Variability of Energy System Contributions in Basketball Across Playing Positions, Phases of Play, and Competition Levels: A Systematic Review

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Variability of Energy System Contributions in Basketball Across Playing Positions, Phases of Play, and Competition Levels: A Systematic Review

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Abstract

Study Purpose. Basketball performance involves intermittent high-intensity activity requiring continuous interaction between anaerobic and aerobic energy systems. Although numerous studies have examined metabolic demands in basketball, findings remain fragmented when analyzed separately by playing position, phase of play, or competition level. This systematic review aimed to synthesize existing evidence on how energy system contributions vary across these three contextual dimensions.

Materials and Methods. A systematic review was conducted in accordance with the PRISMA 2020 guidelines. Literature searches were performed in PubMed, Scopus, SPORTDiscus, and Google Scholar for studies published between 2015 and 2025. Following title abstract screening and full-text evaluation, 15 studies met the inclusion criteria and were included in a qualitative synthesis. A meta-analysis was not performed due to substantial heterogeneity in study designs, outcome measures, and methodological approaches across the included studies.

Results. The included studies predominantly investigated elite male basketball players, with fewer studies examining youth athletes and female players. Across studies, consistent patterns of energy system utilization were identified. Guards demonstrated the greatest reliance on ATP-PC and glycolytic systems due to frequent accelerations, changes of direction, and short-duration peak efforts. Forwards exhibited a mixed anaerobic–aerobic metabolic profile reflecting multifunctional tactical roles, whereas centers predominantly relied on the ATP-PC system associated with repeated jumping, physical contact, and explosive actions. Across game phases, fast-break and transition play were dominated by ATP-PC contribution, while prolonged half-court play showed increased glycolytic involvement.

Conclusion. Energy system contributions in basketball vary systematically according to playing position, phase of play, and competition level. However, interpretation of these findings is limited by methodological heterogeneity and the indirect estimation of energy system contributions. Despite these limitations, the integrated synthesis provides a comprehensive framework to inform position-specific and context-sensitive conditioning strategies.

Keywords: Basketball, Energy Systems, Playing Position, Phase of Play, Competition Level.

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Introduction

Basketball is a high-intensity sport that requires an integrated combination of physical, technical, and tactical abilities. The variability of energy system contributions is a fundamental determinant of player performance. Efficient energy management, particularly the balance between aerobic and anaerobic systems, is essential for sustaining basketball performance across different playing contexts (Gottlieb et al., 2021; Power et al., 2022). The increasing pace of modern basketball further demands a deeper understanding of energy utilization within real gameplay contexts.

Previous research reinforces the central role of energy systems in shaping performance. (Gottlieb et al., 2021) emphasized the importance of specific conditioning programs to sustain performance consistency. (Power et al., 2022) demonstrated that variations in aerobic and anaerobic contributions are strongly influenced by game intensity and phase. Explosive actions such as sprints, rebounds, and drives rely heavily on anaerobic pathways, whereas transitions and recovery phases depend more on aerobic metabolism. (Khoramipour et al., 2021) reported metabolic differences across positions, with guards exhibiting higher energy expenditure than centers. (He & Jiang, 2023) highlighted the necessity of integrating aerobic and anaerobic training to enhance glycolytic capacity and metabolic resilience.

Although the literature provides valuable insights, it has not yet synthesized the dynamics of energy system contributions across playing positions, phases of play, and competition levels in a comprehensive manner. This gap underscores the need for a systematic review capable of consolidating findings across studies to present a holistic understanding. Previous research using player tracking data has demonstrated that basketball performance demands vary substantially according to playing position and in-game context, highlighting the need for integrated physiological and tactical analyses (Sampaio et al., 2015).

Physiologically, basketball relies on three primary energy pathways: ATP-PC, anaerobic glycolysis, and the aerobic oxidative system (Cui et al., 2019). The dominance of each pathway is determined by the intensity and duration of actions. Metabolic demands also differ by position; guards typically require higher anaerobic capacity for explosive movements, whereas centers depend more on strength and localized muscular endurance

Based on these considerations, this review aims to analyze the variability of energy system contributions according to playing position, phase of play, and competition level. The guiding questions are: (1) how energy system contributions differ among positions; (2) how phases of play influence the dominance of specific systems; and (3) how competition levels shape patterns of energy utilization.

Materials and Methods

Study participants

In this systematic review, the units of analysis were primary research studies that met the predefined inclusion criteria. The included studies investigated basketball players across different competition levels (elite, sub-elite, and youth) and playing positions (guards, forwards, and centers), involving both male and female athletes. No primary data collection or direct human participation was conducted, as all data were obtained from previously published studies..

Study organization

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). A comprehensive literature search was performed using PubMed, Scopus, SPORTDiscus, and Google Scholar, covering publications from 2015 to 2025 to capture contemporary basketball performance research.

Search terms were organized into thematic groups related to basketball, energy systems (ATP-PC, anaerobic glycolysis, and aerobic metabolism), and contextual factors (playing position, phase of play, and competition level). These terms were combined using Boolean operators (AND, OR) to identify relevant studies. Reference lists of included articles were also screened to ensure comprehensive coverage. Examples of search strings included combinations such as "basketball AND energy systems", "basketball AND ATP-PC", "basketball AND anaerobic glycolysis", and "basketball AND playing position".

Study Selection Process

The study selection process consisted of three sequential stages:

1. Title and abstract screening,
2. Full-text assessment, and
3. Application of inclusion and exclusion criteria.

Duplicate records were removed prior to screening. The initial search identified 350 records, of which 60 full-text articles were assessed for eligibility. Following full-text evaluation, 15 studies met all inclusion criteria and were included in the qualitative synthesis. Studies were included if they investigated energy system contributions in competitive basketball players during match play or structured training and reported outcomes by playing position, phase of play, or competition level. Studies focusing on non-basketball sports, recreational populations, non-physiological outcomes, or lacking sufficient methodological detail were excluded

Eligibility Criteria and Quality Considerations

In the study selection process, article screening and eligibility assessment were conducted independently by two reviewers to reduce potential selection bias. Disagreements were resolved through discussion until consensus was reached. Inclusion and exclusion criteria were applied consistently across all stages of screening.

Given the heterogeneity of study designs, outcome measures, and analytical approaches, a formal quantitative risk-of-bias assessment tool was not applied. Instead, methodological quality was evaluated narratively based on study design, measurement validity, sample characteristics, and clarity of reported outcomes. The synthesis followed a thematic comparative framework, in which findings were grouped and compared across playing positions, phases of play, and competition levels to identify consistent patterns and key differences.

Statistical analysis

Because this study is a qualitative systematic review, no meta-analysis was performed. Data extraction focused on study characteristics, participant profiles, measurement methods, and reported contributions of ATP-PC, glycolytic, and aerobic energy systems. The analysis involved thematic synthesis and cross-study comparison to identify patterns across positions, phases of play, and competition levels. This systematic review protocol was not prospectively registered in the PROSPERO database.

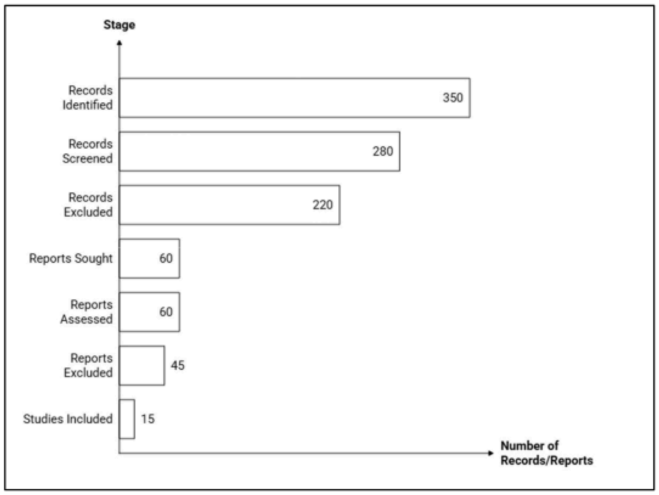

Figure 1. PRISMA Flow Diagram of Study Selection

Results

1. Study Characteristics

A total of 15 studies met the inclusion criteria and were included in the qualitative synthesis. The studies encompassed basketball players from elite, sub-elite, and youth competition levels, representing various playing positions (guards, forwards, and centers). Methodological approaches included time motion analysis, GPS-based external load monitoring, physiological testing, and metabolomics analysis. An overview of the included studies is presented in Table 1.

Table 1. Characteristics of the Studies Included in the Systematic Review

No	Authors	Playing Position	Game Phase	Competition Level	Type of Evidence
1	(Emilija Stojanović, 2017)	General positional demands	General intensity	Elite vs Sub-elite	Systematic Review
2	(García et al., 2020)	Guard & Center	Game quarters	Elite	Observational
3	(Khoramipour et al., 2020)	-	Game quarters (metabolic)	Elite	Observational (metabolomics)
4	(Freitas et al., 2020)	Position vs efficiency	-	Elite vs Sub-elite	Systematic Review
5	(Salazar et al., 2020)	Guard, Forward, Center	Half-court	Elite	Observational

6	(Alonso et al., 2020)	Guard (peak physical load)	Peak window (1-5 min)	Youth	Observational
7	(Vázquez-guerrero & Garcia, 2020)	-	Fast-break & Half-court	Elite	Observational
8	(Gottlieb et al., 2021)	Energy profile by position	Recovery	Multi-level	Review
9	(Khoramipour et al., 2021)	Backcourt vs Frontcourt	-	Elite	Observational (metabolomics)
10	(Stojmenović et al., 2022)	VO_2max by position	-	Elite	Cross-sectional (CPET)
11	(Figueira et al., 2022)	-	3x3 vs 5x5	Youth	Experimental
12	(Feu, 2023)	Center vs Guard	-	Elite	Observational
13	(López-Pérez, 2024)	-	3v3 SSG	Youth	Systematic Review
14	(Huynh et al., 2024)	Positional training intensity	-	Elite Collegiate	Observational
15	(Duscha, 2025)	-	-	Elite Collegiate	Validation Protocol (CPET)

2. Results Based on Playing Position

The literature indicates clear differences in metabolic patterns and demands across playing positions in Table 2.

Table 2. Metabolic Demands and Energy System Contributions Based on Playing Position

Position	Supporting Studies	Evidence (Summary of Findings)	Physiological Interpretation	Training Implications
Guard	(Alonso et al., 2020; Emilija Stojanović, 2017; García et al., 2020; Huynh et al., 2024; Salazar et al., 2020; Stojmenović et al., 2022)	Highest total distance and acceleration counts; greatest 1-5 min peak loads; highest VO_2max; repeated explosive actions	Dominant reliance on the glycolytic and ATP-PC systems	Training: repeated sprint training, agility, and change-of-direction (COD) drills
Forward	(Emilija Stojanović, 2017; Salazar et al., 2020)	High COD frequency; mixed external load demands; frequent rotational movements and help-defense actions	Mixed anaerobic-aerobic contribution	Training: mixed conditioning, agility-strength work

Center	(Feu, 2023; García et al., 2020; Salazar et al., 2020; Stojmenović et al., 2022)	High jump frequency; frequent physical contact; low distance but high-intensity actions	Predominant reliance on the ATP-PC system	Training: explosive power work, plyometric training

Across the included studies, consistent positional differences in energy system contributions were observed. Guards demonstrated the highest overall physical demands, characterized by greater total distance covered, higher acceleration and deceleration frequencies, and elevated short-duration peak loads. These demands were consistently associated with a dominant reliance on the ATP-PC and anaerobic glycolytic systems, reflecting frequent explosive actions and repeated high-intensity movements.

Forwards exhibited a mixed metabolic profile, with studies reporting moderate-to-high external load demands combined with frequent changes of direction and rotational movements. As a result, energy system contributions in forwards reflected a balance between anaerobic and aerobic pathways, depending on tactical involvement and game context.

Centers showed a distinct metabolic pattern characterized by lower total running distance but higher frequencies of jumping, physical contact, and short explosive actions. Across studies, these demands were associated with a predominant reliance on the ATP-PC system, with limited but context-dependent engagement of glycolytic and aerobic pathways.

These positional patterns were consistently reported across elite and sub-elite competition levels.

3. Results Based on Game Phases

The contribution of energy systems shifts according to tactical context in Table 3.

Table 3. Energy System Dominance Across Different Game Phases

Game Phase	Supporting Studies	Key Evidence	Dominant Energy System	Scientific Explanation
Fast-break / Transition	(Alonso et al., 2020; Vázquez-guerrero & Garcia, 2020)	Highest peak demands; intense sprinting and deceleration	ATP-PC / Alactic anaerobic	Actions lasting < 6 seconds
Half-court Offense/Defense	(Salazar et al., 2020; Vázquez-guerrero & Garcia, 2020)	Dominance of COD, acceleration, and deceleration	Glycolytic	Combination of explosive actions and positional control
Time-out / Recovery	(Emilija Stojanović, 2017; Gottlieb et al., 2021)	Rapid HR reduction; efficient recovery	Aerobic	Indicator of oxidative capacity

Quarter Dynamics (Q1-Q4)	(García et al., 2020; Khoramipour et al., 2020)	Q1-Q3 anaerobic-dominant; Q4 increasingly aerobic	Shift from anaerobic → aerobic	Fatigue drives metabolic transition
3x3 vs 5x5 Phases	(Figueira et al., 2022; López-Pérez, 2024)	3x3 shows more explosive demands; 5x5 more stable demands	3x3: anaerobic; 5x5: mixed	Differences in game format demands
Overtime	-	No direct studies available	Aerobic contribution increases	General physiological interpretation

Energy system dominance varied substantially according to phase of play, with clear and repeatable patterns across studies. Fast-break and transition phases were consistently identified as the most metabolically demanding moments, characterized by maximal or near-maximal sprinting efforts of short duration. These actions were dominated by the ATP-PC system, reflecting the alactic nature of high-intensity movements lasting less than six seconds.

During half-court offensive and defensive phases, studies reported increased frequencies of accelerations, decelerations, and changes of direction combined with longer action sequences. These characteristics were associated with a greater contribution of the anaerobic glycolytic system, supporting sustained high-intensity efforts within structured tactical play.

Recovery-related phases, including stoppages, time-outs, and low-intensity sequences, demonstrated a greater reliance on the aerobic system, highlighting its role in restoring phosphocreatine stores and supporting repeated high-intensity performance.

Several studies also reported quarter-by-quarter variations, with anaerobic systems dominating early game phases and a gradual increase in aerobic contribution during later quarters, particularly the final period.

4. Results Based on Competition Level

Elite players demonstrate greater metabolic efficiency compared with sub-elite and youth players in Table 4.

Table 4. Energy System Characteristics Across Competition Levels

Level	Supporting Studies	Evidence (Detail)	Energy Characteristics	Training Implications
Elite	(Duscha, 2025; Emilija Stojanović, 2017; Fan, 2023; Freitas et al., 2020; García et al., 2020; Huynh et al., 2024; Salazar et al., 2020; Vázquez-guerrero & Garcia, 2020)	Greater metabolic efficiency; higher peak demands; better intensity regulation	Anaerobic dominance during peak actions; aerobic system supports recovery	High-intensity conditioning

Sub-elite	(Emilija Stojanović, 2017; Freitas et al., 2020)	Lower aerobic performance; less efficient	Greater aerobic reliance as compensation	Aerobic capacity training
Youth	(Alonso et al., 2020; Figueira et al., 2022; López-Pérez, 2024)	Developing energy capacity; 3x3 more anaerobic; 5x5 more aerobic	Immature and unstable energy system	Fundamental metabolic conditioning

Differences in energy system utilization were also evident across competition levels. Elite players consistently demonstrated greater metabolic efficiency, characterized by the ability to sustain high-intensity actions with smaller fluctuations in physiological load. Peak demands were largely supported by anaerobic pathways, while the aerobic system played a critical role in facilitating rapid recovery between efforts.

Sub-elite players exhibited similar activity profiles but showed earlier shifts toward aerobic contribution, suggesting lower anaerobic efficiency during repeated high-intensity sequences.

Youth players displayed the greatest variability in energy system contributions. Studies indicated less stable metabolic patterns, influenced by biological maturation and developing technical proficiency. Game format also played a role, with 3×3 basketball demonstrating higher anaerobic demands compared with 5×5 basketball, which showed more balanced energy system engagement.

5. Comparison and Limitations

When compared with previous systematic reviews focusing on basketball physical and physiological demands, the present review extends existing evidence by integrating playing position, phase of play, and competition level within a single analytical framework. Earlier reviews have predominantly emphasized external load indicators or competition-level differences, often without explicitly linking these demands to underlying energy system contributions. By synthesizing findings across multiple contextual dimensions, this review provides a more comprehensive interpretation of how ATP-PC, glycolytic, and aerobic systems interact dynamically during basketball performance.

Nevertheless, several limitations of this review should be acknowledged. The included studies employed heterogeneous methodologies, such as time motion analysis, GPS-based monitoring, physiological testing, and metabolomics, each of which offers indirect estimates of energy system contribution and varies in ecological validity. In addition, differences in competition formats, performance metrics, and analytical approaches limited direct comparability across studies. The qualitative nature of the synthesis also restricts causal inference. Future research should prioritize standardized measurement protocols and multimodal assessment approaches to improve the precision and comparability of energy system analyses in basketball.

Conclusions

The present systematic review synthesizes current evidence on energy system contributions in basketball by integrating three contextual dimensions: playing position, phase of play, and competition level. The findings confirm that basketball performance is underpinned by a highly dynamic and context-dependent metabolic profile, in which the relative contribution of ATP-PC, glycolytic, and aerobic systems shifts according to tactical roles, game situations, and competitive demands.

Positional Differences in Energy System Contributions. One of the most consistent findings across studies is the presence of distinct metabolic profiles across playing positions. Guards demonstrated the greatest reliance on ATP-PC and anaerobic glycolytic systems, reflecting their frequent involvement in accelerations, decelerations, changes of direction, and transition play. These demands align with the tactical responsibilities of guards as primary ball handlers and initiators of offensive actions, which require repeated short-duration, high-intensity efforts.

Forwards exhibited a hybrid metabolic profile, with balanced engagement of anaerobic and aerobic systems. This pattern reflects their multifunctional role, which combines perimeter movement, interior play, defensive rotations, and transitional support. The variability observed in forwards highlights the influence of tactical context and team strategy on metabolic demands.

Centers consistently showed a predominant reliance on the ATP-PC system, driven by repeated explosive actions such as jumping, screening, and physical contact in confined spaces. Despite lower total running distances, the intensity and mechanical load of these actions impose substantial anaerobic–alactic demands. Collectively, these positional distinctions reinforce the need for position-specific conditioning strategies, rather than uniform training prescriptions. Influence of Game Phases on Metabolic Demands. Energy system contributions were also strongly influenced by phase of play, emphasizing the importance of situational context in basketball performance. Fast-break and transition phases were dominated by ATP-PC contribution due to the brief duration and maximal intensity of sprinting actions. In contrast, half-court offensive and defensive phases elicited greater glycolytic involvement, reflecting longer sequences of high-intensity movements interspersed with tactical decision-making.

Recovery-related phases, including stoppages and low-intensity periods, highlighted the role of the aerobic system in facilitating phosphocreatine resynthesis and maintaining repeated-sprint ability. The observed quarter-by-quarter metabolic shifts, particularly the increased aerobic contribution in later game periods, further underscore the cumulative effects of fatigue and the importance of aerobic efficiency in sustaining performance across an entire match. Competition Level and Metabolic Efficiency. Competition level emerged as a key modifier of energy system utilization. Elite players demonstrated superior metabolic efficiency, characterized by the ability to tolerate higher peak demands while maintaining more stable physiological responses. This efficiency likely reflects advanced technical proficiency, tactical awareness, and long-term training adaptations that optimize both anaerobic capacity and aerobic recovery processes.

Sub-elite players showed similar activity patterns but tended to rely on aerobic pathways earlier during repeated high-intensity efforts, suggesting lower anaerobic efficiency. Youth players exhibited the greatest variability in energy system contributions, influenced by biological maturation and developing technical skills. Differences between game formats, such as 3×3 and 5×5 basketball, further emphasized how structural constraints can alter metabolic demands, particularly in developing athletes. Practical Implications for Training Design. The integration of positional roles, game phases, and competition levels provides a multidimensional framework for understanding basketball's metabolic demands. Conditioning programs should therefore be tailored not only to playing position but also to the tactical contexts most frequently encountered during competition. For example, guards may benefit from repeated-sprint and glycolytic-focused training, while centers may require greater emphasis on explosive power and alactic capacity, supported by sufficient aerobic conditioning for recovery.

Limitations and Future Directions. This review is limited by the heterogeneity of methodologies used across studies and the absence of direct measures of energy system contribution during live match play. The qualitative nature of the synthesis precluded meta-analysis. Future research should integrate real-time physiological monitoring, wearable sensor technologies, and advanced analytical approaches, such as machine learning, to more precisely characterize energy system dynamics in basketball.

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This study is a systematic review based exclusively on previously published literature. Therefore, no direct data collection involving athletes, coaches, or supporting staff was conducted. The authors would like to thank academic colleagues and anonymous reviewers for their constructive feedback, which contributed to improving the clarity, rigor, and overall quality of this manuscript.

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