as well as the least validity. The researchers explained these findings as the result of the more complex motor structure of this jump. Indeed, assessing the 1-LEG test among both soccer and basketball players may have created a limitation, as these two ball games require different physical abilities [16,33]. Rodríguez-Rosell et al.'s [32] findings led us to create a more unique 1-LEG test specifically for basketball players, assessing a basic movement that is learned and acquired when one first begins to play basketball, yet this test is constantly repeated during practice and games at all levels and ages while holding a ball. As such, the use of the ball during tests should not perceived as a limitation and may even be advantageous when assessing jumping, specifically among basketball players [1,11].

The skills exhibited in the novel test are relatively complex, requiring explosive power on two planes (horizontal and vertical) while holding a ball. However, for professional basketball players, these are basic, frequently used skills in both warmups, practice, and games [10]. For this reason, we chose to only assess highly experienced basketball players from professional clubs—to ensure that they possess very good control of the examined movement, and this was performed as a means of decreasing the limitation of a learning curve (i.e., learning a new skill specifically for the test) between the test and the retest. Moreover, unlike previous studies, we assessed a combination of a horizontal jump of up to 1.5 m forward—as the jump in the test was performed after a horizontal run with the ball and as a natural continuation of this action [11,32].

The main findings of the study indicate a high correlation between the test/retesting results for both legs, with mean scores remaining very similar. The magnitude of correlation of the new test was nearly perfect (r > 0.9) for both legs. Moreover, as only one point was found to be outside the confidence interval (CI), our findings enhance the reliability and validity of the new test for both legs.

Although the new test was found to be valid for both legs, differences were seen in the mean scores when comparing the test/retest results. For the dominant leg, better scores were seen in the test (U1D), while, for the non-dominant leg, better scores were seen in the retest, conducted 72 h after the initial test (U2ND). This finding could stem from the ongoing need for strong coordination skills with the dominant leg when playing basketball—as no differences were seen in the test-retest scores for this leg. Although the test was performed on one leg, it was performed after a layup—which could explain the large differences in mean scores compared to the CMJ tests that were performed on one leg without accelerating beforehand. According to the Bland-Altman plot, accuracy is higher for the dominant (preferred) leg, as compared to the non-dominant leg, where variability is higher. This is apparently due to the fact that the participants are more used to using the dominant leg in games and practice, so there is more consistency.

For the horizontal tests, the highest correlation was seen for the 10 m sprint test (r > 0.670), which required greater acceleration than the 5 m sprint, as well as a greater combination of horizontal and vertical movements. In the vertical tests, the CMJ presented very high correlations for all assessments, with the highest correlation being between the CMJF and the CMJDF (r > 0.8). As in these tests, the participants were required to jump with their hands free, not on their hips, and this could explain the higher significance of the results.

The highest correlation was seen for the BP test (r > 0.9), where both horizontal and vertical skills were combined. As this is a typical requirement when playing basketball, this finding enhances the importance and relevance of the newly developed test. As with the novel testing protocol, the BP test requires strong capabilities of both vertical and horizontal lower limb explosive power [5]. The participants possessed a strong foundation for doing so, based on their training in plyometrics and in explosive power—which is why we compared the BP test and our newly proposed test. Yet, despite the combination of movements, the BP test is not as specific as the new test in replicating and assessing basketball players' explosive power. As such, our findings indicate the significance of the newly proposed test for assessing lower limb explosive power among basketball players in the field.

The findings of this research are in line with those of previous studies that assessed standardized tests for measuring lower limb explosive power and complex coordination (that require both horizontal and vertical capabilities) for a range of ball games [11,32,34,35]. Yet, to the best of our knowledge, this is the first research study to examine a unique test for the game of basketball, compared to other standardized tests that could be relevant to a number of different sports.

The current study has important value for research and assessment in sports in general, and in basketball in particular. However, the research does entail a number of limitations. First, the participants only included male basketball players from an elite youth league team in Israel. As such, future studies could benefit from administering the test to a more varied sample to include a larger range of positions and ages, as well as both male and female players. In addition, it would be interesting to examine the new test for jumps using both legs, such as penetration to the basket, as well as assessing the test on non-professional basketball players who have not been trained to develop necessary coordination and control.

6. Conclusions and Practical Applications

The game of basketball is unique, as it requires lower limb explosive power combined with high coordination capabilities. Professional basketball teams of all ages are committed to a tight and strenuous schedule. As a result, trainers and coaches may encounter difficulties in assessing the players' physical abilities, especially during the game season [1,36–38].

In addition, although a number of validated tests assess explosive power and players of ball games, none are specifically suited to the game of basketball, thereby making the assessment task more difficult [1].

The novel test that we developed, which is specific for the game of basketball, could provide trainers and coaches with a unique and applicable field tool for assessing players' lower limb explosive power—especially during busy schedules [39]. Doing so will save time, as only the one test will be needed, rather than having to employ a range of tests. In addition to saving resources, using this novel test could enhance results, assessments, and comparisons, as it is suited to the game of basketball, with its unique and specific movements. Moreover, as the new test is performed on one leg, it can be used to assess players' dominant and non-dominant legs individually—offering insights into symmetry and differences between the legs, as well as the ability to return to playing after an injury. As such, the test could also be helpful for strength and conditioning coaches and physiotherapists.

It is important to note that the standardized tests that assess explosive power, as presented in this study, remain relevant and important—and they may offer additional insights and conclusions. However, when seeking a more focused and specific test for the game of basketball, the unique test presented in this article offers added value to the field of basketball and its assessments.

Author Contributions: Conceptualization—A.S. had the original idea of the paper and wrote the paper, R.G.—main collaborator, P.E.A. and J.C.-G.—directors and final approvals of the text. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee at the authors' affiliated academic institution (Reference number: 407).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author and the first author. The data are not publicly available due to ethical and privacy restrictions.

Acknowledgments: We thank the participants of the study for their commitment and efforts. We also wish to thank the individual players and coaches for taking part in this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gottlieb, R.; Shalom, A.; Calleja-Gonzalez, J. Physiology of Basketball–Field Tests. Review Article. *J. Hum. Kinet.* **2021**, *77*, 159–167. [CrossRef] [PubMed]
2. Gál-Pottyondy, A.; Petró, B.; Czétényi, A.; Négyesi, J.; Nagatomi, R.; Kiss, R.M. Collection and Advice on Basketball Field Tests—A Literature Review. *Appl. Sci.* **2021**, *11*, 8855. [CrossRef]
3. Delextrat, A.; Cohen, D. Physiological Testing of Basketball Players: Toward a Standard Evaluation of Anaerobic Fitness. *J. Strength Cond. Res.* **2008**, *22*, 1066–1072. [CrossRef] [PubMed]
4. Abdelkrim, N.; El Fazaa, S.; El Ati, J.; Tabka, Z. Time-motion analysis and physiological data of elite under-19-year-old bas-ketball players during competition. *Br. J. Sports Med.* **2007**, *41*, 69–75. [CrossRef]
5. Gottlieb, R.; Eliakim, A.; Shalom, A.; Iacono, A.; Meckel, Y. Improving Anaerobic Fitness in Young Basketball Players: Plyom-etric vs. Specific Sprint Training. *J. Athl. Enhanc.* **2014**, *3*, 1000148.
6. Arede, J.; Vaz, R.; Franceschi, A.; Gonzalo-Skok, O.; Leite, N. Effects of a combined strength and conditioning training pro-gram on physical abilities in adolescent male basketball players. *J. Sports Med. Phys. Fitness* **2019**, *59*, 1298–1305. [CrossRef]
7. Ciacci, S.; Bartolomei, S. The effects of two different explosive strength training programs on vertical jump perfor-mance in basketball. *J. Sports Med. Phys. Fitness* **2018**, *58*, 1375–1382. [CrossRef]
8. Mancha-Triguero, D.; García-Rubio, J.; Calleja-González, J.; Ibáñez, S.J. Physical fitness in basketball players: A systematic review. *J. Sports Med. Phys. Fitness* **2019**, *59*, 1513–1525. [CrossRef] [PubMed]

9. Aksović, N.; Bjelica, B.; Milanović, F.; Milanovic, L.; Jovanović, N. Development of Explosive Power in Basketball Players. *Turk. J. Kinesiol.* **2021**, *7*, 44–52. [CrossRef]
10. Apostolidis, N.; Nassis, G.P.; Bolatoglou, T.; Geladas, N.D. Physiological and technical characteristics of elite young basketball players. *J. Sports Med. Phys. Fitness* **2004**, *44*, 157–163. [PubMed]
11. Karcher, C.; Buchheit, M. Shooting Performance and Fly Time in Highly Trained Wing Handball Players: Not Everything Is as It Seems. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 322–328. [CrossRef] [PubMed]
12. Gómez-Carmona, C.D.; Feu, S.; Pino-Ortega, J.; Ibáñez, S.J. Assessment of the Multi-Location External Workload Profile in the Most Common Movements in Basketball. *Sensors* **2021**, *21*, 3441. [CrossRef] [PubMed]
13. Ferioli, D.; Rampinini, E.; Martin, M.; Rucco, D.; La Torre, A.; Petway, A.; Scanlan, A. Influence of ball possession and playing posi-tion on the physical demands encountered during professional basketball games. *Biol. Sport* **2020**, *37*, 269–276. [CrossRef]
14. Hoare, D.G. Predicting success in junior elite basketball players—The contribution of anthropometic and physiological attributes. *J. Sci. Med. Sports* **2000**, *3*, 391–405. [CrossRef] [PubMed]
15. Fragoso, I.; Ramos, S.; Teles, J.; Volossovitch, A.; Ferreira, A.P.; Massuça, L.M. The Study of Maturational Timing Effect in Elite Portuguese Adolescent Basketball Players: Anthropometric, Functional and Game Performance Implications. *Appl. Sci.* **2021**, *11*, 9894. [CrossRef]
16. Sheppard, J.M.; Young, W.B. Agility literature review: Classifications, training and testing. *J. Sports Sci.* **2006**, *24*, 919–932. [CrossRef]
17. Chaouachi, A.; Brughelli, M.; Chamari, K.; Levin, G.T.; Ben Abdelkrim, N.; Laurencelle, L.; Castagna, C. Lower Limb Maximal Dynamic Strength and Agility Determinants in Elite Basketball Players. *J. Strength Cond. Res.* **2009**, *23*, 1570–1577. [CrossRef]
18. McInnes, S.E.; Carlson, J.S.; Jones, C.J.; McKenna, M.J. The physiological load imposed on basketball players during compe-tition. *J. Sports Sci.* **1995**, *13*, 387–397. [CrossRef]
19. Stojanovic, M.D.; Ostojic, S.M.; Calleja-González, J.; Milosevic, Z.; Mikic, M. Correlation between explosive strength, aero-bic power and repeated sprint ability in elite basketball players. *J. Sports Med. Phys. Fitness* **2012**, *52*, 375–381.
20. Currell, K.; Jeukendrup, A.E. Validity, Reliability and Sensitivity of Measures of Sporting Performance. *Sports Med.* **2008**, *38*, 297–316. [CrossRef] [PubMed]
21. García-López, J.; Peleteiro, J.; Rodgríguez-Marroyo, J.A.; Morante, J.C.; Herrero, J.A.; Villa, J.G. The validation of a new meth-od that measures contact and flight times during vertical jump. *Int. J. Sports Med.* **2005**, *26*, 294–302. [CrossRef] [PubMed]
22. World Medical Association. World Medical Association Declaration of Helsinki. *JAMA* **2013**, *310*, 2191. [CrossRef] [PubMed]
23. Bosquet, L.; Berryman, N.; Dupuy, O. A Comparison of 2 Optical Timing Systems Designed to Measure Flight Time and Contact Time During Jumping and Hopping. *J. Strength Cond. Res.* **2009**, *23*, 2660–2665. [CrossRef] [PubMed]
24. Glatthorn, J.F.; Gouge, S.; Nussbaumer, S.; Stauffacher, S.; Impellizzeri, F.M.; Maffiuletti, N.A. Validity and Reliability of Optojump Photoelectric Cells for Estimating Vertical Jump Height. *J. Strength Cond. Res.* **2011**, *25*, 556–560. [CrossRef]
25. Condello, G.; Khemtong, C.; Lee, Y.H.; Chen, C.H.; Mandorino, M.; Santoro, E.; Liu, C.; Tessitore, A. Validity and Reliability of a Photoelec-tric Cells System for the Evaluation of Change of Direction and Lateral Jumping Abilities in Collegiate Basketball Athletes. *J. Funct. Morphol. Kinesiol.* **2020**, *5*, 55. [CrossRef]
26. Chu, D.A. *Jumping into Plyometrics*; Human Kinetics: Champaign, IL, USA, 1998.
27. Markovic, G.; Dizdar, D.; Jukic, I.; Cardinale, M. Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *J. Strength Cond. Res.* **2004**, *18*, 551.
28. Freitas, T.T.; Martinez-Rodriguez, A.; Calleja-González, J.; Alcaraz, P.E. Short-term adaptations following Complex Train-ing in team-sports: A meta-analysis. *PLoS ONE* **2017**, *12*, e0180223. [CrossRef] [PubMed]
29. Myles, P.S.; Cui, J.I. Using the Bland–Altman method to measure agreement with repeated measures. *Br. J. Anaesth.* **2007**, *99*, 309–311. [CrossRef]
30. Giavarina, D. Understanding Bland Altman analysis. *Biochem. Med.* **2015**, *25*, 141–151. [CrossRef]
31. Hopkins, W.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. [CrossRef]
32. Rodríguez-Rosell, D.; Mora-Custodio, R.; Franco-Márquez, F.; Yáñez-García, J.M.; González-Badillo, J.J. Traditional vs. Sport-Specific Vertical Jump Tests: Reliability, Validity, and Relationship with the Legs Strength and Sprint Performance in Adult and Teen Soccer and Basketball Players. *J. Strength Cond. Res.* **2017**, *31*, 196–206. [CrossRef] [PubMed]
33. Young, W.B.; McDowell, M.H.; Scarlett, B.J. Specificity of sprint and agility training methods. *J. Strength Cond. Res.* **2001**, *15*, 315–319. [PubMed]
34. Sheppard, J.M.; Cronin, J.B.; Gabbett, T.J.; McGuigan, M.R.; Etxebarria, N.; Newton, R.U. Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *J. Strength Cond. Res.* **2008**, *22*, 758–765. [CrossRef]
35. Shalfawi, S.A.I.; Sabbah, A.; Kailani, G.; Tønnessen, E.; Enoksen, E. The relationship between running speed and measures of vertical jump in professional basketball players: A field-test approach. *J. Strength Cond. Res.* **2011**, *25*, 3088–3092. [CrossRef]
36. Huyghe, T.; Alcaraz, P.E.; Calleja-González, J.; Bird, S.P. The underpinning factors of NBA game-play performance: A sys-tematic review (2001–2020). *Phys. Sportsmed.* **2022**, *50*, 94–122. [CrossRef] [PubMed]
37. Edwards, T.; Spiteri, T.; Piggott, B.; Bonhotal, J.; Haff, G.G.; Joyce, C. Monitoring and Managing Fatigue in Basketball. *Sports* **2018**, *6*, 19. [CrossRef]

38. Davis, J.K.; Oikawa, S.Y.; Halson, S.; Stephens, J.; O'Riordan, S.; Luhrs, K.; Sopena, B.; Baker, L.B. In-Season Nutrition Strategies and Recovery Modalities to Enhance Recovery for Basketball Players: A Narrative Review. *Sports Med.* **2022**, *52*, 971–993. [CrossRef]
39. Huyghe, T.; Scanlan, A.; Dalbo, V.; Calleja-González, J. The Negative Influence of Air Travel on Health and Performance in the National Basketball Association: A Narrative Review. *Sports* **2018**, *6*, 89. [CrossRef]