Review

A Narrative Review on a Deep Understanding of the Dominant Physiological Energy Systems in Basketball and the Importance of Specificity and Uniqueness in Measuring Basketball Players

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A Narrative Review on a Deep Understanding of the Dominant Physiological Energy Systems in Basketball and the Importance of Specificity and Uniqueness in Measuring Basketball Players

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Abstract: Basketball playing entails the repetitive performance of short intense actions using lower limb explosive power. As such, it is important to measure this capability in basketball players, especially among young players, and to optimize training programs and game plans. After presenting an in-depth understanding of the specific physiological requirements when playing basketball, as well as the type of movements required, The aim of this review is to better understand the importance of the physiological energy systems in basketball, to examine the contribution of each energy system and, accordingly, to heighten awareness of the importance and dominance of the alactic anaerobic physiological system in basketball, for actions requiring high level explosive power. This review of the literature depicts the horizontal and vertical physical movements and physiological requirements entailed in playing basketball, and presents eight standardized anaerobic alactic measurement tools relevant to the game. As some of these tests suit a number of ball games, the findings of this review article are important for making order of the elements unique to basketball as well as additional parameters to consider when testing basketball players. By reliably and validly testing the anaerobic alactic capabilities of basketball players, test results can be used for training purposes and for improving game outcomes. Despite the fact that much of the information in this review is familiar to coaches, highlighting the specific needs of basketball may help them to choose the most suitable tools, and may also shed light on new directions for developing basketball-specific assessment tests.

Keywords: physiology; basketball; testing; explosive; unique; specific movements

1. Introduction

In sports in general and in competitive team sports in particular, it is important to frequently assess players' physiological capabilities in order to design, implement, and evaluate training programs and track players' progress throughout the season, especially in young players, [1,2]. Among team sports, basketball is characterized by short, intense, anaerobic actions that are performed throughout the game [1,3,4] using anaerobic power, i.e., explosive power for up to 10 seconds [5]. In other words, the main energy source that contributes to these alactic anaerobic activities are adenosine triphosphate (ATP) / creatine phosphate (CP), referred to as ATP-CP, that are stored in the muscles and are easily accessible [6]. In addition, the glycolysis system also contributes

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to anaerobic activities. For actions that last more than 10 seconds and up to three minutes, the body's anaerobic glycolysis is required [7].

Although in basketball the more dominant source is anaerobic alactic energy [3,5], it is also characterized by specific anaerobic actions, such as jumps, sudden stops, short sprints, and change of direction [2,8]. The body's aerobic system also plays a key role in players' recovery, to ensure successful frequent repetition of high intensity anaerobic actions [9,10]. Moreover, the introduction of new rules to the game of basketball in May 2000 (e.g., reduced attack time from 30 to 24 seconds and reduced time on the backcourt from 10 to 8 seconds) are believed to have altered the demands of basketball – both tactical and physical – increasing the speed and intensity of the game [11,12]. In turn, these changes also impact the players' physiological characteristics, resulting in higher physical demands on the players and expected improved athletic abilities. Such new demands mainly relate to the players' need to recruit their explosive power for performing and maintaining the rapid anaerobic pace of the game [13,14].

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

The main aim of this review is to better understand the importance of the physiological energy systems in basketball, to examine the contribution of each energy system and, accordingly, to heighten awareness of the importance and dominance of the alactic anaerobic physiological system in basketball, for actions requiring high level explosive power. In addition, the review clarifies the specific movements of basketball players in the various movement planes, including more complex movements that combine both horizontal and vertical movement such as penetrating for a layup. The review also offers the most relevant specific tests found in the literature. At the same time, it sheds light on the need for more designated field tests to assess players' explosive power abilities, because today, many such tests serve for a variety of ball games. It is important to take additional parameters into consideration when tests are conducted for basketball players. Although many of these issues are known to coaches and researchers, it is important to make order of all the elements unique to basketball.

The review will begin with the physiological energy systems activated in basketball. In most basketball related activities, both the aerobic and the anaerobic energy systems are involved, yet the ratio between the two energy sources varies according to the demands of the specific activity [2,3,5], including its intensity and duration (Table 1).

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Table 1. Physiological Energy Systems.

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

Legend: Repeated sprint ability (RSA)

Dominant system in Basketball

1.1. The physiological anaerobic alactic system that is dominant in basketball

The body's energetic potential is utilized by breaking down ATP which is adenosine triphosphate [19]. Energy is released from the molecule when one of the three phosphate groups is degraded through a rapid chemical process by the ATPase enzyme [6,19]. As a result, two new molecules are created: adenosine diphosphate (ADP), with only two phosphate bonds, and the free phosphate (P), as seen in **Figure 1.**

Figure 1. Flowchart, Energy potential from ATP molecules.

ATP, often referred to as the body's "energy currency", enables the body to perform a range of biological activities [7]. These include complex and rapid actions needed for performing, completing, and recovering from actions performed in basketball [2]. Despite their vast importance, ATP resources in muscles are relatively small. With only 5-7 millimoles per kg of muscle during rest, this energy source is only sufficient for very short periods of time [7]. The fastest and simplest way to

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renew ATP is by also utilizing the body's CP resources, which offer about 3-5 times more energy (about 20-25 millimoles per kg of muscle) than the ATP [5,7]. As such, CP resources are an important and immediate energy resource for the body's cells, transferring their phosphate to the ADP to create new ATP molecules [7,20], as seen in **Figure 2.**

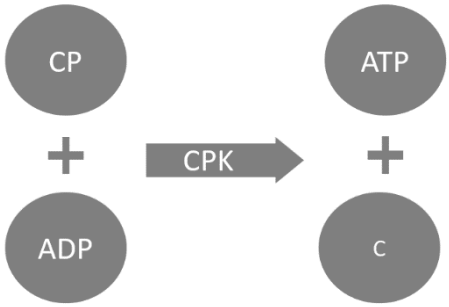

Figure 2. Flowchart, ATP-CP energy system**.**

This rapid process takes place within the cell through a reaction that is enhanced by the creatine phosphokinase (CPK) enzyme. As CP is readily available in the body's cells and this chemical process is extremely fast, this anaerobic means for renewing muscle energy is referred to as the "immediate anaerobic system" [20,21]. However, as the quantity of CP in the muscle is also relatively small, it too is limited to only providing energy for a number of seconds. The combined ATP-CP resources in the muscles provide immediate energy for quickly contracting the muscle. Without the intervention of CP, the ATP resources would suffice for a maximum of 1-2 seconds of activity [3,5,7]. In addition, the optimal anaerobic supply reflects the ability of the immediate anaerobic system (ATP-CP) to release energy and activate muscles at maximum pace for short periods, of up to 10 seconds [3,5]. Greater efficacy of the ATP-CP enzyme activity is seen among athletes and people with a high percentage of fast twitch (FT) muscle fibers [19,20].

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

1.2. Explosive power and anaerobic alactic demands in basketball

Analysis of the physiological requirements of basketball players over the past few decades indicates great reliance on the body's anaerobic metabolism to perform sprints and jumps throughout a game [22]. Moreover, the relatively high blood lactate concentration values recorded during games indicate the central involvement of the player's anaerobic capacity [2,5]. As evaluating these factors during basketball practices and games is important, researchers and coaches have developed a range of tests for assessing anaerobic alactic system, and the effectiveness of the players' physical conditioning. For example, Abdelkrim et al. [3] found that in elite male basketball players under 19, the new rules of basketball meant longer time periods performing high-intensity activities and an increased number of actions per game. Despite this, blood lactate concentration values were found to be slightly lower than those reported in earlier studies [3–5]. Such changes to the players' metabolic load during basketball games must be addressed when developing and applying suitable physical conditioning programs and tests.

In a review that assessed the most important and relevant measurement tests for basketball players, researchers found that following the introduction of the new rules of the game, basketball playing is mainly dependent on anaerobic power rather than on anaerobic capacity [5,15]. To assess the effectiveness of basketball training programs, tests should therefore specifically address players' lower limbs, through tests such as vertical jump (VJ), agility T tests, and short distance sprints (5-

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meter), rather than tests like the suicide run that lasts about 30 seconds [5]. These tests all assess anaerobic alactic capabilities and explosive power of the players' lower limbs - as seen in basketball training and games.

1.3. Specific movements in basketball

As explained, basketball players' successful performance depends greatly on their anaerobic alactic systems, with shorter, more intense actions that require greater explosive power [1,2]. As such, training and tests should be developed in line with this important factor. However, it is also important to understand the more frequent movements required of basketball players in each situation. During practices and games, key actions include vertical movements (rebounds and jump shots), horizontal actions (change of direction and sprints), and a combination of the two (usually during shot blocking or when penetrating the basket) [22]. As these high-intensity actions are continuously performed throughout the game [2,10], professionals in the field seek optimal training methods for developing these physical capabilities among basketball players, especially their explosive power [2].

2. Explosive capability assessments

The ability to produce great power in short periods of time is of the utmost importance in basketball. As such, an emphasis is placed on enhancing explosive power among players of all levels and ages [5,22]. Doing so is not solely a theoretical exercise in fitness training and physiological principles; it requires the developing of reliable and valid measuring techniques that offer accurate and consistent outcomes [23,24]. Moreover, to provide coaches with applicable rather than theoretical outcomes, measurement protocols must accurately replicate movements that athletes perform in practices and games, while also offering consistent tools to enable comparisons and generalizations [25,26]. Doing so will ensure that differences in results over time are attributed to changes in the athlete's performance rather than to differences in measuring systems. In addition, when applying measurement protocols, external factors should be controlled (such as time of day, the surface on which the test is conducted, and pre-test requirements), to avoid these environmental conditions and timeframes from impacting the test results. For example, in basketball, tests for explosive power should be conducted at three different points-in-time (immediately prior to the training program, about halfway through the program, and immediately after the training program), to gather maximum relevant data about the efficacy of the training program and its outcomes [1,6].

Basketball is unique in that it requires players to perform both horizontal and VJ. As such, the literature offers a range of tests for measuring horizontal, vertical, and combined explosive power in basketball players [1,22,28]. This article addresses those tests that specifically examine players' lower limb explosive power, which plays a central role in most basketball actions (Table 2).

Table 2. Specific Anaerobic Alactic Tests for Basketball Players.

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

Following are details of these eight basketball-specific tests.

2.1. 5/10-meter sprint speed test

The 5/10-meter sprint speed test is used to evaluate players' horizontal explosive power through cyclical movement (i.e., sprinting from a standing starting point). The athlete is asked to perform two sprints from a standing starting point, with 3-5 minutes' rest between the two sprints. The best time out of the two is recorded. The advantage of using photo-electric cells is threefold, as it provides

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athletes with an external "start" signal, automatically stops the measurement upon sprint completion, and if required, can record intermediate times during the sprint with modular systems [2,29,30].

2.2. Standing broad jump test

The standing broad jump assessment is also used to assess basketball players' anaerobic alactic capabilities. For this test, the athletes are instructed to stand with both feet together by the starting line. They then create momentum for the jump by bending their knees and moving their arms forward. The recorded measurement is the best jump out of three, measured with a standard measuring tape. If the athlete falls backwards during any of the jumps, the jump is disqualified, and the athlete is asked to repeat the jump. From 1900 to 1912, the standing broad jump was part of the Olympic competitions. However, it has not been part of regular global competitions for over a century. In most cases, this test is used for assessing explosive power among basketball players in clubs that do not have access to advanced equipment [2,31,32].

2.3. Drop jump test

The drop jump test, which can be conducted as a horizontal drop jump (HDJ) or as a vertical drop jump (VDJ) test, is used for measuring and developing athletes' stretch-shortening cycle ability [33]. The athletes are instructed to stand on a pre-set box (at a height of 0.30-0.40 meters). The athletes then drop down to the ground, quickly bend their knees, and immediately perform a rebound jump as quickly as possible (< 0.25 seconds), minimizing their contact time with the ground. For the HDJ, they must jump as far forward as possible, while for the VDJ, they must jump up as high as possible. The test ends with their controlled landing on the ground [34,35].

2.4. 2x5-meter change of direction ability test

The 2x5-meter change of direction ability (CODA) test is especially suitable for measuring basketball players' anaerobic alactic capabilities. The test measures sprinting time, turning, and changing direction. The athletes are instructed to perform a 5-meter run in one direction, turning around as quickly as possible, and then perform the same 5-meter run back to the starting point (a 10-meter run in total). Basketball players must possess strong agility capabilities to cope with the multiple stimuli and instantaneous decision making involved in the dynamic environment in which the game is played. In most cases, the T-test and pro-agility test are the gold standard for assessing agility among athletes [1,16,36]. However, in light of this review of the anaerobic alactic tests that are most suitable and specific for basketball players, the 2 x 5-meter CODA test should be conducted when examining the players' anaerobic alactic and change of direction capabilities [37–40].

2.5. Countermovement jump test

The countermovement jump (CMJ) test assesses explosive power in a VJ, with athletes standing up straight, then bending their knees and quickly extending them to leave the ground and rise up as high as possible. The athletes are usually instructed to place their hands on their hips during the jump, to minimize upper limb momentum. Players perform up to three jumps in total, with about two minutes' rest between jumps. Jumps can be performed using one or both legs and a transmitting and receiving bar is employed that enables the accurate measurement of flight and contact times during jumps [2,24].

2.6. Squat jump test

The sixth test reviewed in this article is the squat jump test, which also offers a tool for specifically measuring basketball players' vertical explosive power. For this measurement assessment, the athletes assume a low squat position, refrain from any movement, then jump as up as high as possible. During the test, the players are usually asked to place their hands on their hips or behind their back, to prevent momentum from their upper limbs that could impact this assessment [2,18].

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2.7. Bounding power test

The bounding power test also examines basketball players' anaerobic alactic abilities. The athletes are asked to stand on one leg and jump horizontally as far forward as they can, six consecutive times. Alternating the jumping legs after each jump means that a total of three jumps are performed with each leg. This test combines both horizontal and vertical capability assessments. In most tests, the athlete performs the final jump using both legs, into a sand box. This test is performed twice, with the longer distance being recorded. Results are measured manually using a tape measure [1,41].

2.8. Spike jump test

Finally, the eighth test presented in this review is the spike jump test, which examines the horizontal and vertical explosive power of basketball players, using what is considered a specific volleyball jump. First, upstretched arm length is measured. Next, they are asked to jump up as high as possible (after taking three or four steps forward, or not). Their upstretched arm length is then measured at the height of their jump. Their static upstretched arm length is then subtracted from their jump arm length, to achieve the relative height of the jump. A standing jump test can also be conducted for this assessment test [42]. These tests are specific for assessing explosive power in ball games and especially for professional basketball players who are required to manifest high levels of explosive power. Elite players will exhibit significantly higher levels in these tests than amateurs or players from lower leagues [5,43].

3. Discussion

This article reviews the existing lower-limb anaerobic alactic tests that are suitable for measuring professional basketball players' abilities, in all levels and ages, a total of eight assessment tests. The modern game of basketball has become more intensive following the introduction of new rules in 2000. As such, basketball players' agility and anaerobic alactic [3,5] abilities, rather than aerobic capabilities, play a more central role in their performance. Basketball players today are highly conditioned athletes, which is necessary for achieving consistent high-level performance throughout the season [12,44,45]. Moreover, the game is unique as it requires players to perform horizontal movements, vertical ones, and a combination of the two [2,46]. These high-intensity movements are intermittently performed throughout the game, at different time intervals and from different positions on the court [5,28]. As such, sports researchers, trainers, and strength and conditioning coaches continue to strive to identify optimal measurements tests that are specific to basketball [18,22].

Trainers and researchers often use 20 or 27-meter tests for assessing players' abilities, as this is similar to the length of a basketball court [6]. However, video analysis indicates that basketball players rarely have to sprint across the entire court. Rather, they mainly perform high intensity runs lasting 1.7-2.1 seconds, which is more similar to the 5/10-meter run [3,22]. To the best of our knowledge, both theoretical and practical field tests are lacking that examine both horizontal and vertical capabilities specifically for basketball players. For example, one study has developed a new unique test for assessing the explosive power of basketball players with a ball [47]. This test is highly important and sheds light on the significance of unique tests in basketball. We chose not to present this test in the article because it needs to be further examined in additional studies, including differences by gender, age groups, and playing positions [2,47–50]. However, it is definitely a significant step forward. The need for additional unique tests to measure the variety of movements presented in this article regarding explosive power is required on the basketball court, as well as for the uniqueness of the agility component that incorporates elements of explosive power within it [2,16]. Furthermore, the need for unique tests in basketball is also relevant for assessing the aerobic physiological system, which received less focus in this review. Researchers in this field have started to develop additional unique tests in this area as well [2,51], and their use is also important, including continued thinking and development of additional unique tests [47,51]. Moreover, a number of tests

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assess athletes' upper body explosive strength (such as the 1-RM bench press test). These were not reviewed in this article as these skills are less frequently used in basketball.

Efforts have been made to create tests that specifically assess lower limb explosive power among basketball players [2,5]. Although studies indicate correlations between vertical and horizontal power [42,47,52], the scientific literature lacks specific tests for examining this power in combined vertical and horizontal movements [1,39,53]. In a study on handball players [46], no association was observed between the CMJ tests and the players' time in the air – an action that entails both horizontal and vertical movements. As such, CMJ may not be a reliable tool for predicting jumping ability specific to handball players. On the other hand, a different study revealed a strong connection between CMJ outcomes and the volleyball jump serve, which also combines both horizontal and vertical components, similar to the spike jump in basketball [42]. As such, connections among these variables seem to differ from sport to sport, and perhaps even among athletes with different levels of development. Moreover, it is unclear as to whether CMJ test protocols and others can reliably predict specific basketball jumping abilities (e.g., jumping time when leaping up towards the basket on one leg in various specific jumping styles while holding the ball).

Additional examples of inadequate tests can be seen in a number of intervention studies relating to ball games. While the outcomes of these studies indicate improvements in maximal sprint, strength, plyometric, and complex training, as seen in CMJ performance assessments [1,54–56], it is unclear whether these improvements can be transferred to additional game situations, such basket penetrating and layups. Indeed, transferring physical improvements seen in training to actual ball games is not easy to assess – as additional factors must be addressed, such as players' technical abilities and complex interactions.

Since the main factor for assessing basketball players' capabilities is their anaerobic alactic system, tests that examine their anaerobic glycolytic energy system are less relevant. Tests should specifically focus on players' lower limb explosive power, such as the 5/10-meter sprint test rather than the 20-meter test. Moreover, it seems that while multiple tests exist, there is no standardization of these assessment tools – national or international. For example, while the horizontal and vertical drop jump tests may offer important tools for assessing basketball players' plyometric and jump height abilities, drop height and jump height are not always identical and as such, could result in different measurements [33,34]. Additional limitations of the existing tests can be seen in tests such as the spike jump that combines both horizontal and VJ capabilities, as differences in players' shoulder joint flexibility may impact the outcomes of the test and hinder the ability to reliably compare athletes' measurements [42].

Finally, the issue of upper-limb momentum should be addressed, as biomechanical and physiological tools used to study the VJ often attempt to neutralize the athletes' arm movement (by performing the test with their hands on their hips or behind their back). This is done in an attempt to isolate the effect of leg muscle power as a means for seeking causal relationships between improved lower body muscular power and jump height. However, this does not replicate the exact jump movements that athletes in general and basketball players in particular perform during practice and games – especially as jumping without arm momentum is not an action that is performed in competitive sports [18].

4. Conclusions and Practical Applications

Based on the literature review presented in this paper, it seems that specific tests for basketball players are lacking, especially tests for examining agility [16,35] a skill that requires lower-limb explosive power. The literature also lacks measurement tests for examining lower limb explosive power that requires both horizontal and vertical movements combined, as required in penetration of the basket [5,18]. It is especially difficult to replicate the dynamic, constantly changing environment that is typical of basketball games – an environment filled with simultaneous multiple stimuli in which players must make split-second decisions that could impact the outcome of the game. Future studies could benefit from developing and researching basketball specific tools for assessing players'

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anaerobic alactic energy systems in relation to their lower-limb explosive power. Developing such tools could significantly enhance research and performance in basketball.

Assessment tests must provide useful input and insights that trainers and coaches can utilize in the field. As such, it is important to comply with the principle of specificity in training, whereby a given motor skill is improved (and tested) as it is performed during actual games [2,5,9]. Indeed, with specific respect to basketball, developing an applicable, reliable, and valid field-specific test for assessing players' anaerobic capabilities is important. As such, this article helps to make order regarding the specific demands made on the players' physiological energy systems – especially the alactic anaerobic system – and the role they play during a basketball game, as well as the specific patterns of movements. Despite the fact that much of the information in this review article is familiar to coaches and trainers, highlighting the specific needs of basketball may help them to choose the most suitable tools, and may also shed light on new directions for developing basketball-specific and unique assessment tests.

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