DOCTORAL THESIS

INTERNATIONAL DOCTORAL SCHOOL

Doctoral Programme in Sport Science

Validity and reliability of a unique aerobic field test for estimating VO_{2max} among basketball players and the differences by gender, ages and relative age effect.

Author:

Ronen Gottlieb

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THESIS SUPERVISORS' AUTHORISATION
FOR THESIS SUBMISSION

Prof. Pedro E. Alcaraz Ramón and Prof. Julio Calleja González, as Supervisors of the Doctoral Thesis 'Validity and reliability of a unique aerobic field test for estimating VO_{2max} among basketball players and the differences by gender, ages and relative age effect by Mr Ronen Gottlieb in the Doctorate Programme 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 25th, 2023.

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ABSTRACT

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.

This study aimed at developing and validating an innovative field test for measuring the aerobic capacity of basketball players during games. Such capacity is necessary for recovering from high frequency anaerobic actions such as sprinting and continuing to perform well. To recover, the body must rebuild its creatine phosphate reserve and emit accumulated phosphate in very short periods of time. The participants included 21 male basketball players on an elite youth league in Israel, aged 16.4 years on average. In addition to participating in the proposed test (Yo-Yo Recovery Test for Basketball Players) twice (test/re-test), the players also performed three previously validated tests (Bruce Protocol Stress Test, Yo-Yo Intermittent Recovery Level 1 Test, and Yo-Yo Endurance Test). For each test, the players' time and distance covered were documented, as were their maximum

oxygen consumption and heart rate during recovery, and their perceived level of exertion. Our findings indicate the validity and reliability of the proposed aerobic field test for basketball players. Moreover, the test requires shorter times and distances for obtaining results than the other three tests. As such, this tool could be highly beneficial for basketball coaches in creating optimal training programs and game plans for each individual player and for the entire team.

When playing basketball, athletes must optimally perform repeated short sprints with minimal recovery time, requiring both anaerobic and aerobic abilities, including high VO_{2max}. Yet differences have been seen between young male and female basketball players in this measure. The aim of this quantitative study was to examine differences in players' VO_{2max} by gender, age group, and relative age effect (RAE) using the novel Yo-Yo Recovery Test for Basketball Players. The study included 438 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. To assess RAE, the participants in each category were divided into three trimesters of four months, based on their date of birth. The participants' VO_{2max} was assessed using the novel aerobic test. In this study, we hypothesized that male players will exhibit greater aerobic capacity than female players of the same age and that older players will exhibit greater aerobic capacity than younger ones. Our findings supported these hypotheses, as male players presented better physical fitness results than female players in all age categories. Moreover, female players in the under-18 category presented better results than those in the under14 category, but not more than those in the under-16. Differences in the relative age effect on performance were seen between the genders and within the female participants. While the male participants presented a steady improvement with age, the results of the girls showed a different pattern. 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' aerobic capacity.

RESUMEN

El juego de baloncesto se caracteriza por periodos de actividad cortos e intensos con una frecuencia media/ alta. El baloncesto implica tipos específicos de movimientos, requisitos fisiológicos y fuentes de energía. La duración de las respuestas fisiológicas que implican respuestas de ATP, CP y glucólisis a este tipo de actividad es de 5-6 segundos para un solo sprint, y la contribución del sistema aeróbico es inferior al 10%. Los períodos de recuperación en el baloncesto, por regla general, no son lo suficientemente largos para llenar el vacío de actividades de tan alta intensidad. Es difícil lograr el mismo nivel de rendimiento de forma constante a lo largo del tiempo en sprints repetidos. Esto significa que los jugadores de baloncesto necesitan una gran capacidad atlética para demostrar la velocidad, la fuerza y la potencia necesarias para producir una actuación exitosa de la manera más competente. Por lo tanto, se necesitan pruebas que ayuden a los entrenadores a monitorear a sus jugadores y asegurarse de que tengan la capacidad fisiológica requerida para el juego. El objetivo de las pruebas de condición física es evaluar la condición de los atletas en términos de cada componente de condición física, para determinar qué se debe mejorar a través del programa de entrenamiento y realizar nuevas pruebas en momentos establecidos para evaluar si su condición ha cambiado. La literatura ofrece una serie de pruebas ampliamente utilizadas para medir la aptitud aeróbica y anaeróbica. Este artículo repasa las demandas fisiológicas del baloncesto y analiza las pruebas de campo más utilizadas en la actualidad. El artículo destaca la necesidad de un test específico que sirva a los entrenadores y preparadores físicos en el seguimiento de sus jugadores. Este estudio tuvo como objetivo desarrollar y validar una prueba de campo innovadora para medir la capacidad aeróbica de los jugadores de baloncesto durante los partidos. Tal capacidad es necesaria para recuperarse de acciones anaeróbicas de alta frecuencia como correr y continuar con un buen desempeño. Para recuperarse, el cuerpo debe reconstruir su reserva de fosfato de creatina y

emitir fosfato acumulado en períodos de tiempo muy cortos. Los participantes incluyeron a 21 jugadores de baloncesto masculinos en una liga juvenil de élite en Israel, con una edad promedio de 16,4 años. Además de participar en la prueba propuesta (Yo-Yo Recovery Test for Basketball Players) dos veces (test/re-test), los jugadores también realizaron tres pruebas previamente validadas (Bruce Protocol Stress Test, Yo-Yo Intermittent Recovery Level 1 Test, y Yo-Yo Test de Resistencia). Para cada prueba, se documentaron el tiempo y la distancia recorrida por los jugadores, así como su consumo máximo de oxígeno y frecuencia cardíaca durante la recuperación, y su nivel de esfuerzo percibido. Nuestros hallazgos indican la validez y confiabilidad de la prueba de campo aeróbico propuesta para jugadores de baloncesto. Además, la prueba requiere tiempos y distancias más cortas para obtener resultados que las otras tres pruebas. Como tal, esta herramienta podría ser muy beneficiosa para los entrenadores de baloncesto en la creación de programas de entrenamiento y planes de juego óptimos para cada jugador individual y para todo el equipo.

Al jugar baloncesto, los jugadores deben realizar de manera óptima sprints cortos repetidos con un tiempo de recuperación mínimo, lo que requiere habilidades tanto anaeróbicas como aeróbicas, incluido un alto VO_{2max}. Sin embargo, se han observado diferencias entre los jóvenes jugadores de baloncesto masculinos y femeninos en esta medida. El objetivo de este estudio cuantitativo fue examinar las diferencias en el VO_{2max} de los jugadores por sexo, grupo de edad y efecto relativo de la edad (RAE) utilizando la novedosa prueba de recuperación Yo-Yo para jugadores de baloncesto. El estudio incluyó a 438 jóvenes jugadores de baloncesto, hombres y mujeres, de una variedad de ligas israelíes, que se dividieron en tres categorías: sub-14, sub-16 y sub-18. Para evaluar la RAE, los participantes de cada categoría se dividieron en tres trimestres de cuatro meses, según su fecha de nacimiento. El VO_{2max} de los participantes se evaluó mediante la nueva prueba aeróbica. En este estudio, planteamos la hipótesis de que los jugadores masculinos exhibirán una mayor capacidad aeróbica que las jugadoras de la misma edad y que los jugadores mayores exhibirán una mayor capacidad aeróbica que los más jóvenes. Nuestros Los hallazgos respaldaron estas hipótesis, ya que los jugadores masculinos presentaron

mejores resultados de aptitud física que las jugadoras en todas las categorías de edad. Además, las jugadoras de la categoría sub-18 presentaron mejores resultados que las de la sub-14, pero no más que las de la sub-16. Se observaron diferencias en el efecto de la edad relativa sobre el rendimiento entre los géneros y dentro de las participantes femeninas. Mientras que los participantes masculinos presentaron una mejora constante con la edad, los resultados de las chicas mostraron un patrón diferente. Los hallazgos se presentan en una tabla de logros que presenta los resultados de aptitud física esperados por edad y género, para beneficio de los entrenadores de baloncesto y preparadores físicos al momento de evaluar la capacidad aeróbica de sus jugadores.

KEY WORDS

Aerobic, Anaerobic, Basketball players, Explosive, Fitness field test, Gender Maximal aerobic capacity, Performance analysis of sport, Relative Age Effect, Yo-Yo recovery 1Test.

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"*Some people want it to happen, some wish it would happen, others make it happen.*" - **Michael Jordan**

GENERAL TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

ATP	Adinozine tree phosphate
COD	Change of direction
CMJ	Countermovement jump
CP	Creatine phosphat
HR	Harte rate
VO_{2max}	Maximal aerobic capacity
VJ	Vertical jump
RAE	Relative age effect
YYREC1	Yo-Yo recovery test level 1
YYRECB	Yo –Yo recovery test for basketball
YYEND	Yo Yo endurance test
RSA	Repeated sprint ability
RPE	Rating of perceived exertion

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I – INTRODUCTION

1 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, in order to recover faster (Castagna et al., 2008).

Besides, 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% (Delextrat et al., 2008). 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. Thus, 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 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) 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).

Furthermore, it is a sport that requires a complex combination of individual technical skills, team strategies, tactics and psychological and motivational aspects. In the recent years, there has been a clear increase in the physical demand of the competition due to changes in regulations and tactical evolution of the game These changes include a decrease on (Abdelkrim et al., 2010). The available time to attack the basket from 30 to 24 s, a reduction in the time spent on the backcourt from 10 to 8 s as well as a different subdivision of the game into four 10 min quarters instead of two 20 min halves (Crisafulli et al., 2002).

A field test for basketball players is a performance evaluation designed to assess an athlete's basketball skills and physical fitness (Petway et al., 2020). It typically involves a variety of exercises and drills that simulate game situations and test an athlete's speed, agility, endurance, strength, and overall athleticism. These tests are used by coaches and scouts at all levels, from youth leagues to professional teams, to identify players who have the potential to excel on the court (Abdelkrim, 2010). The results of the field test can help coaches and scouts make informed decisions about which players to recruit or select for their teams. Basketball field tests can vary depending on the level of competition and the specific needs of the team or coach. Some common drills and exercises used in basketball field tests include:

- ✓ Shooting drills: This involves testing an athlete's accuracy and consistency in shooting the ball from various spots on the court (Pojskić, 2011).

- ✓ Dribbling drills: This evaluates an athlete's ball handling skills, ability to change direction quickly, and control of the ball under pressure (Santos, 2020).
- ✓ Defensive drills: This measures an athlete's ability to stay in front of their opponent, block shots, and steal the ball.

  Conditioning tests: This assesses an athlete's endurance and fitness level through exercises such as running, jumping, and sprinting.
- ✓ Agility drills: This evaluates an athlete's ability to move quickly and change direction on the court, such as performing shuttle runs and lateral jumps (Sekulic, 2017).

Vertical jump tests: This measures an athlete's explosive power and jumping ability, which are essential for rebounds and blocking shots (Meylan, 2009).

Speed and acceleration tests: This assesses an athlete's ability to sprint and accelerate quickly on the court.

Basketball field tests are an important tool for coaches and scouts to identify talented players and assess their potential to succeed at different levels of competition. However, it's important to note that these tests are just one piece of the puzzle, and that other factors such as game performance, character, and attitude should also be considered when evaluating players for a team (Gottlieb, 2020).

Another important aspect of basketball field tests is injury prevention. Coaches and trainers may use these tests to identify any physical limitations or imbalances that could increase an athlete's risk of injury, and then develop an individualized training program to address these issues (Alexander, 2016).

By conducting regular tests, coaches and trainers can track an athlete's physical development and identify areas of improvement. This can help athletes set goals and work towards achieving them, as well as help coaches and scouts make informed decisions about the athlete's potential for growth and success (Stephen, 2016).

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 (Gottlieb, 2020).

To establish the validity and reliability of a field test, researchers typically compare the results of the test to a gold standard measure of VO_{2max}, such as a laboratory-based maximal exercise test. The degree of agreement between the field test and gold standard measure can indicate the validity of the field test.

Reliability refers to the consistency and repeatability of the test results. This can be assessed by administering the test multiple times to the same group of participants and calculating the degree of agreement between the results.

Regarding differences by gender, ages, and relative age, it is possible that these factors may impact the validity and reliability of the field test. For example, research has shown that Time-motion analysis has shown that during a basketball game, the total number of movements performed by players depends on the competition level. According to (Ferioli et al, 2019) higher level competitors execute a mean of 703 movements, performing over 100 high-intensity actions per minute of playing time. Of note, players perform more than one jump per minute played (an average of more than 27 during a match and are involved in high-intensity running activities, such as sprinting, every 39 s. In this regard, jumping capability, the ability to perform repeated sprint efforts and change of direction (COD) ability are amongst the most important determinants of high performance in basketball. Different studies (Hori, 2008) have shown that better players tend to display higher neuromuscular performances measured by the means of strength, vertical jump (VJ), sprint, repeated sprint, and COD abilities. In particular, considering VJ, differences of 8.8% in jump height have been reported between elite players and average-level practitioners. Similar conclusions were drawn concerning COD ability, as differences of 6.2% were found in COD tests outcomes among athletes with different skill levels (Cormery, 2008). Therefore, based on the match- demands data and the evidence of superior neuromuscular performance in basketballers of higher competition level, it can be inferred that the development of physical capabilities is crucial in this sport, as it may allow players to run faster and jump higher than the opponents, to sustain match-related contacts and hits and, ultimately, exploit their technical and tactical skills during a game.

Time motion analysis can provide coaches and trainers with valuable insights into the performance of their players. For example, it can help identify which players are the most active on the court, how much energy they expend during different activities, and how much time they spend in different areas of the court. This information can then be used to adjust training programs and game strategies to improve performance (Ostojic, 2006).

Overall, time motion analysis is a valuable tool for coaches, trainers, and players looking to optimize their performance on the basketball court.

There are differences in time motion analysis between male and female basketball players. Research has shown that in general, male players tend to cover more ground and expend more energy than female players during a game. However, it's important to note that individual differences in player style and position can also affect time motion analysis, regardless of gender (Scalan, 2015).

Some specific differences in time motion analysis between male and female basketball players include:

Speed: Male players tend to move at a faster pace than female players, covering more ground in a shorter amount of time (Stojanovic, 2017).

Jumping: Male players tend to jump higher and more frequently than female players during a game ((Stojanovic, 2017).

Agility: Female players tend to be more agile than male players, which means they can change direction more quickly and move more fluidly on the court (Alemdaroğlu, 2012).

Endurance: While both male and female players require endurance to play a full game, research suggests that female players may have a greater aerobic endurance capacity than male players (Craig, 2015).

Physical contact: Male basketball players tend to experience more physical contact during a game, which can affect their time motion analysis (Stojanovic, 2017).

Do these differences are generalizations and do not apply to all male and female basketball players? Individual players may have their own unique styles and strategies that affect their time motion analysis.

This is partly due to the fact that male players are typically larger and stronger than female players. Defensive strategies: Female basketball players may use different defensive strategies than male players, which can affect their time motion analysis. For example, female players may rely more on positioning and footwork rather than physical contact to defend their opponents. Offensive strategies: Male and female basketball teams may use different offensive strategies, which can affect the time motion analysis of their players. For example, male teams may rely more on individual players to score points, while female teams may use more of a team-based approach.

Playing time: Male basketball players typically play for longer periods of time than female players. This means that male players may have more opportunities to cover ground and expend energy during a game.

Recovery time: Female basketball players may have a shorter recovery time between games than male players. This can affect their time motion analysis, as players may not have as much time to recover from previous games before playing again.

Overall, time motion analysis can provide valuable insights into the performance of male and female basketball players. By identifying differences in time motion analysis between genders, coaches and trainers can tailor their training programs and game strategies to optimize performance for their players.

Rest breaks: Male basketball players may take longer rest breaks during a game than female players. This can affect their time motion analysis, as players may have more time to recover and recharge before returning to the court.

Female basketball players may show more emotional responses to the game than male players. This can affect their time motion analysis, as players may need to expend additional energy and focus to manage their emotions during the game.

The number of rebounds, changes of direction, sprints, and lateral movements in basketball can vary greatly depending on the style of play, position, and individual performance of each player. However, here are some general guidelines for each activity:

Changes of direction: Changes of direction are a critical part of basketball, particularly for guards and forwards who need to evade defenders and create scoring opportunities. The number of changes of direction can vary depending on the player's position and style of play. In general, a player may change direction several times per possession.

Sprints: Sprints occur frequently in basketball, particularly during fast breaks and transitions. Players who are responsible for leading fast breaks, such as point guards and small forwards, may sprint more often than other players. On average, a player may sprint 100-150 meters per game.

Lateral movements: Lateral movements, such as shuffling and sliding, are important for both offensive and defensive players. Guards and small forwards may perform more lateral movements than centers and power forwards. In general, a player may perform several lateral movements per possession.

Here are some statistics related to basketball (Stojanovic, 2017):

The number of time-motion events in basketball can vary greatly depending on the game's pace, style, and individual performance of each player. However, here are some general guidelines for each activity:

Running/jogging: Players in basketball spend a significant amount of time running and jogging up and down the court. According to research, players can cover anywhere from 3.9 to 4.3 miles (6.3 to 6.9 KM) per game, depending on their position and the style of play. Walking: Players also spend some time walking on the court, particularly during slower-paced moments, such as during timeouts or when the ball is out of bounds.

Sprinting: Players will sprint during fast breaks and transitions or when trying to create separation from defenders. The number of sprints can vary depending on the player's position and style of play. In general, a player may perform 30-50 sprints per game.

Jumping: Jumping is a key component of basketball, as players frequently jump to shoot, block shots, and grab rebounds. Players can jump anywhere from 20 to 30 times per game, depending on their position and style of play.

Change of direction: Basketball requires players to change direction frequently to evade defenders and create scoring opportunities. The number of changes of direction can vary depending on the player's position and style of play. In general, a player may change direction several times per possession.

Defensive slides: Defensive slides are lateral movements that are critical for defensive players. Guards and small forwards may perform more defensive slides than centres and power forwards. In general, a player may perform several defensive slides per possession.

These are general guidelines, and the number of time-motion events can vary greatly depending on the style of play, position, and individual performance of each player. Time-motion analysis can provide a more detailed analysis of a player's movement patterns during a game.

The number of possessions in a basketball game can vary depending on the pace of the game, the number of turnovers, and the rebounding rate. In general, a team will have a possession when they gain control of the ball and then attempt to score a basket. The opposing team will then have a possession when they gain control of the ball, either through a steal, rebound, or a change of possession after a successful shot.

The number of possessions in a basketball game in Europe can vary depending on the pace of the game, the rules of the specific league or tournament, and the style of play of the teams. However, in general, European basketball games tend to have fewer possessions than NBA games. (Huyghe, 2022). In the Euro League, which is the top professional basketball league in Europe, teams generally average between 60 and 70 possessions per game. This is lower than the average number of possessions in an NBA game, which can range from 70 to 100 possessions per game.

The lower number of possessions in European basketball can be attributed to several factors. For example, European basketball generally emphasizes a more team-oriented style of play, with an emphasis on ball movement, player movement, and offensive and defensive systems. This style of play often leads to slower-paced games, with fewer fast breaks and more deliberate offensive sets.

Field tests are a type of physical fitness test that can be used to assess an athlete's performance in basketball. These tests are often used by coaches and trainers to evaluate a player's strengths and weaknesses, as well as to track progress over time. Here are some common field tests used in basketball: Vertical jump test: This test measures a player's ability to jump vertically and is a good indicator of explosive power. The player stands under a wall-mounted apparatus with a series of horizontal slats that are gradually increased in height. The player jumps as high as possible and touches the highest slat they can reach.

Agility test: This test measures a player's ability to change direction quickly and efficiently. The player runs through a series of cones or markers in a specific pattern, trying to complete the course as quickly as possible.

Sprint test: This test measures a player's speed and acceleration. The player runs a specified distance, such as a full court or a half court, as quickly as possible.

One common field test used to measure aerobic capacity in basketball players is the Yo-Yo Intermittent Recovery Test (Yo-Yo IR). Here's how it works:

The player starts at one end of the court and runs to the other end before the beep sounds. The player then turns and runs back to the starting point before the next beep sounds. The player continues running back and forth, with the distance between the two points increasing gradually over time. If the player fails to reach the line before the beep sounds twice in a row, the test is over and the distance covered is recorded.

The Yo-Yo IR test measures a player's ability to perform repeated high-intensity efforts with short rest periods, which is similar to the demands of basketball gameplay. The test is usually repeated several times, with a short rest period between each attempt, and the results are used to assess the player's aerobic fitness level.

Another field test that can be used to measure aerobic capacity in basketball players is the beep test or the 20-meter shuttle run test. This test involves running back and forth between two markers placed 20 meters apart, with the speed increasing over time. The test is designed to measure an athlete's maximal oxygen uptake (VO_{2max}) and is a good indicator of aerobic fitness. Both of these tests are effective ways to measure aerobic capacity in basketball players and can provide coaches and trainers with valuable information about the player's fitness level and areas for improvement. Good achievements for aerobic capacity field test in basketball. Good achievements for the aerobic capacity field test in basketball can vary depending on the test used and the age, gender, and skill level of the player. Here are some general benchmarks for the Yo-Yo Intermittent Recovery Test (Yo-Yo IR) that can be used as a guide:

Beginner-level basketball players may reach a distance of around 600-800 meters on the Yo-Yo IR test. Intermediate-level basketball players may reach a distance of around 900-1,200 meters. Advanced-level basketball players may reach a distance of 1,300 meters or more. It's important to note that these are just general benchmarks, and individual results can vary depending on a range of factors, including age, gender, weight, and training history. Additionally, the results of the test should be interpreted in conjunction with other measures of fitness and skill, such as sprint times, agility tests, and shooting accuracy. Overall, achieving a high score on the Yo-Yo IR test or other aerobic capacity field tests can indicate that a basketball player has good endurance, energy levels, and overall fitness, which can translate to better performance on the court.

It's important to note that the Yo-Yo IR test is just one measure of aerobic capacity and fitness in basketball players, and should be used in conjunction with other tests and evaluations to develop a comprehensive picture of the player's overall physical abilities. Other factors, such as skill level, experience, and game strategy, can also impact performance on the court.

Research has shown that the distance covered on the Yo-Yo IR test can be used to predict an athlete's VO_{2max}, using the following equation: VO_{2max} (ml/kg/min) = 36 + (0.01 x distance covered in meters x body weight in kg).

Research has shown that on average, males tend to have higher aerobic capacity than females, which can impact their performance in sports such as basketball that require endurance and cardiovascular fitness. However, it's important to note that individual differences and training can also play a significant role in an athlete's aerobic capacity, regardless of gender.

Studies have found that male basketball players typically have higher maximal oxygen uptake (VO_{2max}) levels than female players, which is a measure of the body's ability to consume and use oxygen during exercise. This can be attributed to differences in body composition, with males generally having a higher percentage of lean muscle mass and lower body fat levels, which can improve aerobic capacity.

However, some studies have shown that with appropriate training, female basketball players can improve their aerobic capacity to levels comparable to male players (Alemdaroğlu, 2012). Additionally, factors such as skill level, strategy, and teamwork can also influence performance in basketball and may be more important than gender differences in aerobic capacity.

Overall, while there may be differences in average aerobic capacity between male and female basketball players, individual differences and training can play a significant role in an athlete's performance, and it's important not to make assumptions based solely on gender.

Research has shown that aerobic capacity, as measured by maximal oxygen uptake (VO_{2max}), tends to increase with age and training in both adult and youth basketball players. However, there may be some differences in the absolute levels of VO_{2max} between adults and youth (adult basketball players generally have higher VO_{2max} levels than youth players) This can be attributed to a number of factors, including differences in body composition, training history, and physiological maturity. Adults tend to have more lean muscle mass and less body fat than youth, which can improve aerobic capacity. Additionally, adults may have more years of training and experience than youth players, allowing them to develop higher levels of aerobic fitness.

However, it's important to note that youth basketball players can still develop and improve their aerobic capacity with appropriate training. Youth athletes who engage in regular training can see significant improvements in VO_{2max} over time.

Overall, while there may be some differences in absolute levels of aerobic capacity between adult and youth basketball players, both groups can improve their fitness with appropriate training and experience.

During adolescence, there are significant changes in body composition, hormonal balance, and other physiological factors that can impact aerobic capacity (Sergio, 2023).

In summary, a wide range of factors can impact aerobic capacity in basketball players of all ages, including nutrition, sleep and recovery, environmental factors, and individual differences. By taking a holistic approach to training and considering these factors, coaches and trainers can help basketball players improve their aerobic fitness and optimize their performance on the court.

1.1 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).

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 minutes (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, because 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 (Gottlieb et al., 2014). 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 (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)
	RSA

1.2 THE PHYSICAL REQUIREMENTS OF A BASKETBALL GAME

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, 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 VO2max, 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-l (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).

1.3 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).

1.4 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:

1.4.1 **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; Sergej et al., 2006).

1.4.2 **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).

1.4.3 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).

1.4.4 **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 (Attia, 2017). Each player performs 2 sprints from a high start, with recovery of 3-5 min of rest between runs. The best time is recorded (Haugen, 2019).

1.4.5 **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). 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).

1.4.6 **Repeat Sprint Ability (RSA) Test**

Many team sports require participants to repeatedly produce maximal or near maximal sprints of short duration (1–7s) with brief recovery periods, over an extended period of time (60 – 90 min). Therefore, an important fitness component for these sports is what is often termed repeated sprint ability RSA (Bishop, 2001). This type of practice involves the metabolic changes occurring during this type of exercise, such as energy system contribution, adenosine triphosphate depletion and resynthesize, phosphocreatine degradation and resynthesize, glycolysis and glycogen lysis, 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).

1.4.7 **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 (Kipp, 2020). 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 (Barker, 2018).

1.4.8 **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 (Gottlieb, 2014).

1.4.9 **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 (Zarizi et al., 2021). 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 (Krishnan, 2018). If the athlete falls backwards during any of the jumps, the jump is disqualified, and the athlete is asked to repeat the jump (Thomas, 2020). 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 (Hardy, 2018).

1.4.10 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).

1.4.11 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).

1.5 DIFFERENCES IN AEROBIC CAPACITY BY GENDER AND AGE

Studies show that boys tend to have greater aerobic capacity than girls of similar ages, due to a range of factors, including differences in body composition, size, and hormones. For example, at the age of 14, boys have about 25% more VO_{2max} than girls, due to increased muscle mass in the former compared to increased fat tissue in the latter, as well as higher testosterone levels – thereby creating greater aerobic capacity in boys (Ziv, 2009).

Studies on basketball players tend to focus on developing analytical measuring tools, with the aim of enabling coaches and trainers to optimize their players' performance (Gottlieb et al., 2021). Yet assessment techniques much be sensitive to differences in basketball-playing abilities among players of different genders and ages. For example, dribbling in seen more in male basketball games, while running is seen more in female basketball games (Ziv, 2009). Studies also show that VO_{2max} values among female players are within the 44.0-54.0$_{mLO2/kg/min}$ range, compared to the 50-60 mLO_2/kg/min range among male players (Lidor, 2007). However, large variations can be seen in studies on VO_{2max} values among men, such as 45.3-5.9 $_{mLO2/kg/min}$ (Gocentas, 2004), 45.3-65.2$_{mLO2/kg/min}$ (Tavino, 1995), or 49.8-63.4 $_{mLO2/kg/min}$ (Abdelkrim, 2010). Such variations could stem from differences in the measurement tool or protocol that were applied in various studies.

1.5.1 EFFECT OF AGE ON AEROBIC CAPACITY

Athletes VO_{2max} refers to their maximal oxygen uptake – the highest rate at which they are able to consume oxygen during exercise (Craig, 2015). The VO_{2max} measure is an optimal tool for assessing athletes' aerobic fitness, i.e., the body's ability to deliver oxygen to the muscles while exercising and then use it to generate energy. The degree of this ability differs between people, and depends on components that are involved in the delivery of the oxygen to the muscles (including pulmonary, haematological, and cardiovascular elements), as well as on the oxidative mechanisms of the muscles that are taking part in the current exercises (Armstrong, 2006).

In young males, a gradual increase is seen in their VO_{2max}, from age 8 to 16 years, with the greatest annual increases occurring between the age of 13-15 years. In young females, on the other hand, this increase is less consistent, with their VO_{2max} being on a steady incline until they reach the age of 13 years, at which time it starts to level off. In addition, both the peak VO_{2max} and its gradual increase among young males are higher than among young females (Armstrong, 2006).

1.5.2 RELATIVE AGE EFFECT ON AEROBIC CAPACITY

In sports, in addition to the athletes' chronological age, the term Relative Age Effect (RAE) is also applied, referring to differences within the same age group. While chronological age differences imply different levels of performance and experience due to physical developmental and maturational, RAE refers to differences between people in the same age category, whereby those who were born earlier in the year present improved physical, emotional, and cognitive development compared to their peers who were born later in the year (Ibañez, 2018). Yet considerable inconsistencies on RAE can been seen in the literature. For example, athletes who were born early in the competition year were more highly represented than those who were born late in that year (Baker, 2007), yet no age-related differences were seen in the relative VO_{2max} of 7–13-year-old children (McMurray, 2002). As such, a consistent and applicable measuring tool should be used across studies, to enable comparisons and generalizations.

Following this literature review, the aim of the current study was to examine the aerobic capacity of young elite basketball players via their VO_{2max}, based on age, gender, and RAE using the validated Yo-Yo Recovery Test for Basketball Players (Gottlieb et al., 2022).

II – JUSTIFICATION

2 JUSTIFICATION

Team sport games in general, and basketball in particular, are characterized by short intense activities that are repeatedly carried out throughout the game (Petway et al., 2021). These include short intense activities such as jumping, sprinting, change of direction, and agility, as well as moderate-intensity exercises that last up to 60 seconds (Stolen, 2005). In addition, basketball players also need to present aerobic capabilities (Mancha et al., 2019) during games and practices (Castagna et al., 2008), and as such, need to also develop strong aerobic capacities (Padulo et al., 2016). Due to their importance to the players' performance, a range of methods for testing aerobic and anaerobic athletic capabilities have been developed over the past two decades (Petway et al., 2020). After performing intense activities during practices and games, the athlete's body needs to produce adenosine triphosphate (ATP), creatine phosphate (CP), and glycolysis. Rebuilding CP requires the use of blood lactate concentrations and the removal of phosphate that accumulates in the cells (Wragg, 2000). Yet short recovery periods while playing basketball and other ball games are not always sufficient for refilling these resources after high intensity activities, and it is therefore difficult for players to consistently achieve the same level of performance throughout the game (Meckel, 2009). In other words, the players' ability to continuously play well over time throughout the practice or game depends on the rebuilding of their CP reserves and removal of waste products (Meckel, 2009). Moreover, since the introduction of the 24-second shot clock (Abdelkrim et al., 2007), the concept of playing quickly has become even more crucial among players (Petway et al., 2020). In turn, this has led to even higher physical demand on players, increasing the importance of explosive strength (Stojanovic et al., 2012). As a result, fitness professionals strive to develop effective training methods for promoting and developing the physical abilities of basketball players (Freitas et al., 2017), as well as optimal techniques for monitoring and evaluating various fitness components (Edward, 2018) as a means for enhancing the players' ability to perform at their optimal and maximum capacity (Freitas et al., 2019). While basketball is considered an anaerobic-dominated game (with actions including jumping, changing direction, and footwork), these activities occur with such high frequency that they take their toll on the players (Castagna, 2008). During a game, a basketball player performs an average of 105 intense movements (each lasting two-six seconds) every 21 seconds while the clock is running. These movements lead to the consumption of 60%-75% of the body's VO_{2max} and the players' heart rate reaches 70%-90% of their maximum heartrate (Meckel, 2009). While the overall distance that a player sprints during the game accounts for less than 10% of the overall distance that an athlete moves throughout the game, these infrequent sprints have a significant impact on the players' athletic capabilities and performance during a game (Wragg, 2000). Moreover, the ability to recover from these activities and repeat them without fatigue is based on the fast renewal of CP stores and the fast removal of lactic acid from the muscle. Research indicates that a high aerobic capacity (measured via the player's VO_{2max} may enhance this recovery process, enabling the player to perform high intensity actions throughout the basketball game (Glaister, 2005). The VO_{2max} measure relates to the maximum rate at which the body can inhale, distribute, and use VO_{2max} while performing physical activity (Akalan et al., 2004). For basketball players, optimal VO_{2max} is 55 ml/kg/min (Marinkovic, & Pavlović, 2013).

Hence, the development of a comprehensive and effective evaluation tool that overcomes the drawbacks of current assessments, while accurately measuring the distinct aptitudes essential for basketball, presents a formidable task. This evaluation would offer coaches and sport scientist a valuable resource to appraise and enhance the individual basketball proficiencies of their players.

For the author's knowledge indicates that no previous research has described a particular test, this statement implies that the author believes their test to be original or novel and give a good solution for a field test.

III – OBJECTIVES

3 HYPOTESIS AND OBJECTIVES

The main aim of this thesis was to develop and assess the reliability and validity of a unique new test that optimally measures the aerobic capacity in basketball players.

This objective suggests that the study aims to investigate how these factors may influence or contribute to certain outcomes. Let's break down each component:

Age: The study intends to explore how age differences may impact the variables under investigation. Age can be a significant factor in various contexts, such as cognitive abilities, physical performance, or behavioral patterns. By considering different age groups, researchers can identify potential variations or trends across these groups.

Gender: This component focuses on investigating potential differences between males and females in relation to the variables being studied. Gender can play a role in various aspects of human behaviour, physiology, and psychology.

Relative Age Effect: The relative age effect refers to the phenomenon where individuals born closer to a specific cut off date within a certain period experience advantages or disadvantages in various domains, such as sports, academics, or professional development. By examining the relative age effect, researchers aim to understand how birthdate-related factors may influence outcomes and performance.

Table 9 will give the coaches the different between age and gender.

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

Table 2 The first stage- objective 1

QUESTION	HYPOTHESIS	GOAL
Do field tests give us the occurs measurements for basketball players? It is enough field tests that presented in the literature to assess specific physical abilities of basketball players?	Yes, but more specific tests are required that examine physiological and specific movement that relevant to the game.	To review the field test in the literature and to show the needs of unique tests with very specific requirements for basketball players.

Table 3 The second stage- objective 2

QUESTION	HYPOTHESIS	GOAL
Does a new of aerobic capacity test, will be more efficient for basketball players?	The test is very specific and combines change of direction and defence movement as in the game. Reliability and validity are needed to consider a good new test.	To build a new version of YoYo test for basketball players.

Table 4 The third stage- objective 3

QUESTION	HYPOTHESIS	GOAL
Does the new test is suitable for gender, age and relative age effect?	Yes, we will see differences in the performance according to age, gender. The girls, young group will do less distance than boys and adult group. Boys and girls that born in the first three month of the year, will achieve the best results.	To examine differences in age, gender and relative age effect in the game. According to the results we will try to determine specific standards for the new test.

Specific objectives:

- To compare the new unique test to laboratory aerobic test (gold standard).

- To compare the new test to two field tests that common in the literature.

- 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 (U-14, U-16, and U-18).

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

To compare and examine differences in relative age effect among 3 different ages and gender.

IV – MATERIAL AND METHODS

4 MATERIAL AND METHODS

4.1 STUDY 1- VALIDITY AND RELIABILITY OF A UNIQE AEROBIC FIELD TEST FOR ESTIMATING VO2MAX AMONG BASKETBALL PLAYERS

4.1.1 Participants

A total of 25 basketball players on an elite youth league in Israel participated in this study. On average, these male participants were aged 16.4 years (0.5±) with height=180cm (±5.5), body mass=72kg (±4.9), and body fat=10.8% (±1.9%). They had been playing basketball for eight years, and their weekly routine included five basketball practices, two fitness practices, and one league game. Four inclusion criteria were applied in this study, whereby the player had: (a) participated in at least 90% of the weekly training sessions during the 10-month season leading up to the research; (b) regularly participated in the previous competitive season; (c) had a clean bill of health; and (iv) had not incurred injuries or pain and were not administering medication.

To reduce interference in the experiment, the participants were asked to refrain from consuming stimulants (e.g., caffeine) or depressants (e.g., alcohol) for 24 hours prior to the testing, and to refrain from eating for about three hours prior to the testing. They were also asked to avoid strenuous activity for at least 24 hours before the testing. As the participants were minors, their parents signed an informed written consent form. Although anonymity could not be assured due to the nature of the study, all data obtained were treated with the utmost confidentiality and scientific rigor, and were used solely for the purpose of this research project. The study was conducted in compliance with the Organic Law 15/1999 of December 13 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza (World Medical Association, 2013).

4.1.2 Design and Procedure

To eliminate circadian variation, all participants completed the tests at the same time of day, at 4 pm, in normal ambient conditions, with a temperature of 20.2 ±0.5°C and relative humidity of 65.3% ±3.5%. The tests were conducted in indoor laboratories and on regular indoor basketballs courts; the participants wore basketball shoes and appropriate sportswear.

Each participant participated in four tests: one laboratory test and three field tests, within three days of each other. Immediately before each test, the participants performed a 15-minute warmup on the basketball court where they regularly practice and play: 4 minutes of layups (right/left); eight minutes of mobility movements and dynamic stretches; and three minutes of accelerations and decelerations.

Measures

To measure VO_{2max} specifically among basketball players, we developed the innovative Yo-Yo Recovery Test for Basketball Players. To test and validate this new field tool, the data achieved from the novel test was compared to three already-validated tests based on distance covered, VO_{2max}, heartrate, and perceived test difficulty.

4.1.3.1 *Bruce Protocol Laboratory Stress Test*

Bruce Protocol (Bruce, 1949). Each participant was asked to continuously run on the treadmill, subject to gradually increasing intensity every three minutes (increased speed and inclination) for a total of seven times or until the subject was unable to continue to perform due to fatigue (Figure 1).

Figure 1 Vo2 max test (labratory)

4.1.3.2 *Yo-Yo Intermittent Recovery Level 1 (YYIR1)*

Previous assessments of this test (Bangsbo et al., 2012) show a correlation of r=0.77 with VO_{2max} values. Each test section is comprised of a 40-meter run (20 meters in one direction, 20 meters back to the starting point, and a 10-second recovery period (Figure 2). The test gradually increases from 10kph by 0.5 kph for each new 40-meter section, until the participant is unable to continue to perform due to fatigue. The version applied in this study was developed specifically for sports such as basketball, that require intense physical efforts separated by sections of incomplete recovery (Castagna, 2008).

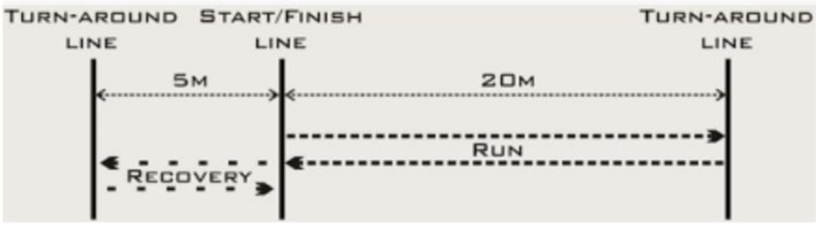

Figure 2 track of yo yo recovery test (level 1)

4.1.3.3 *Yo-Yo Endurance (YYEND) Test*

Developed by Léger et al. (1988), this test requires participants to run back and forth in 20-meter sections with increased intensity effort until the participant is unable to continue due to fatigue. Previous assessments of this test show a very high correlation of r=0.92 with VO_{2max} and is reliable and valid for predicting aerobic capacity among a range of populations (St. Clair Gibson et al., 1988). The sprints begin at a speed of 8 km/h and increase by 0.5 km/h approximately every minute, as dictated by an audio disc. The results are determined by the number of times the athlete is able to perform these sprints until overcome by fatigue. The test was chosen for this study due to its similarity to the activity patterns that are routinely performed by athletes every few months, as a means for evaluating their aerobic fitness (Figure 3).

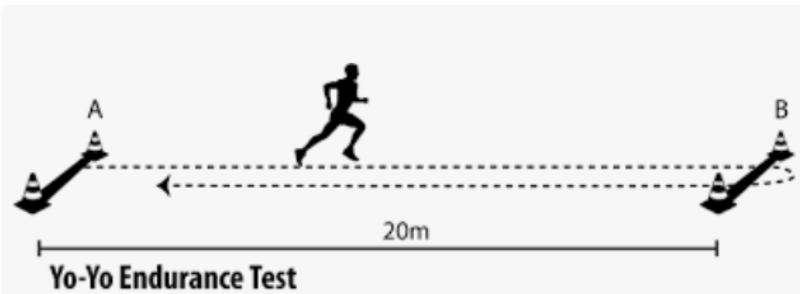

Figure 3 track of yo yo endurance test

4.1.3.4 *Yo-Yo Recovery Test for Basketball Players (YYRECB)*

This unique test was developed to examine recovery specifically among basketball players and is comprised of movements from the game of basketball, including running, changing directions, and defensive strides – with short and intense discrete parts for recovery. The procedure includes running (18 meters) + defensive strides in one direction (2 meters) / defensive strides (2 meters) + running (18 meters) back to the starting point / recovery walking (five meters + five meters in both directions) for 10-20 seconds (Figure 4). Each participant performed this test twice for means of validation (i.e., test/re-test), while the previous three test were only performed once. In addition to documenting the distance covered in each test, the time it took to complete the tests, and the participants' VO_{2max}, we also measured their maximum heartrate (HR_{MAX}) towards the end of each test, based on the number of heartbeats (contractions) per minute (bpm) – using the Polar HR monitor and transmitter (Polar Electro, Lake Success, NY, USA) that was validated by Goodie et al. (2000). Finally, after each test, the participants were asked to rate the difficulty of the test using the Rated Perceived Exertion (RPE) Scale (Borg, 1998). The scale ranges from zero (felt nothing at all [like sitting in a chair]) to 10 (felt very heavy [like at the end of an exercise stress test or other very difficult activity]).

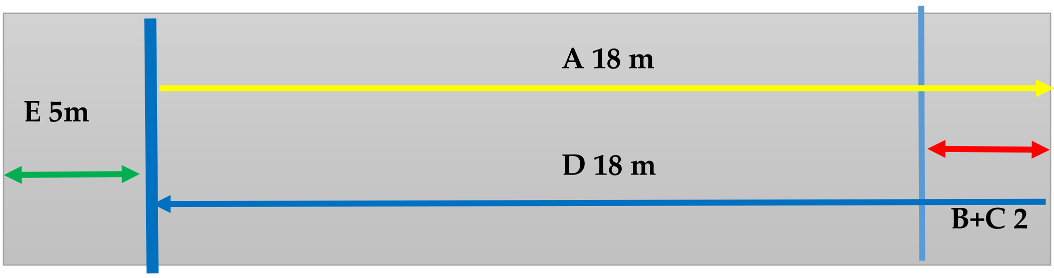

Figure 4 track of the new test (yyrecb)

A. Running forward (18 meters) – Yellow line.

B+C. Defensive steps (2 meters) – Red line

D. 18 meter Running back to the starting (blue line)

E. Recovery, 10-20 seconds walking (10 meters: 5 meters back and forth) Green line.

4.2 STUDY 2- DIFRENCES IN AEROBIC CAPACITY OF BASKETBALL PLAYERS BY GENDER, AGE, AND RELATIVE AGE EFFECT

4.2.1 Participants

The study included 438 young basketball players, both male and female, from five clubs in Israel. First, anthropometric measurements were taken for each participant, including height (m), body mass (kg), and body fat (%). Height was measured using a stadiometer (SECA®, Germany) with a 1 cm accuracy; body mass and fat were measured using electronic scales (Tanita BC®, 418, Japan), with a 0.1-kg accuracy (Slaughter et al., 1988). All participants had been playing basketball for three to eight years, and each week conducted at least two fitness practices, participated in three to five basketball practices, and one league game. The players also had to present a clean bill of health, with no injuries, aches, or ongoing medication. After contacting the basketball clubs and coaches to request their participation in the study, informed consent was received from both the players and their parents. The participants were also informed that their participation in the study was not mandatory. Although anonymity could not be promised due to the nature of the study, the participants and their parents were assured that the utmost confidentiality and scientific rigor would be applied throughout the study, and that the achieved data would only be used for the purpose of this research project. Dates for conducting the study at each club were set, so as not to interfere with their training and competitions. The study was approved by the Bioethics Committee at the first author's affiliated academic institution (registration number 367).

4.2.2 Procedures

After contacting the basketball clubs and coaches to request their participation in the study, informed consent was received from both the players and their parents. The participants were also informed that their participation in the study was not mandatory. Although anonymity could not be promised due to the nature of the study, the participants and their parents were assured that the utmost confidentiality and scientific rigor would be applied throughout the study, and that the achieved data would only be used for the purpose of this research project. Dates for conducting the study at each club were set, so as not to interfere with their training and competitions.

To eliminate circadian variations, all participants completed the test at the same time of day (6 pm), in normal ambient conditions, and with a temperature of 23.1 ±0.5°C and relative humidity of 70.5% ±3.5%. The assessments were conducted by the researchers together with the team's coach, inside official indoor basketballs courts; the participants were required to wear their regular sportswear and basketball shoes. Prior to the study, the players were instructed to refrain from caffeine and other stimulants, alcohol and other depressants, and strenuous physical activities for at least 24 hours prior to the research assessments. They were also asked to not consume food for about three hours prior to the testing.

4.2.3 Tools

The novel Yo-Yo Recovery Test for Basketball Players was developed for assessing players' VO_{2max} in relation to their reference from specific movements that are common in the game of basketball (such as short sprints, changing directions, and defensive strides). During the test, the participants were first asked to run in one direction for 18 meters along a clearly marked path inside the basketball court, followed by 2 meters of defensive strides in the same direction. Without stopping or resting, this was immediately followed by an additional 2 meters of defensive strides in the opposite direction (i.e., towards the starting point), followed by their running back to the starting point for another 18 meters. The participants then had 10-20 seconds recovery, during which time they were required to walk 5 meters in both directions (figure 4).

The speed at which the participants were instructed to run for each round was dictated by audio sounds. Moreover, this speed increased from round to round. The participants were asked to perform this procedure until they were too tired to continue, while wearing an HR band on their chest (GARMIN®, Olathe, KS, USA).

At this point, the total distance that they had covered was calculated (also via audio recordings), and their physical measures were assessed. (1) Sound file from the novel test; (2) Formula for calculating

$VO_{2max} = 0.0146x + 32.078$, with x representing the distance covered during the test (Gottlieb, 2022); (3) HR; and (4) Table of rate perceived exertion (on a scale of 1-10).

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 (U-14), Under-16 (U-16), and Under-18 (U-18), and (5) three relative age groups according to the players' month of birth: tri1 (January-April), tri2 (May-August), and tri3 (September-December). The following four dependent variables were also analysed in this study: (1) distance (m), i.e., the number of meters covered during the test; (2) predicted VO_{2max}; (3) HR; and (4) rate of perceived exertion (RPE), on a scale of 1 (easiest) to 10 (hardest).

4.3 STATISTICS

4.3.1 Statistics of study 1

Standard statistical parameters (mean±SD) were calculated for the anthropometric data and physical performance test results. Normality was tested through analysis of the censored exposure data subject to the constrained maximization of the Shapiro-Wilk W statistics (<30). Reliability of the new test was measured via Intra-class Correlation Coefficient (ICC), effect size (ES), coefficient of variation (CV%), The level of significance was set to $p< 0.05$. Effect size (Cohen's d) was used to calculate differences in means, and the following thresholds were used to express the magnitudes: trivial<2.0, small 0.2–0.59, moderate 0.60– 1.19, large 1.2–1.99, or very large >2.0, and validity was measured using Pearson correlation tests. In line with Hopkins et al. (2009), correlation coefficients were considered 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 ($r>0.9$), or perfect ($r=1$), Validity and intra/inter-evaluator reproducibility were evaluated by the ICC. Analysis of the Bland-Altman concordance (Giavarina, 2015). Significance levels Confidence intervals were set to 95% for both reliability and validity analyses, were $p<0.05$. SPSS v17.0 (SPSS, Inc., Chicago, IL) was used for conducting statistical analyses.

4.3.2 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 relative age effect groups. Correlation coefficients were considered 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 ($r>0.9$), or perfect ($r=1$), Statistical analyses were performed using the SPSS v.21 software (Inc, Chicago, IL, USA); statistical significance was set at $p<.05$.

V – RESULTS

5 RESULTS

5.1 RESULT OF STUDY 1

Pearson correlations were performed once for all measures and twice for the YYRECB (test/re-test), which was found to be reliable, without significant differences in HRMAX and distances covered. Internal correlation (ICC 95%CI) between repetitions was 0.971, and coefficient of variation (CV%) 2.66-9.88, until 10% its good.(Table 5).

Table 5 Reliability (Test/Re-Test) for the New YYRECB test

Variable	test/retest	Mean	ES (95%CI)	CV% (95%CI)	ICC (95%CI)
Level	Test	10.94	0.13	5.71	0.953*
	Re-test	11.02			
HR (end)	Test	191	0.11	2.65	0.922*
	Re-test	191.57			
Total Distance (meter)	Test	1605.71	0.52	9.49	0.972*
	Re-test	1613.33			
Total Time (sec)	Test	1006.9	0.38	7.85	0.948*
	Re-test	1009.48			
RPE (6-20)	Test	17.29	1.05	6.01	0.946*
	Re-test	17.29			
All Variable					**0.971**

Magnitude of correlation: *nearly perfect

ES = effect size, CI = confidence interval (95%), CV= coefficient of variation,

ICC = interclass correlation (Cronbach's Alpha)

Very high correlations were found between VO_{2max} (mL x kg−1 x min−1) and YYRECB (r=0.769; 95% confidence interval [CI]; P<.0001). Significant differences were also seen in distances covered in the YYRECB test compared to those covered in the YYREC1 and YYEND tests (r=0.748 and r=0.723, respectively; 95% CI; P<.0001), (Table 6).

Bland-Altman analysis of reliability is derived from agreement between measures (Lu Mj et al., 2016), enabling reporting of the mean bias and the upper/lower VO_{2max}. As shown in Table 6, when tested against the VO_{2max}, the innovative YYRECB demonstrated a high correlation for distance (r=0.769). When tested against YYREC1 and YYEND, the YYRECB demonstrated high correlations for distance (r=0.723 and r=0.748, respectively). The Bland-Altman Difference Plot for analysing VO_{2max} in the YYRECB resulted in zero, indicating complete agreement and lack of bias (Giavarina, 2015). The formula for estimating VO_{2max} in the YYRECB test is: VO_{2max} =0.0146x+32.078 (x=the distance covered during the test); mean=0. Complete agreement was seen between the laboratory test and the YYRECB (CI 95% -1: +1, CI mean -3.5: +3.6), as well as a very good correlation up to 55 ml/kg/min (Figure 5).

Table 6 Validity accociation and agreement between Yo-Yo Tests

	YYRECB				
Variable					
	ICC (CI 95%)	SD	Bland-Altman		
			Bias	VO_{2max} (lower)	VO_{2max} (upper)
YYIR1	0.645*	5.01	6.6	-2.5	2.1
YYEND	0.859*	5.66	3.9	-2.4	0.7
YYRECB	0.769*	3.81	3.6	-3.5	0

*Correlation is significant (p< 0.01) level (2-tailed)

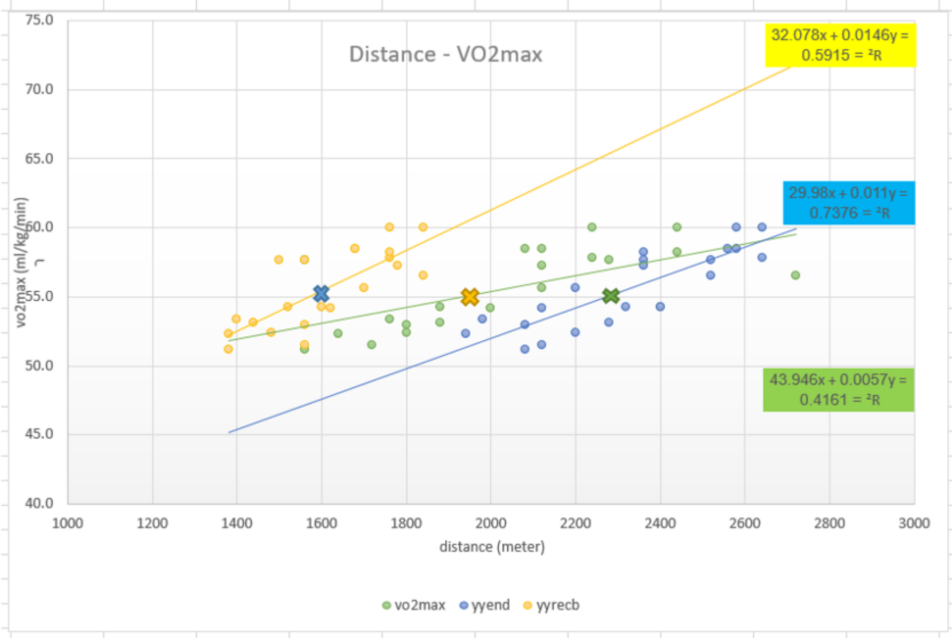

Figure 5 Formula for estimating VO2max

For the Bland-Altman analysis of VO $_{2max}$ and YYREC1, mean=2.1 (Figure 6). As such, 2.1 must be added to the result to compare YYREC1 results to laboratory results (CI 95% -0.5: + 3, CI mean -2.5: + 6.6).

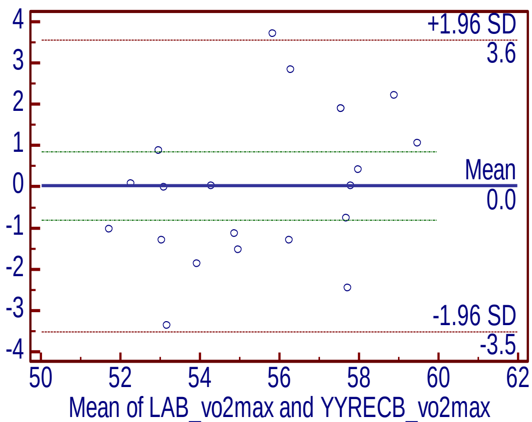

Figure 6 Bland-Altman Plot for VO2max laboratory and YYRECB tests

Finally, Bland-Altman analysis of VO_{2max} and YYEND presented mean=0.7, as seen in Figure 7. Therefore, 0.7 must be added to YYEND results in order to compare to the innovative test to the laboratory test (CI 95% 0: +1; CI mean -2.5: +4).

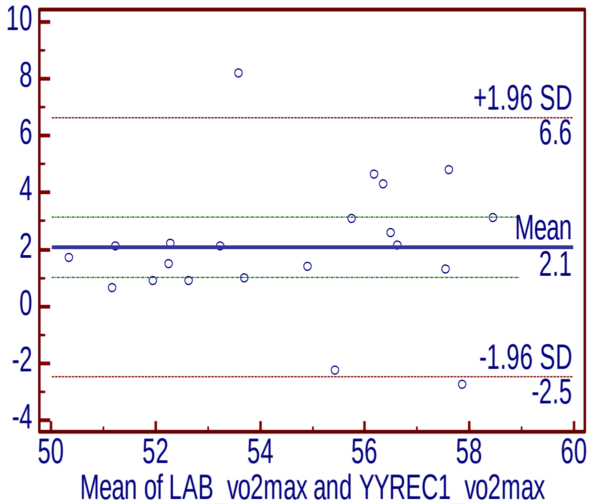

Figure 7 Bland-Altman Plot of VO2max laboratory and YYREC1

5.2 RESULT OF STUDY 2

Table 7 presents the participants' physical characteristics, including body mass, height, and body fat by age group and gender.

Table 7 participants' physical characteristics

Basketball players' physical characteristics					
		N	Body Mass (kg)	Height (m)	BMI (INDEX)
Male	U-14	71	77.3	1.85	22.59
	U-16	80	66.3	1.79	20.69
	U-18	70	57.8	1.72	19.54
Female	U-14	71	47.2	1.57	19.15
	U-16	73	57.7	1.62	21.99
	U-18	73	59.8	1.65	21.97

Table 8 presents the participants' descriptive data by gender (including age, distance covered during the test, VO_{2max}, and RPE, and distance by trimester. As seen in Figure 6, significant differences were seen between the genders in their mean distance covered, regardless of age, whereby the mean distance for males (1,421.6± 218.8 meters) was significantly greater than for females (1,116.9±137.2 meters). Moreover, improvement in these results in line with increased age was also evident, whereby older players covered greater distances.

Table 7 ***Participants' Descriptive Statistics***

gender	age	no.	distance (meter)	Vo2max	RPE	distance by trimester (meter)		
						jenuary-april	may-august	september-december
Male	u14	71	1274.31±195.5	50.68±2.8	7.49±0.48	1409.23±178.9*	1219.05±89.1*	1176.67±203.2
	u16	80	1383±233.13*	52.27±3.36	7.58±0.49	1360±250.67	1392±189.78	1360±250.67
	u18	70	1607.43±226.03*	55.5±3.5	7.7±0.56	1560±249	1576±213.6	1681.67±210.83*
Female	u14	71	1056.34±137.3	47.5±1.99	7.6±0.54	1204±104.13	1023.45±68*	946.09±44.4*
	u16	73	1212.60±129.4*	49.78±1.87	7.61±0.56	1342.4±100.7	1190.67±66.17*	1068.89±40.7
	u18	73	1231.78±144.8*	50.06±2.1	7.62±0.48	1385.60±101.9	1209.09±72.9*	1103.08±68.04

Legend:* tri1-tri3 * tri2-tri3 *age from previous age group; * gender (P<0.05)

In addition, interactions were also seen between age and gender, whereby improved distances in the female participants began to decrease after the age of 16, unlike the continued increase seen in males at the same ages (Figure 8).

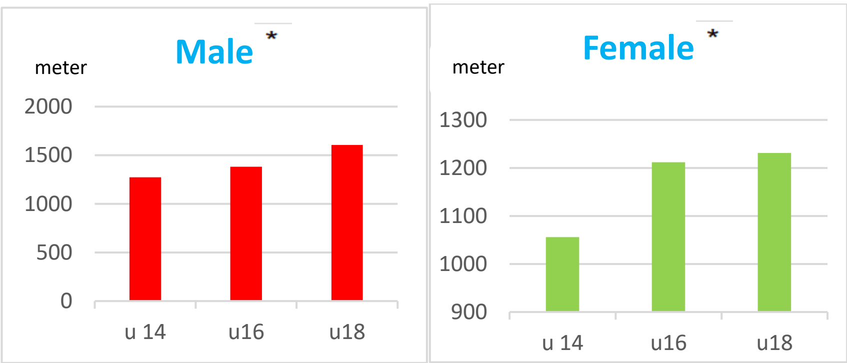

Figure 8 Average Distances Covered by Gender (boys and girls in different age)

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

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

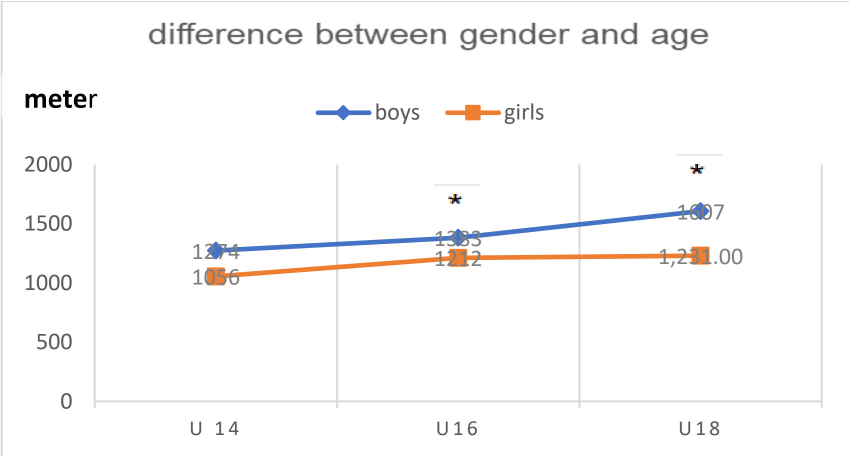

Figure 9 Differences in Average Distances by Age and Gender Interactions

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

The male participants showed consistent significant improvement in the mean distances covered by age, with a significant increase from U-14 (1274.3±195.5 meters) to U-16 (1383±233.1 meters), and from U-16 to U-18 (1607.4±257.8 meters) $p<0.05$. With the female participants, on the other hand, no such consistency was seen, in light of an increase from U-14 (1056.3±1212.6 meters) to U-16 (1212.6±129.4 meters), yet with no significant change from U-16 to U-18 (1231.7±144.8 meters), as depicted in Figure 9. Moreover, when examining interactions between gender and time, different results were seen for each trimester.

When examining RAE among all age groups of female participants, a significant decline was seen in performance between trimesters, with the highest score awarded on the first trimester (1329.8±116.5 meters), a steep decline on the second trimester (1135.8±108.5 meters), and the lowest was seen for the third trimester (1040±87.8 meters), as seen in figure 8. For the male participants, however, interactions were seen across all three trimesters, in addition to an interaction between time and gender. As seen in figure 9, while the results of the U-14 male participants followed this pattern of decline throughout the year (tri1=1409.3±41.6 meters; tri2=1219±46.3 meters; and tri3= 1176.6±43.3 meters), this pattern is not seen in the U-16 or U-18 age group.

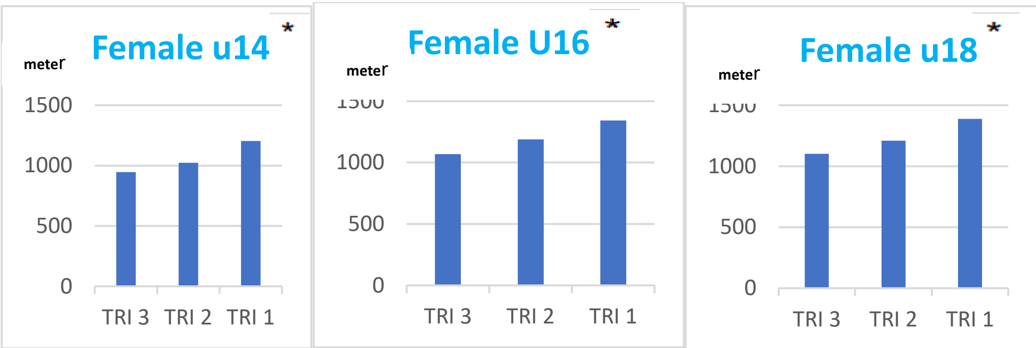

Figure 10 Female Participants: RAE and Mean Distances Girls, U-14, U-16, U-18

* p<0.05 tri1-tri2 and tri1-tri3 (U14)

* p<0.05 tri1-tri2 (U16)

* p<0.05 tri1-tri2 (U18)

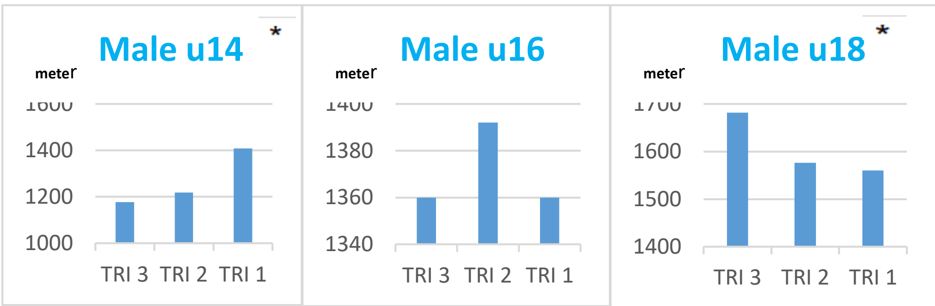

Figure 11 Male Participants: RAE and Mean Distances Boys, U-14, U-16, U-18

* p<0.05 tri1-tri2 (U14)

* p<0.05 tri3-to tri2 and tri1 (U18)

The declined performance among trimesters in the male U-16 group was smaller than that of the female U-16 group and of the male U-14 group. For all groups, most declines among trimesters were seen between tri1 and tri2, that also exhibited a significant decline between tri2 and tri3. However, in the male U-16-year group, no decline was seen between tri1 and tri2, and the decline that was seen between tri2 and tri3 was very small. Interestingly, for the male U-18 group, a significant increase was seen between all three trimesters (1560 meters tri 1, 1576 meters tri 2, and 1681 meters tri 3

The participants' subjectively exerted effort was significantly higher than the measures presented in the literature regarding RPE (Borg, 1998), thereby indicating that they found the test harder than would have been expected of them. No significant differences were found in RPE between the age groups and genders ($p<0.05$).

Table 8 Achievements Table (Yo-Yo Recovery Test for Basketball Players) Girls U-14, U-16, U18 and Boys U-14, U-16, U18

Achievement table (yyrecb)

FEMALE			MALE		
assessment	**distance (m)**	**age**	**assessment**	**distance (m)**	**age**
excellent	1370>		excellent	1800>	
very good	1231-1370		very good	1601-1800	
good	1091-1230	**U18**	good	1401-1600	**U18**
poor	951-1090		poor	1201-1400	
unprepared	950<		unprepared	1200<	
assessment	**distance (m)**	**age**	**assessment**	**distance (m)**	**age**
excellent	1330>		excellent	1610>	
very good	1201-1330		very good	1381-1610	
good	1071-1200	**U16**	good	1151-1380	**U16**
poor	941-1070		poor	920-1150	
unprepared	940<		unprepared	920<	
assessment	**distance (m)**	**age**	**assessment**	**distance (m)**	**age**
excellent	1180>		excellent	1460>	
very good	1051-1180		very good	1271-1460	
good	921-1050	**U14**	good	1081-1270	**U14**
poor	791-920		poor	891-1080	
unprepared	790<		unprepared	890<	

VI – DISCUSSION

6 DISCUSSION

This study determined the validity and reliability of a new specific field test, that could optimally predict VO_{2max} for a B player. The main findings of the present study were: The results showed that the new version of the Yo-Yo (YYRECB) test, with effort patterns replicating real B sessions, could be considered a valid and reliable B-specific field test for assessing B players' endurance fitness.

The medium values of VO_{2max} in B for enough aerobic capacity is around 55 ml/kg/min, so, the players that reach 1600 meter, can stop the test, and need to maintain this aerobic conditioning in the B practices. The demands of the test for reaching the target are less time consuming and thus advantageous for the players. No difference was found in RPE and HR among tests (Lab, yyend and yyrec1), showing that the objective subjective variables were similar with this new version.

The aerobic and anaerobic capacity of an athlete, may determine the outcome of the competition and therefore it's important to evaluate the athletes' ability regarding these aspects during practice (Sözen, & Akyıldız, 2018). In particular, traditionally, the aerobic capacity of an athlete has been evaluated using different methods, including continuous exercise tests such us the 12-minute running test VO_{2max} test in the laboratory (Bangsbo, 2012). In this sense, the VO_{2max} is a widely used measurement for physical activity and refers to the "maximal rate at which oxygen can be taken in, distributed, and used by the body during physical activity" (Akalan, Kravitz, & Robergs, 2004). It is the most common measure referred to by trainers in the tracking of their players' activities related two aerobic performances. The VO_{2max} is measured as millilitres of oxygen per kilogram of body mass per minute and therefore, a high VO_{2max} can be representative of a high level of fitness (Tiago. et al. 2008). Directly measuring VO_{2max} in the laboratory requires specialized personnel and extensive equipment, making this type of testing costly and impractical to conduct by the trainer in the field (Akalan, Kravitz, & Robergs, 2004).

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. The B involves specific movements of the players on the field (Petway et. Al. 2021). These movements include repeated sprints with limited recovery time between the sprints (Meckel, 2008), as well as the frequent changing of the direction of movement. While the measurement of VO_{2max} in the laboratory can be used to evaluate the player's aerobic capability, measuring VO_{2max} in a field test is (Gottlieb et. Al. 2021) expected to provide this capability more effectively.

The aim of the study was to test the validity and reliability of a field test used to measure the PLAYER'S aerobic capacity during activity and which included specific movements aligned to duplicate the movements observed during a B game (Gottlieb, 2022).

The development of this field tests has enabled less time consuming and lower cost assessment of the physical capability of players on the field (Gottlieb, 2021 The Yo-Yo intermittent recovery level 1 (YYREC1) test is a field test that is used to assess VO_{2max} without involving laboratory facilities (Castagna ,2007). The results from the YYREC1 are used to estimate VO_{2max}.The YYREC1 test focuses on the capacity to carry out intermittent exercise leading to a maximal activation of the aerobic system (Schmitz, Pfeifer, Kreitz, Borowski, Faldum, & Brand, 2018). In this study, the validity and reliability of a new field test that VO_{2max} in B players were tested. Testing of the correlation and agreement of the new field test (YYRECB) against a VO_{2max} test in the laboratory, that represents the ideal scientific test, was conducted. In the Bland Altman analysis, completed agreement was found between VO_{2max} in the laboratory and YYRECB. Correlation and agreement were also tested against other recognized field test methods (YYEND and YYREC1). YYEND and YYREC1 have been shown to be highly correlated with VO_{2max} (r= 0.77/0.92) respectively. The Bland Altman analysis of VO_{2max} in the laboratory and YYREC1, showed that 2.1 must be added to the result to compare to the laboratory test. The Bland Altman analysis of VO_{2max} in the laboratory and YYEND, showed that an addition of 0.7 to the result is needed to compare to the laboratory test

The demands of the test for reaching the target are less time consuming and thus advantageous for the players. The results from the study showed that the new version of the Yo-Yo (YYRECB) test, with effort patterns replicating real B sessions, can be considered a valid and reliable B specific field test for assessing B players' endurance fitness. The B's unique requirements for aerobic capacity stem from the nature of the intermittent activity during the game. Although Yo-Yo tests have been used to test for aerobic capacity in players, research has not shown any test to be specifically aligned to correspond to the ratio of activity to rest.

Displayed by the players during the B game. In this study, a unique aerobic field test (YYRECB) to estimate VO_{2max} was introduced and tested for its reliability and validity in examining the aerobic fitness of players. The field test was designed to align with the specific needs of B players. Accurate assessment of the aerobic capabilities of B players enables the trainer to adapt their training program according to the needs of the players and for the players to maintain optimal aerobic conditioning throughout the B season. When tested using effort patterns that closely replicated movement on the B court during real B session, the new version of the Yo-Yo test (YYRECB) was shown to be a valid and reliable B specific field test. Its use is valuable for assessing B players endurance fitness. The findings from the study also indicate that YYRECB can be considered a specific field test for B, providing the coaches with an indication of the aerobic energy capacity of the players during intermittent activity during a B game. Therefore, the use of the YYRECB test by B coaches and fitness trainers may be considered of value in attaining an acceptable and accurate indication of the aerobic capacity of their B players. The Yo-yo test performances have been shown to be highly variable during different periods over the course of a season of football league with peak performance in soccer often demonstrated mid-season (Mohr, & Krustrup, 2013). Thus, to provide a more accurate indication of aerobic capability of players throughout the season, the recommendation for the practical application of the YYRECB test is for it to be conducted 3 times per year. The first test may be carried out after one week into pre-season. The test may be conducted for a second time after 3-4 weeks in pre-season and finally, repeated for the third time, in mid-season. Based on these findings, future studies may include modifying the YYRECB field test for use in various additional sports, especially where the movements of the players may follow patterns of intermittent activity, similar in nature to those observed in B.

The study highlights the importance of VO_{2max} in the performance of young basketball players, as it affects their ability to perform strenuous actions with active and passive recovery. The Yo-Yo Recovery Test for Basketball Players, which is a unique field test that evaluates VO_{2max} specifically for basketball players, was used in this study to examine differences in VO_{2max} by gender, age group, and RAE. Results showed that male participants had higher VO_{2max} than female participants in all age groups, and that older players performed better than younger ones. Moreover, the effect of age on performance varied by gender and within the female participants, with different improvement patterns seen in male and female players. Additionally, RAE had an impact on performance, with different results seen across trimesters. The participants' self-reported RPE scores indicated the reliability of the Yo-Yo Recovery Test for

Basketball Players. This study could provide valuable insights into the training and performance needs of young basketball players, and could help coaches and trainers develop more effective training programs tailored to the specific needs of each player.

The development of field tests has emerged as an alternative approach to evaluate VO_{2max}, allowing trainers to evaluate their players in the field without requiring specialized equipment (Gottlieb, 2022). One of the most popular field tests used to assess aerobic endurance is the Yo-Yo intermittent recovery test level 1 (YYREC1), which has been shown to be a valid and reliable measure of VO_{2max} in a range of athletes (Bangsbo, 2012). However, the YYREC1 is not specific to any particular sport, and therefore, there has been a need to develop sport-specific field tests.

The present study aimed to determine the validity and reliability of a new B-specific field test, the YYRECB test, which replicates the effort patterns of real B sessions. The results showed that the YYRECB test is a valid and reliable measure of endurance fitness in B players, with no significant differences found in RPE and HR between the test and other measures such as the lab test, YYEND, and YYREC1

The target VO_{2max} for B players is around 55 ml/kg/min, and players who reach 1600 meters in the YYRECB test can be considered to have achieved this target. The advantage of using the YYRECB test is that it is less time-consuming than other traditional methods, making it more practical for trainers to use in the field.

Overall, the development of sport-specific field tests such as the YYRECB test could provide trainers with a more accurate and efficient way to evaluate the aerobic capacity of their players. This information can be used to design more effective training programs that target the specific needs of their athletes, ultimately leading to better performance outcomes.

The nature of the B game involves specific movements and repeated sprints with limited recovery time between them (Meckel, 2009), as well as frequent changes in direction. Measuring VO_{2max} in the laboratory can evaluate a player's aerobic capability, but a field test is expected to provide results more aligned with a player's capabilities during a game. The aim of this study was to test the validity and reliability of a field test designed to measure the aerobic capacity of B players during activity, with effort patterns replicating those seen in real B sessions (Stojanovic, 2017).

The Yo-Yo intermittent recovery level 1 (YYREC1) test is a field test used to assess VO_{2max} without laboratory facilities (Bangsbo, 2012).. In this study, the validity and reliability of a new field test (YYRECB) measuring VO_{2max} in B players were tested. The new field test was compared against a goal standard VO_{2max} test in the laboratory, which represents the ideal scientific test, as well as against other recognized field test methods (YYEND and YYREC1). The results showed that YYRECB was a valid and reliable B-specific field test for assessing B players' endurance fitness. Therefor the new version of Yo-Yo test may be considered as a good and applied field test which to replace the old version

The target VO_{2max} for B players to have enough aerobic capacity is around 55 ml/kg/min. Players who reach 1600 meters can stop the test but need to maintain this aerobic conditioning during B practices. The results of this study indicate that accurate assessment of the aerobic capabilities of B players enables trainers to adapt their training program according to the players' needs and for the players to maintain optimal aerobic conditioning throughout the B season.

The YYRECB was shown to be a specific field test for B, providing coaches with an indication of the aerobic energy capacity of players during intermittent activity during a B game. Therefore, the use of the YYRECB test by B coaches and fitness trainers may be considered of value in attaining an acceptable and accurate indication of the aerobic capacity of their B players. To provide a more accurate indication of aerobic capability of players throughout the season, the recommendation for the practical application of the YYRECB test is for it to be conducted three times per year.

In conclusion, the main findings of the present study suggests that the YYRECB field test could be considered a valuable validity and reliability tool for assessing B players' endurance fitness. Future studies may include modifying the YYRECB field test for use in various other sports, especially where the movements of the players may follow patterns of intermittent activity, similar in nature to those observed in basketball.

VII – CONCLUSIONS

7 CONCLUSIONS

7.1 GENERAL CONCLUSIONS

The scientific literature suggests that highly conditioned players elevate the level of basketball. Conditioning is key for consistent high-level performance throughout the season. However, there is a concern that excessive focus on intensive training and competition at a young age mostly, may impede an players ability to develop transferable athletic skills and increase the risk of burnout and injury. Basketball players require a combination of horizontal and vertical triaxle movements model, which makes it challenging for fitness coaches to choose effective training methods and tests for assessing power.

Studies show a correlation between horizontal and vertical power in basketball players, but there is a lack of specific tests for assessing power where these movements are combined. There is a need for sport-specific tests that reflect jumping ability and power in basketball. Improvement in performance could be achieved through various types of training, but it is unclear whether these improvements can be transferred to game situations.

Aerobic capacity is essential for rapid recovery from sprints and repeated jumps in basketball. Both anaerobic and aerobic energy pathways contribute to energy sources, causing fatigue and lowering the rate of activity, which impairs a player's game quality. There are various laboratory and field tests available to measure aerobic capacity in basketball players, with the laboratory VO_{2max} test being the most accurate but costly. Field tests such as the Cooper test and Level 1 Yo-Yo tests yield good predictions of VO_{2max}, but sport-specific elements need to be considered when adapting the tests for particular sports.

Overall, the transfer of physical improvements from training to team ball games is difficult to predict, considering technical abilities, complex interactions between players, and other factors. Coaches and fitness coaches need to find the most effective training methods and tests that reflect the specific demands of basketball to enhance performance and reduce the risk of injury.

In summary, basketball players require a combination of horizontal and vertical movement's triaxle, as well as a high level of aerobic capacity, to perform at a high level. There is a need for specific tests to assess power in basketball players, especially for movements that combine horizontal and vertical planes. While various training methods have been shown to improve physical abilities, it is still unclear whether these improvements can be transferred to game situations. Coaches and fitness coaches must correctly measure their players' aerobic capacity before the season begins, and while various field tests are available, they must be adapted to the specific demands of the sport. Finally, predicting the transfer of physical improvements from training to team ball games is challenging due to the complex interactions between players and technical abilities required in the game.

7.2 SPECIFIC CONCLUSIONS

The specific conclusions of the studies comprising the present thesis are displayed below. Importantly, the following conclusions are only applicable to players with similar characteristics to those presented in each investigation.

7.2.1 REVIEW ARTICLE – THE NEEDS FOR FIELD TEST

Basketball players require a combination of horizontal and vertical movements, triaxle as well as a high level of aerobic capacity, to perform at a high level. There is a need for specific tests to assess power in basketball players, especially for movements that combine horizontal and vertical planes. While various training methods have been shown to improve physical abilities, it is still unclear whether these improvements can be transferred to game situations. Coaches and fitness coaches must correctly measure their players' aerobic capacity before the season begins, and while various field tests are available, they must be adapted to the specific demands of the sport. Finally, predicting the transfer of physical improvements from training to team ball games is challenging due to the complex interactions between players and technical abilities required in the game.

7.2.2 STUDY 1

The YYRECB test is specifically designed to evaluate the aerobic capacity of Basketball players and can provide valuable information about their performance and training needs. Given that the test is conducted on a basketball court, it is more relevant to the demands of the game compared to laboratory-based tests. Additionally, the test could be modified to suit players of different ages and fitness levels, making it a versatile tool for evaluating and improving the performance of Basketball players.

7.2.3 STUDY 2

This study introduces the Yo-Yo Recovery Test for Basketball Players (YYRECB), a new assessment tool for evaluating the aerobic capacity (VO_{2max}) of young basketball players in a specific and accurate manner on the basketball court. The study involved male and female players from five different league clubs, and the results showed that young male basketball players aged 14-18 have greater aerobic capacity than female players of the same ages. In addition, relative age effects (RAE) were observed in young male players of all age groups (U-14, U-16, and U-18), but not in young female players.

The YYRECB test has several advantages over traditional laboratory-based tests, as it can be conducted on real basketball courts and requires less time and distance for obtaining the required data. The test could also be modified to suit players of different ages and fitness levels, by adjusting the duration of active recovery periods or increasing the running distance or speed. The study recommends that coaches and trainers take into account the differences between young male and female players when planning training programs, especially during the age of pubertal changes.

Overall, the YYRECB test provides valuable insights into the recovery capabilities of young basketball players and can be used by coaches and trainers to plan effective training programs and optimize performance outcomes by gender and age.

VIII – LIMITATIONS AND FUTURE WORK

8 LIMITATIONS AND FUTURE WORK

Some limitations of the studies composing the present thesis must be addressed:

Although this study has made significant contributions to the field, there are some limitations that should be considered. One potential limitation is the fact that the ability to change directions in basketball is a skill that improves with practice, so the results of younger participants may be affected by their lack of technique. Additionally, recovery time between rounds in the test is predetermined, which is not the case in real basketball games where recovery times may differ. To address these limitations, future studies could include random recovery times between runs (such as 5, 10, 15, or 20 seconds) and an additional task that involves making basketball-related decisions, such as shooting, passing, or dribbling, after each round. These modifications would provide a more accurate representation of the demands of a real basketball game and improve the ecological validity of the test.

Despite its theoretical and practical contribution to the field, the current study has limitation, only youth male basketball players participated in the study.

Future studies could benefit from evaluating the test based on a larger range of gender, ages, and positions, to enable generalization of the findings.

Based on the findings of this study, the new version of the Yo-Yo test may be considered a suitable field test to replace the old version. Coaches and fitness trainers in basketball can easily administer this test on the basketball court and estimate VO_{2max} based on the distance covered. These results are in contrast to other studies that found a significant correlation between the two versions of the test. These findings are particularly important in basketball because the new test, which includes more specific movements such as changing direction and defensive slides, is likely to be more effective and related to the game.

After the completion of the present thesis, future research lines arise from the results obtained. In this regard, potential future investigations that could bring further understanding on the topics studied herein are presented below: To develop a basketball-specific test, it is essential to consider the fundamental movements and skills required in basketball, such as running, jumping, changing directions, and dribbling. These movements should be incorporated into the test to ensure that it accurately measures the abilities required for basketball performance. In addition, recovery times between rounds in the test should reflect the recovery times observed during actual basketball games. Furthermore, it is important to consider the energy systems utilized during basketball play. Basketball is characterized by short bouts of high-intensity activity interspersed with periods of low-intensity activity. As such, the test should reflect these energy demands to ensure that it is a valid measure of basketball-specific fitness. This could be achieved by incorporating periods of intense activity, such as sprints, into the test. It is essential to establish the reliability and validity of the test. To achieve this, the test should be administered to a large and diverse sample of basketball players to ensure that it accurately reflects the demands of the sport. Additionally, the test should be compared to other established measures of basketball performance to establish its validity.

In summary, developing a basketball-specific test that accurately measures the abilities required for basketball performance is essential. Such a test could provide coaches with a valuable tool for assessing their athletes' fitness levels and monitoring their progress. However, to ensure the test's effectiveness, it is crucial to consider the fundamental movements and energy systems required in basketball, incorporate recovery times that reflect actual game situations, and establish the test's reliability and validity.

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9 BIBLIOGRAPHICAL REFERENCES

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X – APPENDIXES

10 APPENDIXES

10.1 APPENDIX 1

PHYSIOLOGY OF BASKETBALL – FIELD TEST. REVIEW ARTICLE

Reference:

Gottlieb, R. Shalom, A., & Calleja-Gonzalez, J. (2021). Physiology of Basketball – Field Tests. Review Article. Journal of Human Kinetics, 77(1), 159-167. https://doi.org/10.2478/hukin-2021-0018.

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Section III – Sports Training

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Physiology of Basketball – Field Tests. Review Article

by
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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

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sprints, changes of direction, dunks, rebounds and blocked shots (Gottlieb et al., 2014). This means 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 minutes (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, because 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)
	RSA

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 (Castagna 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

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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; Sergej 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 (Garcia-Lopez 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.

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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; Sergei 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 vertical jump (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

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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).

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10.2 APPENDIX 2

VALIDITY AND RELIABILITY OF A UNIQE AEROBIC FIELD TEST FOR ESTIMATING VO2MAX AMONG BASKETBALL PLAYERS

Reference:

Gottlieb, R., Shalom, A., Alcaraz, P.E., & Calleja-González, J. (2022). Validity and reliability of a unique aerobic field test for estimating VO2max among basketball players. Scientific Journal of Sport and Performance, 1(2), 103-114. https://doi.org/10.55860/TRMF2461.

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ORIGINAL ARTICLE

Validity and reliability of a unique aerobic field test for estimating VO_{2max} among basketball players

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ABSTRACT

This study aimed at developing and validating an innovative field test for measuring the aerobic capacity of basketball players during games. Such capacity is necessary for recovering from high frequency anaerobic actions such as sprinting and continuing to perform well. To recover, the body must rebuild its creatine phosphate reserve and emit accumulated phosphate in very short periods of time. The participants included 21 male basketball players on an elite youth league in Israel, aged 16.4 years on average. In addition to participating in the proposed test (Yo-Yo Recovery Test for Basketball Players) twice (test/re-test), the players also performed three previously validated tests (Bruce Protocol Stress Test, Yo-Yo Intermittent Recovery Level 1 Test, and Yo-Yo Endurance Test). For each test, the players' time and distance covered were documented, as were their maximum oxygen consumption and heartrate during recovery, and their perceived level of exertion. Our findings indicate the validity and reliability of the proposed aerobic field test for basketball players. Moreover, the test requires shorter times and distances for obtaining results than the other three tests. As such, this tool could be highly beneficial for basketball coaches in creating optimal training programs and game plans for each individual player and for the entire team.
Keywords: Performance analysis of sport, Fitness field test, Maximal aerobic capacity, Anaerobic activities, Yo-Yo Test.

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INTRODUCTION

Team sport games in general, and basketball in particular, are characterized by short intense activities that are repeatedly carried out throughout the game (Petway et al., 2021). These include short intense activities such as jumping, sprinting, change of direction, and agility, as well as moderate-intensity exercises that last up to 60 seconds (Stolen, 2005). In addition, basketball players also need to present aerobic capabilities (Mancha et al., 2019) during games and practices (Castagna et al., 2008), and as such, need to also develop strong aerobic capacities (Padulo et al., 2016). Due to their importance to the players' performance, a range of methods for testing aerobic and anaerobic athletic capabilities have been developed over the past two decades (Petway et al., 2020).

After performing intense activities during practices and games, the athlete's body needs to produce adenosine triphosphate (ATP), creatine phosphate (CP), and glycolysis (Gastin, 1993). Rebuilding CP requires the use of blood lactate concentrations and the removal of phosphate that accumulates in the cells (Wragg, 2000). Yet short recovery periods while playing basketball and other ball games are not always sufficient for refilling these resources after high intensity activities, and it is therefore difficult for players to consistently achieve the same level of performance throughout the game (Meckel, 2009a). In other words, the players' ability to continuously play well over time throughout the practice or game depends on the rebuilding of their CP reserves and removal of waste products (Meckel, 2009b). Moreover, since the introduction of the 24-second shot clock (Abdelkrim et al., 2007), the concept of playing quickly has become even more crucial among players (Petway et al., 2020). In turn, this has led to even higher physical demand on players, increasing the importance of explosive strength (Stojanovic et al., 2012). As a result, fitness professionals strive to develop effective training methods for promoting and developing the physical abilities of basketball players (Freitas et al., 2017), as well as optimal techniques for monitoring and evaluating various fitness components (Edward, 2018) as a means for enhancing the players' ability to perform at their optimal and maximum capacity (Freitas et al., 2019).

While basketball is considered an anaerobic-dominated game (with actions including jumping, changing direction, and footwork), these activities occur with such high frequency that they take their toll on the players (Castagna, 2008). During a game, a basketball player performs an average of 105 intense movements (each lasting two-six seconds) every 21 seconds while the clock is running. These movements lead to the consumption of 60%-75% of the body's maximum oxygen consumption (VO_{2max}); the players' heartrate reaches 70%-90% of their maximum heartrate (Meckel, 2009a). While the overall distance that a player *sprints* during the game accounts for less than 10% of the overall distance that an athlete *moves* throughout the game, these infrequent sprints have a significant impact on the players' athletic capabilities and performance during a game (Wragg, 2000). Moreover, the ability to recover from these activities and repeat them without fatigue is based on the fast renewal of CP stores and the fast removal of lactic acid from the muscle. Research indicates that a high aerobic capacity (measured via the player's VO_{2max}) may enhance this recovery process, enabling the player to perform high intensity actions throughout the basketball game (Glaister, 2005). The VO_{2max} measure relates to the maximum rate at which the body can inhale, distribute, and use VO_2 while performing physical activity (Akalan et al., 2004). For basketball players, optimal VO_{2max} is 55 ml/kg/min (Marinkovic, & Pavlović, 2013).

Aerobic capacity assessments

A range of tests have been developed for evaluating aerobic capacity and determining the physical capabilities and limitations of basketball players (Mancha et al., 2019). These can be used by professionals to design physical training programs that fit the players' level, track the players' fitness levels over time, and

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create goals for the players. This is especially important, as different sports require players to exert different types and degrees of efforts and present different physical capabilities. For example, basketball players need different levels of VO_{2max} than players of other team sports. As such, the demand for accurate and applicable field testing is of great importance and value (Stone, 2007).

Compared to laboratory tests, field tests have many advantages (Meckel, 2009a). For example, they can be conducted on a large number of players simultaneously (such as an entire basketball team), and they convey a more complete picture of the athletes' coping mechanisms for dealing with physiological, technical, tactical, and mental obstacles during a game – thereby reflecting the true nature of the field in a more accurate manner. In other words, while running on a treadmill in a laboratory may provide researchers with important data and insights, this is not the same as actually running in the field, changing directions (Mancha-Triguero et al., 2019).

As such, *aerobic conditioning*, which relates to sport-specific adaptation training and incorporates skills and movements that are specific to the sport (Stone, 2007) and at intensities that are sufficient for promoting aerobic adaptation, has been increasingly implemented in professional team sports, including basketball. Specifically with basketball, aerobic capacity assessments are important for evaluating players' recovery abilities from both aerobic and anaerobic activities, and they can provide a strong baseline for conducting professional conditioning (Stone 2007), while offering indications about planning and future training, and allowing coaches to understand which factors could assist in improving, maintaining, or increasing players' fitness levels while performing at their optimal levels, given that few specific tests are used to assess this quality in athletes (Mancha-Triguero et al., 2019).

While observing 20 basketball games in the Israeli Premier League, the authors of this study observed that basketball players have incomplete recovery times, which only last between 10 seconds (with fouls that do not require free throws) to 30 seconds (with fouls that result in two free throws) during the game, about a minute during timeout, and longer than two minutes between quarters. On average, recovery times were observed approximately every three possessions. Due to the flow of the game of basketball, it is important to develop a unique aerobic test which can predict players' VO_{2max} that is needed for recovery, based on movements such as running, changing directions, and defensive strides (Manch et al., 2019), according to the frequencies and durations of recovery during games (Calleja-Gonzalez et al., 2016;Calleja-González et al., 2018). The VO_{2max} is measured as millilitres of oxygen per kilogram of body mass per minute (ml/kg/min), and could depict high fitness levels (Figueira et al., 2008). Moreover, VO_{2max} is considered an optimal index for measuring aerobic capacity and maximal cardiorespiratory function (Hawkins et al., 2007). To the best of our knowledge, the literature lacks input regarding aerobic tests that examine activity/rest ratios, as well as related physiological aspects, among players during a basketball game.

The main aim of this study, therefore, was to develop and check the validity and reliability of a unique basketball field test that measures the aerobic capacity of basketball players during the game, while accurately replicating players' movements observed during basketball games. Such a tool could be beneficial to basketball coaches and trainers for designing and strategizing optimal game plays for the team as a whole and for the individual players.

MATERIAL AND METHODS

Participants

A total of 21 basketball players on an elite youth league in Israel participated in this study. On average, these male participants were aged 16.4 years (±0.5) with height = 180 cm (±5.5), body mass = 72 kg (±4.9), and body fat = 10.8% (±1.9%). They had been playing basketball for eight years, and their weekly routine included five basketball practices, two fitness practices, and one league game per week. Four inclusion criteria were applied in this study, whereby the player had: (a) participated in at least 90% of the weekly training sessions during the 10-month season leading up to the research; (b) regularly participated in the previous competitive season; (c) had a clean bill of health; and (iv) had not incurred injuries or pain and were not administering medication.

To reduce interference in the experiment, the participants were asked to refrain from consuming stimulants (e.g., caffeine) or depressants (e.g., alcohol) for 24 hours prior to the testing, and to refrain from eating for about 3 hours prior to the testing. They were also asked to avoid strenuous activity for at least 24 hours before the testing. As the participants were minors, their parents signed an informed written consent form. Although anonymity could not be assured due to the nature of the study, all data obtained were treated with the utmost confidentiality and scientific rigor and were used solely for the purpose of this research project. The study was conducted in compliance with the Organic Law 15/1999 of December 13 on the Protection of Personal Data and the 2008 Helsinki Statement, updated in Fortaleza (World Medical Association, 2013).

Design and Procedure

To eliminate circadian variation, all participants completed the tests at the same time of day, at 4 pm, in normal ambient conditions, with a temperature of 20.2 ± 0.5°C and relative humidity of 65.3% ± 3.5%. The tests were conducted in indoor laboratories and on regular indoor official basketballs courts; the participants wore basketball shoes and appropriate sportswear.

Each participant participated in 4 tests: one laboratory test and three field tests, within three days of each other.

Measures

To measure VO_{2max} specifically among basketball players, we developed the innovative *Yo-Yo Recovery Test for Basketball Players*. To test and validate this new field tool, the data achieved from the novel test was compared to three already-validated tests based on distance covered, VO_{2max}, heart rate, and perceived test difficulty.

1) Bruce Protocol Laboratory Stress Test (Bruce, 1949). Each participant was asked to continuously run on the treadmill, subject to gradually increasing intensity every three minutes (increased speed and inclination) for a total of seven times or until the subject was unable to continue to perform due to fatigue. This is considered the goal standard.
2) Yo-Yo Intermittent Recovery Level 1 (YYIR1). Previous assessments of *this* test (Bangsbo et al., 2012) show a correlation of r = .77 with VO_{2max} values. Each *test* section is comprised of a 40-meter run (20 meters in one direction, 20 meters back to the starting point, and a 10-second recovery period). The test *gradually increases from* 10kph by 0.5 kph for each new 40-meter section, until the participant *is unable to* continue to perform due to fatigue. The version applied in this study was developed specifically for sports such as basketball, that require intense physical efforts separated by sections of incomplete recovery (Castagna, 2008).

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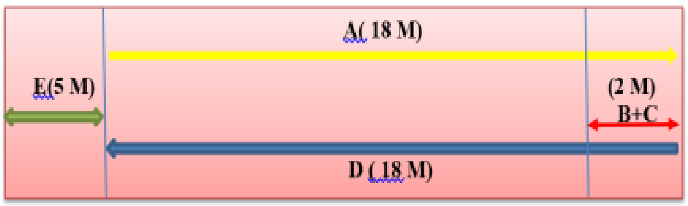
3) Yo-Yo Endurance (YYEND) Test. *Developed by* Léger et al. (1988), *this test requires participants to* run back and forth *in* 20-meter *sections* with increased *intensity* effort until the participant *is unable to continue due to* fatigue. Previous assessments of *this* test show a *very high* correlation of r = .92 with VO_{2max} and is reliable and valid for predicting aerobic capacity among a range of populations (St. Clair Gibson et al., 1988). The sprints *begin* at *a speed of* 8 km/h and increase by 0.5 km/h approximately every minute, as dictated by an audio disc. The results are determined by the number of times the athlete is able to perform these sprints until overcome by fatigue. The test was chosen for this study due to its similarity to the activity patterns that are routinely performed by athletes every few months, as a means for evaluating their aerobic fitness.
4) Yo-Yo Recovery Test for Basketball Players (YYRECB). This unique test was developed to examine recovery specifically among basketball players and is comprised of movements from the game of basketball, including running, changing directions, and defensive strides – with short and intense discrete parts for recovery. The procedure includes running (18 meters) + defensive strides in one direction (2 meters) / defensive strides (2 meters) + running (18 meters) back to the starting point / recovery walking (five meters + five meters *in both directions*) for 10-20 seconds (Figure 1). Each participant performed *this* test twice for means of validation (i.e., test/re-test), while the previous three tests were only performed once.



Note. A. Running forward (18 meters) – Yellow line. B. Defensive steps (2 meters) – Red line. C. Defensive steps (2 meters)- Red line. D. Running back to the starting line (18 meters)- Blue line. E. Recovery, 10-20 seconds walking (10 meters: 5 meters back and forth)- Green line.

Figure 1. Track for conducting new YYRECB Test.

In addition to documenting the distance covered in each test, the time it took to complete the tests, and the participants' VO_{2Max}, we also measured their maximum heart rate (HRmax) towards the end of each test, based on the number of heartbeats (contractions) per minute (bpm) – using the Polar HR monitor and transmitter (Polar Electro, Lake Success, NY, USA) that was validated by Goodie et al. (2000). Finally, after each test, the participants were asked to rate the difficulty of the test using the Rated Perceived Exertion (RPE) Scale (Borg, 1998). The scale ranges from six (felt nothing at all [like sitting in a chair]) to 20 (felt very heavy [like at the end of an exercise stress test or other very difficult activity]).

Statistical analysis

Standard statistical parameters (mean ±SD) were calculated for the anthropometric data and physical performance test results. Normality was tested through analysis of the censored exposure data subject to the constrained maximization of the Shapiro-Wilk W statistics (<30). Reliability of the new test was measured via Intra-class Correlation Coefficient (ICC), and validity was measured using Pearson correlation tests. In line with Hopkins et al. (2009), correlation coefficients were considered *trivial* ($r < .1$), *small* ($.1 < r < .3$), *moderate* ($.3 < r < .5$), *high* ($.5 < r < .7$), *very high* ($.7 < r < .9$), *nearly perfect* ($r > .9$), or *perfect* ($r = 1$). Validity and intra/inter-evaluator reproducibility were evaluated by the ICC as well. Finally, the analysis of the Bland-Altman concordance resulted in a variation coefficient of less than 10%. Significance levels were $p < .05$. SPSS® v17.0 (SPSS®, Inc., Chicago, IL) was used for conducting statistical analyses.

RESULTS

The test/re-test results showed the YYRECB to be very reliable ($r = .97$). In particular, the HR_{max} during the distance covered during tests, time spent on each task, and RPE ratings did not present test/re-test differences (all variables = .971). Very high correlations were found between VO_{2max} (mL x kg^{-1} x min^{-1}) and YYRECB ($r = .769$; 95% confidence interval [CI]; $p < .0001$). Besides, significant differences were also seen in distances covered in the YYRECB test compared to those covered in the YYREC1 and YYEND tests ($r = .748$ and $r = .723$, respectively; 95% CI; $p < .0001$). Pearson correlations were performed once for all measures and twice for the YYRECB (test/re-test), which was found to be reliable, without significant differences in HR_{max} and distances covered. Internal correlation between repetitions was .971 (Table 1).

Table 1. Descriptive statistics (Test/Re-Test) for the New YYRECB test.

Variable		Mean	SD	Coefficient of Variable
Level	Test	10.94	0.14	5.95
	Re-test	11.02	0.13	5.48
VO_{2max} (ml/kg/min)	Test	55.52	0.49	4.07
	Re-test	55.63	0.45	3.74
HR (end)	Test	191	1.1	2.64
	Re-test	191.57	1.11	2.66
Total Distance (min)	Test	1605.71	34.62	9.88
	Re-test	1613.33	31.99	9.09
Total Time (sec)	Test	1006.9	18.02	8.2
	Re-test	1009.48	16.53	7.5
RPE (6-20)	Test	17.29	0.24	6.37
	Re-test	17.29	0.22	5.83

Note. HR end = Heart Rate at the end of the test. RPE = Rate Perceived Extortion. VO_{2max} = Maximal aerobic capacity.

Bland-Altman analysis of reliability is derived from agreement between measures (Lu Mj et al., 2016), enabling reporting of the mean bias and the upper/lower VO_{2max}. As shown in Table 2, when tested against the VO_{2max}, the innovative YYRECB demonstrated a high correlation for distance ($r = .769$). When tested against YYREC1 and YYEND, the YYRECB demonstrated high correlations for distance ($r = .723$ and $r = .748$, respectively). The Bland-Altman Difference Plot for analysing VO_{2max} in the YYRECB resulted in zero, indicating complete agreement and lack of bias (Giavarina, 2015). The formula for estimating VO_{2max} in the YYRECB test is: $VO_{2max} = 0.0146x + 32.078$ (x = the distance covered during the test); mean = 0. Complete agreement was seen between the laboratory test and the YYRECB (CI 95% -1: + 1, CI mean -3.5: +3.6), as well as a very good correlation up to 55 ml/kg/min (Figure 2).

For the Bland-Altman analysis of VO_{2max} and YYREC1, mean = 2.1 (Figure 3). As such, 2.1 must be added to the result to compare YYREC1 results to laboratory results (CI 95% -0.5: + 3, CI mean -2.5: + 6.6).

Finally, Bland-Altman analysis of VO_{2max} and YYEND presented mean = 0.7, as seen in Figure 4. Therefore, 0.7 must be added to YYEND results in order to compare to the innovative test to the laboratory test (CI 95% 0: +1; CI mean -2.5: +4).

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Table 2. Test/re-test reliability and agreement between Yo-Yo Tests.

Variable	YYRECB				
	ICC	SD	Bland-Altman		
			Bias	VO_{2max} (lower)	VO_{2max} (upper)
YYIR1	0.645*	5.01	6.6	-2.5	2.1
YYEND	0.859*	5.66	3.9	-2.4	0.7
YYRECB	0.769*	3.81	3.6	-3.5	0

*Note. *Correlation is significant at the .01 level (2-tailed).*

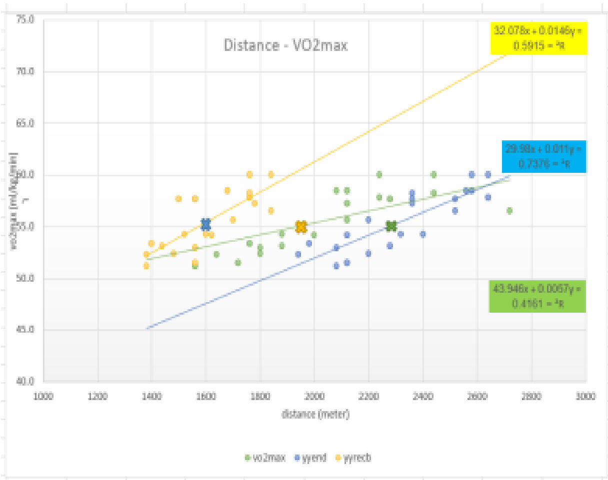

Figure 2. Formula for estimating VO_{2max}.

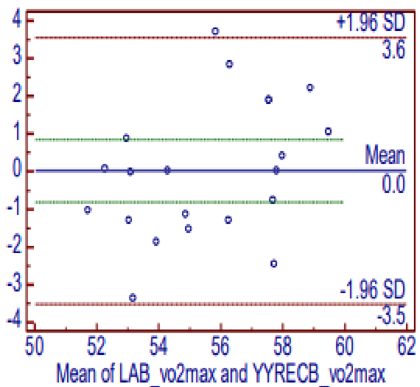

Figure 3. Bland-Altman Plot for VO_{2max} laboratory and YYRECB tests.

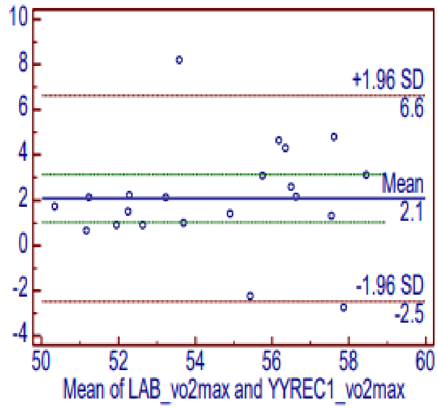

Figure 4. Bland-Altman Plot of VO_{2max} laboratory and YYRECB tests.

DISCUSSION

Basketball involves specific movements on the field (Petway et al., 2021), including frequent changing of direction and repeated sprints with limited recovery time (Meckel, 2009a). Moreover, aerobic conditioning among basketball players is necessary for achieving desired outcomes in practices and games. The main aim of the study was to test the validity and reliability of a novel field test that measures the aerobic capacity of basketball players (i.e., VO_{2max}) based on movements that replicate those performed during games. As this test is also less time consuming and money draining than laboratory tests, and does not require specialized personnel and equipment, this test is more practical for basketball trainers and can be applied in the field (Akalan et al., 2004). Moreover, measuring VO_{2max} in the field is expected to provide results that are more aligned with the players' capabilities during a game (Gottlieb et al., 2021).

Our results indicate the validity and reliability of our proposed version of the Yo-Yo test (i.e., the YYRECB) for assessing basketball players' endurance and fitness in the field, with no differences seen in the players' RPE and heart rate between tests. The Bland-Altman analysis presented completed agreement between the VO_{2max} measured in the laboratory and that measured in the YYRECB. Correlation and agreement were also found when compared to previously validated field tests (i.e., YYEND and YYREC1). Moreover, to achieve the target VO_{2max} needed in basketball (about 55ml/kg/min, Marinkovic & Pavlović, 2013), the players needed to complete 1600 meter. Stopping the test at this level means they will be able to maintain this aerobic conditioning in basketball practices, although there are significant differences between U-14 and U-17, in the VO_{2max} on court specific test (Calleja-Gonzalez et al., 2018).

The Yo-Yo test performances may vary greatly over the course of a season, as seen in the game of soccer, where peak performance is often demonstrated mid-season (Krustrup et al., 2003). Thus, to provide a more accurate indication of aerobic capability of players throughout the season, the YYRECB test should be conducted a minimum number of times a year. For example, one week into pre-season, three-four weeks into the pre-season, and then again mid-season. Based on these findings, future studies may modify the

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YYRECB field test to suit other specific sports, especially where players are frequently required perform intermittent activities as with basketball.

Our research presents a number of limitations. First, only high school male basketball players participated in the study. Future studies could benefit from evaluating the test based on a larger range of gender and ages, to be able to generalize the findings. Moreover, participants must be motivated in order to optimally perform the test. Finally, gathering and deciphering the data was not simple, and required a range of technological means to do so.

Limitations

Despite its theoretical and practical contribution to the field, the current study has limitation, only youth male basketball players participated in the study. Future studies could benefit from evaluating the test based on a larger range of gender, ages, and positions, to enable generalization of the findings.

CONCLUSIONS

Field tests for examining basketball players' aerobic capacity needed for recovery must be aligned with the unique components of the game. The proposed YYRECB test offers a valid and reliable field test for evaluating the recovery capabilities (VO_{2max}) of basketball players that also requires less time and distances to achieve the required data. This test could be beneficial for basketball trainers in planning practices and games and achieving optimal outcomes.

AUTHOR CONTRIBUTIONS

Roni Gottlieb, Asaf Shalom, Dr. Pedro Emilio Alcaraz, and Dr. Julio Calleja-González conceived and designed the investigation tool, analysed and interpreted the data, drafted the manuscript, and approved the final version submitted.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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10.3 APPENDIX 3

DIFRENCES IN AEROBIC CAPACITY OF BASKETBALL PLAYERS BY GENDER, AGE, AND RELATIVE AGE EFFECT

Reference:

Gottlieb, R., Shalom, A., Alcaraz, P. E., & Calleja-González, J. (2023). Differences in aerobic capacity of basketball players by gender, age, and relative age effect. Journal of Human Sport and Exercise, In Press. https://doi.org/10.14198/jhse.2023.184.02.

Original Article

Differences in aerobic capacity of basketball players by gender, age, and relative age effect

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ABSTRACT

When playing basketball, athletes must optimally perform repeated short sprints with minimal recovery time, requiring both anaerobic and aerobic abilities, including high VO_{2max}. Yet differences have been seen between young male and female basketball players in this measure. The aim of this quantitative study was to examine differences in players' VO_{2max} by gender, age group, and relative age effect (RAE) using the novel Yo-Yo Recovery Test for Basketball Players. The study included 438 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. To assess RAE, the participants in each category were divided into three trimesters of four months, based on their date of birth. The participants' VO_{2max} was assessed using the novel aerobic test. In this study, we hypothesized that male players will exhibit greater aerobic capacity than female players of the same age and that older players will exhibit greater aerobic capacity than younger ones. Our findings supported these hypotheses, as male players presented better physical fitness results than female players in all age categories. Moreover, female players 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 the relative age effect on performance were seen between the genders and within the female participants. While the male participants presented a steady improvement with age, the results of the girls showed a different pattern. 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' aerobic capacity.

Keywords: Performance analysis of sport, Fitness field test, Maximal aerobic capacity, Gender, Yo-Yo Recovery Test, Basketball players.

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INTRODUCTION

As basketball is one of the most popular sports in the world, players make great efforts to reach elite performance levels, practicing on a daily basis and frequently participating in basketball competitions at the national and/or international level (Lidor et al., 2007). To achieve and maintain optimal performance levels, basketball players train in line with predefined short-term and long-term programs, with an emphasis on their need to continuously perform anaerobic activities, such as short sprints and direction changes, with relatively short recovery times (10, 30, or 60 seconds). Yet recovery from such actions is dependent on the players' aerobic abilities, specifically their VO_{2max} (Gottlieb et al., 2022). Moreover, an even greater need for aerobic capacity in basketball players has been seen since 2000, when the shot clock rule was introduced (i.e., the 24 seconds permitted for shooting the ball, instead of the former 30 seconds), as well as the transition to four quarters instead of two halves (Stojanovic, 2018).

For example, the intensity of the game can reach up to 95% of the maximum heart rate (HR) value, with players covering more than 3% of the total running distance over 18 km/h. Players also perform quick transitions between offensive and defensive plays, with about 576 transitions being recorded during a full game. This indicates that players should train at a level that is at least equivalent to the physiological demands of an actual a game. However, the typical movement patterns seen in basketball, such as jumping, defensive steps, and repeated sprinting efforts, are known to cause exercise-induced muscle damage due to a combination of eccentric muscle actions and high-intensity concentricity (Doma, K et al., 2018).

In a study conducted by Scalan (2015), female basketball players were found to perform at greater running work rates than male players, while male players performed more dribbling than female players. Female players also performed more low-intensity shuffling and jumping, as well as longer jogging durations than male players. Yet no gender differences were seen in the players' overall intermittent demands, distance travelled, high-intensity shuffling activity, and sprinting requirements while playing.

Studies indicate that high aerobic fitness could improve recovery time and efficacy in basketball players, as well as muscle strength and power, especially in anaerobic activities such as blocking, rebounding, jumping, and changing directions (Meckel et al., 2009). In light of the importance of aerobic capacity in basketball players, a range of practical assessment tools have been developed over the years (Mancha et al., 2019), that can be used, for example, for defining the baseline for future training and assessments (Stone, 2007). These tests can also offer a clearer indication of which skills and capabilities should be enhanced or maintained in individual basket players, for improving their game performance and outcomes (Mancha-Triguero et al., 2019).

Many physiological aspects of basketball playing mature during childhood, including a person's VO_{2max} values; yet studies show that improved aerobic power can also increase these values at a later age. Moreover, VO_{2max} values in males, in relation to body weight, remain stable over time, unlike the gradual decrease that is seen in females. When measuring aerobic metabolism, VO_{2max} values can be examined via a range of variables, such as the transfer of oxygen by the lungs, heart, and blood vessels. When exercising, the oxygen supply chain responds to the aerobic needs of the muscles that are in action at that time, and may reach maximum capacity, depending on the demand. In adults, VO_{2max} values can therefore serve as an indicator of their cardio-vascular limits or endurance (Rodriguez et al., 2003).

In children and adolescents, however, interpreting VO_{2max} is more difficult, as growth changes may interfere in such measurements. Moreover, maximum oxygen consumption levels gradually increase as the child

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ages, in light of both muscular and sexual maturation. Studies show that prior to sexual maturity (~12 years of age), VO_{2max} levels may increase by up to 225 ml/min each year, and is 16% greater in boys than in boys. In girls, this increase comes to a halt at about the age of 12 and then begins to decline, whereas in boys, it continues to increase (Ziv, 2009). It is therefore vital that appropriate tests are developed and applied for assessing VO_{2max} in basketball players, depending on their age and gender.

Differences in aerobic capacity by gender and age

Studies show that boys tend to have greater aerobic capacity than girls of similar ages, due to a range of factors, including differences in body composition, size, and hormones. For example, at the age of 14, boys have about 25% more VO_{2max} than girls, due to increased muscle mass in the former compared to increased fat tissue in the latter, as well as higher testosterone levels – thereby creating greater aerobic capacity in boys (Ziv, 2009).

Studies on basketball players tend to focus on developing analytical measuring tools, with the aim of enabling coaches and trainers to optimize their players' performance (Gottlieb et al., 2021). Yet assessment techniques much be sensitive to differences in basketball-playing abilities between players of different genders and ages. For example, dribbling in seen more in male basketball games, while running is seen more in female basketball games (Ziv, 2009). Studies also show that VO_{2max} values among female players are within the 44.0-54.0 mLO_2/kg/min range, compared to the 50-60 mLO_2/kg/min range among male players (Lidor, 2007). However, large variations can be seen in studies on VO_{2max} values among men, such as 45.3-5.9 mLO_2/kg/min (Gocentas, 2004), 45.3-65.2 mLO2/kg/min (Tavino, 1995), or 49.8-63.4 mLO2/kg/min (Abdelkrim, 2010). Such variations could stem from differences in the measurement tool or protocol that were applied in the various studies.

Effect of age on aerobic capacity

People's VO_{2max} refers to their maximal oxygen uptake – the highest rate at which they are able to consume oxygen during exercise. The VO_{2max} measure is an optimal tool for assessing athletes' aerobic fitness, i.e., the body's ability to deliver oxygen to the muscles while exercising and then use it to generate energy. The degree of this ability differs between people, and depends on components that are involved in the delivery of the oxygen to the muscles (including pulmonary, haematological, and cardiovascular elements), as well as on the oxidative mechanisms of the muscles that are taking part in the current exercises (Armstrong, 2006).

In young males, a gradual increase is seen in their VO_{2max}, from age 8 to 16 years, with the greatest annual increases occurring between the age of 13-15 years. In young females, on the other hand, this increase is less consistent, with their VO_{2max} being on a steady incline until they reach the age of 13 years, at which time it starts to level off. In addition, both the peak VO_{2max} and its gradual increase among young males are higher than among young females (Armstrong, 2006).

Relative age effect on aerobic capacity

In sports, in addition to the athletes' chronological age, the term Relative Age Effect (RAE) is also applied, referring to differences within the same age group. While chronological age differences imply different levels of performance and experience due to physical developmental and maturational, RAE refers to differences between people in the same age category, whereby those who were born earlier in the year present improved physical, emotional, and cognitive development compared to their peers who were born later in the year (Ibañez, 2018). Yet considerable inconsistencies on RAE can been seen in the literature. For example, athletes who were born early in the competition year were more highly represented than those who were born late in that year (Baker, 2007), yet no age-related differences were seen in the relative VO_{2max} of 7–13-

year-old children (McMurray, 2002). As such, a consistent and applicable measuring tool should be used across studies, to enable comparisons and generalizations.

Following this literature review, the aim of the current study was to examine the aerobic capacity of young elite basketball players via their $VO2_{max}$, based on age, gender, and RAE using the validated Yo-Yo Recovery Test for Basketball Players (Gottlieb et al., 2022).

MATERIAL AND METHODS

Participants

The study included 438 young basketball players, both male and female, from five clubs in Israel. First, anthropometric measurements were taken for each participant, including height (m), body mass (kg), and body fat (%). Height was measured using a stadiometer (SECA, Germany) with a 1 cm accuracy; body mass and fat were measured using electronic scales (Tanita BC 418, Japan), with a 0.1-kg accuracy (Slaughter et al., 1988). All participants had been playing basketball for three to eight years, and each week conducted at least two fitness practices, participated in three to five basketball practices, and one league game. The players also had to present a clean bill of health, with no injuries, aches, or ongoing medication.

Procedure

After contacting the basketball clubs and coaches to request their participation in the study, informed consent was received from both the players and their parents. The participants were also informed that their participation in the study was not mandatory. Although anonymity could not be promised due to the nature of the study, the participants and their parents were assured that the utmost confidentiality and scientific rigor would be applied throughout the study, and that the achieved data would only be used for the purpose of this research project. Dates for conducting the study at each club were set, so as not to interfere with their training and competitions.

To eliminate circadian variations, all participants completed the test at the same time of day (6 pm), in normal ambient conditions, and with a temperature of 23.1 ± 0.5°C and relative humidity of 70.5% ± 3.5%. The assessments were conducted by the researchers together with the team's coach, inside official indoor basketballs courts; the participants were required to wear their regular sportswear and basketball shoes. Prior to the study, the players were instructed to refrain from caffeine and other stimulants, alcohol and other depressants, and strenuous physical activities for at least 24 hours prior to the research assessments. They were also asked to not consume food for about three hours prior to the testing. The study was approved by the Bioethics Committee at the first author's affiliated academic institution (registration number 367).

Tools

The novel Yo-Yo Recovery Test for Basketball Players was developed for assessing players' VO_{2max} in relation to their recovery from specific movements that are common in the game of basketball (such as short sprints, changing directions, and defensive strides). During the test, the participants were first asked to run in one direction for 18 meters along a clearly marked path inside the basketball court, followed by 2 meters of defensive strides in the same direction. Without stopping or resting, this was immediately followed by an additional 2 meters of defensive strides in the opposite direction (i.e., towards the starting point), followed by their running back to the starting point for another 18 meters. The participants then had 10-20 seconds recovery, during which time they were required to walk 5 meters in both directions (Appendix 1).

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The speed at which the participants were instructed to run for each round was dictated by audio sounds. Moreover, this speed increased from round to round. The participants were asked to perform this procedure until they were too tired to continue, while wearing an HR band on their chest (GARMIN®, Olathe, KS, USA). At this point, the total distance that they had covered was calculated (also via audio recordings), and their physical measures were assessed. (1) Sound file from the novel test; (2) Formula for calculating VO_{2max} = 0.0146x + 32.078, with x representing the distance covered during the test (Gottlieb, 2022); (3) HR; and (4) Table of rate perceived exertion (on a scale of 1-10).

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 (5) *three relative age* groups according to the players' month of birth: *tri1* (January-April), *tri2* (May-August), and *tri3* (September-December). The following four dependent variables were also analysed in this study: (1) *distance* (m), i.e., the number of meters covered during the test; (2) predicted VO_{2max}; (3) HR; and (4) rate of perceived exertion (RPE), on a scale of 1 (easiest) to 10 (hardest).

Statistical analysis

In this quantitative study, means and standard deviations (SD) were calculated for weight, 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 relative age groups. Statistical analyses were performed using the SPSS v.21 software (Inc, Chicago, IL, USA); statistical significance was set at $p <$ .05.

RESULTS

Table 1 presents the participants' physical characteristics, including weight, height, and body fat by age group and gender.

Table 1. Participants' Physical Characteristics by Mean (SD)

		N	Weight (kg)	Height (m)	FAT%
Male	U18	71	77.3 ± 7.64	1.85 ± 5.28	10.72 ± 1.31
	U16	80	66.3 ± 8	1.79 ± 6.2	10.62 ± 1.27
	U14	70	57.8 ± 8.2	1.72 ± 6.8	11.03 ± 1.29
Female	U18	73	59.8 ± 5.8	1.65 ± 5.01	25.45 ± 4.56
	U16	73	57.7 ± 5.53	1.62 ± 4.76	24.31 ± 3.39
	U14	71	47.2 ± 4.37	1.57 ± 4.96	22.97 ± 5.67

Table 2 presents the participants' descriptive data by gender (including age, distance covered during the test, VO_{2max}, and RPE), and distance by trimester. As seen in Figure 1, significant differences were seen between the genders in their mean distance covered, regardless of age, whereby the mean distance for males (1,421.6 ± 218.8) was significantly greater than for females (1,116.9 ± 137.2). Moreover, improvement in these results in line with increased age was also evident, whereby older players covered greater distances.

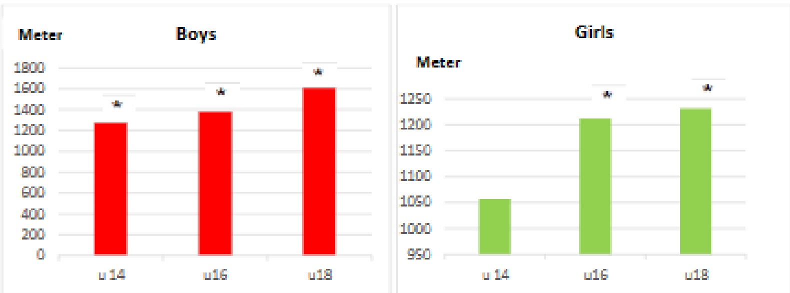
In addition, interactions were also seen between age and gender, whereby improved distances in the female participants began to decrease after the age of 16, unlike the continued increase seen in males at the same ages (Figure 2).

Table 2. Participants' descriptive statistics.

Gender	Age	N	Distance (m)	VO_{2max}	RPE
Males	U14	71	1274.31 ± 195.5	55.5 ± 3.5	7.49 ± 0.48
	U16	80	1383 ± 233.13*	52.27 ± 3.36	7.58 ± 0.49
	U18	70	1607.4 ± 226.03*	50.68 ± 2.8	7.7 ± 0.56
Females	U14	71	1056.34 ± 137.3	47.5 ± 1.99	7.6 ± 0.54
	U16	73	1212.60 ± 129.4*	49.78 ± 1.87	7.61 ± 0.56
	U18	73	1231.78 ± 144.8*	50.06 ± 2.1	7.62 ± 0.48

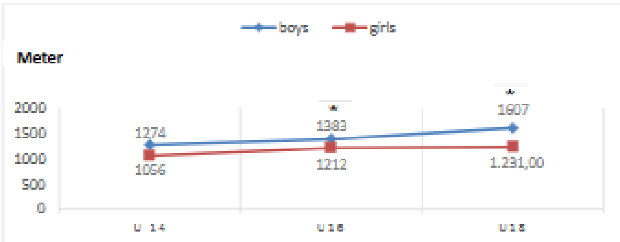
Gender	Distance By Trimester (m)		
	tri 1	tri 2	tri 3
Males	1409.23 ± 178.9	1219.05 ± 89.1*	1176.67 ± 203.2
	1360 ± 250.67	1392 ± 189.78	1360 ± 250.67
	1560 ± 249	1576 ± 213.6	1681.67 ± 210.83*
Females	1204 ± 104.13	1023.45 ± 68*	946.09 ± 44.4*
	1342.4 ± 100.7	1190.67 ± 66.17*	1068.89 ± 40.7
	1385.60 ± 101.9	1209.09 ± 72.9*	1103.08 ± 68.04

Note. * tri1-tri3 * tri2-tri3 *age from previous age group; * gender ($p < .05$).



Note. * Boys U18-U14 and U18-U16 and U16-U14 ($p < .05$). * Girls U18-U14 and U16-U14 ($p < .05$).

Figure 1. Average distances covered by gender.



Note. * Between boys-girls in U14 and U16 and U18 ($p < .05$).

Figure 2. Differences in average distances by age and gender interactions.

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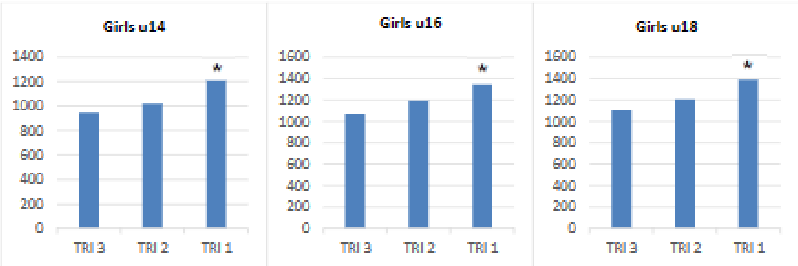
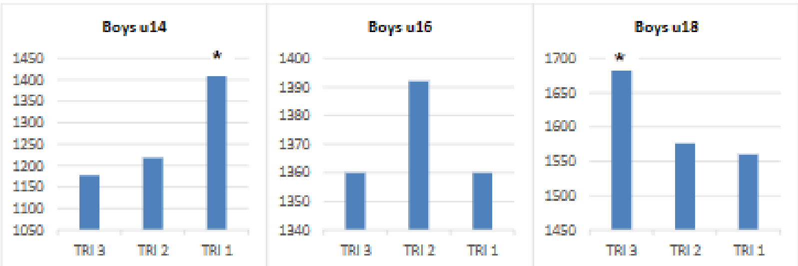
The male participants showed consistent significant improvement in the mean distances covered by age, with a significant increase from U14 (1274.3 ± 195.5) to U16 (1383 ± 233.1), and from U16 to U18 (1607.4 ± 257.8). With the female participants, on the other hand, no such consistency was seen, in light of an increase from U14 (1056.3 ± 1212.6) to U16 (1212.6 ± 129.4), yet with no significant change from U16 to U18 (1231.7 ± 144.8), as depicted in Figure 2. Moreover, when examining interactions between gender and time, different results were seen for each trimester.

When examining RAE among all age groups of *female* participants, a significant decline was seen in performance between trimesters, with the highest score awarded on the first trimester (1329.8 ± 116.5), a steep decline on the second trimester (1135.8 ± 108.5), and the lowest was seen for the third trimester (1040 ± 87.8), as seen in Figure 3. For the male participants, however, interactions were seen across all three trimesters, in addition to an interaction between time and gender. As seen in Figure 4, while the results of the U14 *male* participants followed this pattern of decline throughout the year (tri1 = 1409.3 ± 41.6; tri2 = 1219 ± 46.3; and tri3 = 1176.6 ± 43.3), this pattern is not seen in the U16 or U18 age group.



Note. *$p < .05$ tri1-tri2 and tri1-tri3 (U14). * $p < .05$ tri1-tri2 (U16). * $p < .05$ tri1-tri2 (U18).*

Figure 3. Female participants: RAE and mean distances.



Note. * $p < .05$ tri1-tri2 (U14). * $p < .05$ tri3-to tri2 and tri1 (U18).*

Figure 4. Male participants: RAE and mean distances.

The declined performance between trimesters in the male U16 group was smaller than that of the female U16 group and of the male U14 group. For all groups, most declines between trimesters were seen between tri1 and tri2, except for the female U14 group, that also exhibited a significant decline between tri2 and tri3. However, in the male U16-year group, no decline was seen between tri1 and tri2, and the decline that was seen between tri2 and tri3 was very small. Interestingly, for the male U18 group, a significant increase was seen between all three trimesters.

The participants' subjectively exerted effort was significantly higher than the measures presented in the literature regarding RPE (Borg, 1998), thereby indicating that they found the test harder than would have been expected of them. No significant differences were found in RPE between the age groups and genders.

DISCUSSION

VO_{2max} plays an important role in the overall athletic performance of young basketball players. This factor relates to the body's ability to utilize oxygen as a means for generating energy when exerting physical activity, and is determined by a number of measures, including genetics, diet, overall health, and training (Lidor, 2007). Correlations between VO_{2max} and activity levels suggest that aerobic conditioning is beneficial in basketball players (Narazaki et al., 2009). In order to perform at high levels, basketball players must also possess good cardiovascular fitness. Basketball requires players to have explosive power, while performing strenuous actions combined with active and passive recovery that depends on VO_{2max}.

Players with high VO_{2max} are able to run and move more quickly on the court, while recovering more quickly from intense physical exertion. In turn, this could provide them with a competitive advantage over players with lower on VO_{2max}. The aim of this quantitative study was to examine differences in players' VO_{2max} by gender, age group, and RAE, using the novel Yo-Yo Recovery Test for Basketball Players. Significant differences were found between genders, as the male participants covered greater distances than the female ones in all age groups. Significant differences were also found in the average distance covered during the test, with better test results seen in older players. Moreover, it was also found that the results of the test varied by RAE, with repeated measures for each trimester yielding different results.

Differences in the effect of age on performance were seen between the genders and within the female participants. While the male participants presented a steady improvement with age, the results of the female participants exhibited a different pattern: Although the female players showed similar improvement from U14 to U16, as did the male players, no significant improvement was seen between U16 and U18. This finding is in line with Ramos et al. (2019), indicating the different effects of puberty on the two genders, and the implications of these differences on athletic performance in general, and on aerobic performance in particular.

When conducting repeated measures across the trimesters, an interaction was seen between age and gender. For the female participants, a similar decline in performance was seen in all age groups across trimesters. This finding is in line with the literature, whereby better results will be seen in players who were born earlier in the year than those who were born later in the year (Susana M. 2021). However, very different results were seen in the group of male players, whereby a similar decline was seen between trimesters in the U14 group, a minor decline was seen between trimesters in the U16 group, and an improvement was seen between trimesters in the U18. Finally, the participants' self-reported RPE scores at the end of the test is in line with similar assessments that relate to VO_{2max} tests, thereby indicating the relevance and reliability of the Yo-Yo Recovery Test for Basketball Players.

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Estimated achievement table

Based on the data that was gathered an analysed in this study, we have created an Estimated Achievement Table (Table 3) for the benefit of coaches and trainers of young basketball players. This tailormade scale differentiates between the age and gender of the players and presents the expected distance performance using the using the novel Yo-Yo Recovery Test for Basketball Players, to enable the ranking of players from unprepared to excellent.

Table 3. Achievements Table (Yo-Yo Recovery Test for Basketball Players)

Male			Female		
Age	**Distance (M)**	**Assessment**	**Age**	**Distance (M)**	**Assessment**
	1800>	excellent		1370>	excellent
	1601-1800	very good		1231-1370	very good
U18	1401-1600	good	**U18**	1091-1230	good
	1201-1400	poor		951-1090	poor
	1200<	unprepared		950<	unprepared
Age	**Distance (M)**	**Assessment**	**Age**	**Distance (M)**	**Assessment**
	1610>	excellent		1330>	excellent
	1381-1610	very good		1201-1330	very good
U16	1151-1380	good	**U16**	1071-1200	good
	920-1150	poor		941-1070	poor
	920<	unprepared		940<	unprepared
Age	**Distance (M)**	**Assessment**	**Age**	**Distance (M)**	**Assessment**
	1460>	excellent		1180>	excellent
	1271-1460	very good		1051-1180	very good
U14	1081-1270	good	**U14**	921-1050	good
	891-1080	poor		791-920	poor
	890<	unprepared		790<	unprepared

Limitations

Despite its theoretical and practical contributions to the field, this study has some limitation that should be addressed. First, the ability to change directions in basketball is a skill that improves with practice; as such, the results of the younger participants are more likely to be affected by inaccurate technique. In addition, recovery time between rounds in the test is predetermined, unlike in real basketball games, where recovery times may frequently differ. Future studies could benefit from random recovery times between runs (such as 5, 10, 15, or 20 seconds), and an additional task could be added, where after every round, the player has to make a basketball-related decision, such as shooting, passing and dribbling.

CONCLUSIONS

This study implemented the novel Yo-Yo Recovery Test for Basketball Players in young players, both male and female, from five different league club, to assess their aerobic capacity (VO_{2max}) that plays a central role in their ability to recover from anaerobic actions with minimal recovery time. This unique assessment tool is of the utmost importance, as it enables accurate testing on the basketball court, rather than in laboratory settings and is specific to the game of basketball. The main findings indicate that young male basketball players aged 14-18 have greater aerobic capacity than female players of the same ages. Moreover, RAE can be seen in young male basketball players of all age groups (U14, U16, and U18), yet not in young female players.

The Yo-Yo Recovery Test for Basketball Players test offers a new field test for evaluating players' recovery capabilities basketball players – conducted on real basketball courts and requiring less time and distance for achieving the required data. The test can also be modified to suite players of different ages and fitness levels. For example, providing younger and/or less fit players with longer periods of active recovery, or requiring advanced players to run longer distances or at higher speeds during the test. Moreover, when addressing the age of pubertal changes in basketball training, differences between young male and female players should be taken into account. Finally, this unique test could be especially beneficial for basketball trainers and coaches in planning training programs, practices, and games – to achieve optimal outcomes by gender and age.

AUTHOR CONTRIBUTIONS

Roni Gottlieb, Asaf Shalom, Dr. Pedro Emilio Alcaraz, and Dr. Julio Calleja-González conceived and designed the investigation tool, analysed and interpreted the data, drafted the manuscript, and approved the final version submitted.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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Appendix 1. Timetable: Yo-Yo Intermittent Recovery Test for basketball players.

Yo-Yo intermittent recovery test for B (YYRECB)						
Speed level	Shuttle number	Speed (km/hr)	Level time (sec)	Shuttle distance (m)	Time (min)	Estimate VO_{2max} (ml/min/kg)
1	1	6	24	40	00:24	32.66
2	1	8	18	80	00:52	33.25
2	2	8	18	120	01:20	33.83
3	1	9	16	160	01:46	34.41
3	2	9	16	200	02:12	35.00
3	3	9	16	240	02:38	35.58
4	1	10	14	280	03:02	36.17
4	2	10	14	320	03:26	36.75
4	3	10	14	360	03:55	37.33
4	4	10	14	400	04:19	37.92
5	1	11	13	440	04:42	38.50
5	2	11	13	480	06:05	39.09
5	3	11	13	520	06:33	39.67
5	4	11	13	560	06:56	40.25
6	1	12	12	600	07:29	40.84
6	2	12	12	640	07:51	41.42
6	3	12	12	680	08:18	42.01
6	4	12	12	720	08:40	42.59
7	1	13	11	760	09:01	43.17
7	2	13	11	800	09:22	43.76
7	3	13	11	840	09:43	44.34
7	4	13	11	880	10:14	44.93
7	5	13	11	920	10:35	45.51
8	1	14	10.5	960	10:56	46.09
8	2	14	10.5	1000	11:17	46.68
8	3	14	10.5	1040	11:38	47.26
8	4	14	10.5	1080	12:09	47.85
8	5	14	10.5	1120	12:30	48.43
9	1	15	10	1160	12:50	49.01
9	2	15	10	1200	13:10	49.60
9	3	15	10	1240	13:30	50.18
9	4	15	10	1280	14:00	50.77
9	5	15	10	1320	14:20	51.35
10	1	16	9.5	1360	14:39	51.93
10	2	16	9.5	1400	14:58	52.52
10	3	16	9.5	1440	15:17	53.10
10	4	16	9.5	1480	15:46	53.69
10	5	16	9.5	1520	16:05	54.27
10	6	16	9.5	1560	16:23	54.85
11	1	16.5	9	1600	16:42	55.44
11	2	16.5	9	1640	17:01	56.02
11	3	16.5	9	1680	17:20	56.61
11	4	16.5	9	1720	17:49	57.19
11	5	16.5	9	1760	18:08	57.77
11	6	16.5	9	1800	18:27	58.36
12	1	17	8.5	1840	18:45	58.94
12	2	17	8.5	1880	18:57	59.53
12	3	17	8.5	1920	19:15	60.11
12	4	17	8.5	1960	19:43	60.69
12	5	17	8.5	2000	20:01	61.28
12	6	17	8.5	2040	20:19	61.86

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10.4 APPENDIX 4

TIMETABLE: YO-YO INTERMITTENT RECOVERY TEST FOR BASKETBALL PLAYERS (YYRECB)

Yo-Yo intermittent recovery test for B (YYRECB)						
speed level	shuttle number	speed (km/hr)	level time (sec)	shuttle distance (m)	time (min)	estimate Vo2max (ml/min/kg)
1	1	6	24	40	00:24	32.66
2	1	8	18	80	00:52	33.25
2	2	8	18	120	01:20	33.83
3	1	9	16	160	01:46	34.41
3	2	9	16	200	02:12	35.00
3	3	9	16	240	02:38	35.58
4	1	10	14	280	03:02	36.17
4	2	10	14	320	03:26	36.75
4	3	10	14	360	03:55	37.33
4	4	10	14	400	04:19	37.92
5	1	11	13	440	04:42	38.50
5	2	11	13	480	06:05	39.09
5	3	11	13	520	06:33	39.67
5	4	11	13	560	06:56	40.25
6	1	12	12	600	07:29	40.84
6	2	12	12	640	07:51	41.42
6	3	12	12	680	08:18	42.01
6	4	12	12	720	08:40	42.59
7	1	13	11	760	09:01	43.17
7	2	13	11	800	09:22	43.76
7	3	13	11	840	09:43	44.34
7	4	13	11	880	10:14	44.93
7	5	13	11	920	10:35	45.51
8	1	14	10.5	960	10:56	46.09
8	2	14	10.5	1000	11:17	46.68
8	3	14	10.5	1040	11:38	47.26
8	4	14	10.5	1080	12:09	47.85
8	5	14	10.5	1120	12:30	48.43
9	1	15	10	1160	12:50	49.01

9	2	15	10	1200	13:10	49.60
9	3	15	10	1240	13:30	50.18
9	4	15	10	1280	14:00	50.77
9	5	15	10	1320	14:20	51.35
10	1	16	9.5	1360	14:39	51.93
10	2	16	9.5	1400	14:58	52.52
10	3	16	9.5	1440	15:17	53.10
10	4	16	9.5	1480	15:46	53.69
10	5	16	9.5	1520	16:05	54.27
10	6	16	9.5	1560	16:23	54.85
11	1	16.5	9	1600	16:42	55.44
11	2	16.5	9	1640	17:01	56.02
11	3	16.5	9	1680	17:20	56.61
11	4	16.5	9	1720	17:49	57.19
11	5	16.5	9	1760	18:08	57.77
11	6	16.5	9	1800	18:27	58.36
12	1	17	8.5	1840	18:45	58.94
12	2	17	8.5	1880	18:57	59.53
12	3	17	8.5	1920	19:15	60.11
12	4	17	8.5	1960	19:43	60.69
12	5	17	8.5	2000	20:01	61.28
12	6	17	8.5	2040	20:19	61.86