Performance in sport

Analysis of energy contribution during explosive efforts in basketball players

Análisis de la contribución energética en esfuerzos explosivos en jugadores de baloncesto

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ABSTRACT

Basketball is a high-intensity intermittent sport characterized by short-duration explosive actions that rely on the integrated activation of the anaerobic alactic, glycolytic, and aerobic energy systems. The aim of this study was to describe the relative contribution of the energy systems (ATP-PCr, anaerobic glycolysis, and aerobic metabolism) in basketball players during maximal efforts of different durations. An experimental, cross-sectional, and comparative design was used. Twenty-four male basketball players (26.5 ± 3.2 years; VO_2/kg: 55.0 ± 7.0 ml·kg^{-1}·min^{-1}) were allocated into three groups (n = 8) according to the duration of the maximal effort (7, 15, and 30 s) performed on a cycle ergometer. Post-exercise oxygen uptake was analyzed using a biexponential model to estimate excess post-exercise oxygen consumption (EPOC), and capillary blood lactate was measured. Total energy expenditure was expressed in kilocalories, and the relative contribution of each energy system was calculated. The results showed a predominance of the ATP-PCr system at 7 s, a more balanced energy distribution at 15 s, and a greater glycolytic and aerobic contribution at 30 s, indicating a progressive metabolic transition. These findings support the optimization of intermittent training prescription and sport-specific recovery strategies in basketball according to effort duration.

Keywords: basketball, energy systems, VO_2, bioenergetics.

RESUMEN

El baloncesto es un deporte intermitente de alta intensidad que exige acciones explosivas de corta duración, las cuales dependen de la activación integrada de los sistemas energéticos anaeróbico aláctico, glucolítico y aeróbico. El objetivo de este estudio fue describir la contribución relativa de los sistemas energéticos (ATP-CP, glucólisis anaeróbica y metabolismo aeróbico) en jugadores de baloncesto durante esfuerzos máximos de distinta duración. Se realizó un estudio experimental de diseño transversal y comparativo. Participaron 24 jugadores de baloncesto varones (26,5 ± 3,2 años; VO_2/kg: 55,0 ± 7,0 ml·kg^{-1}·min^{-1}), distribuidos en tres grupos (n = 8) según la duración del esfuerzo máximo (7, 15 y 30 s) realizado en cicloergómetro. El consumo de oxígeno post-ejercicio fue analizado mediante un modelo biexponencial para estimar el EPOC (componentes rápido y lento), y se midió lactato capilar. La energía total se expresó en kilocalorías y se calculó la participación relativa de cada sistema energético. Los resultados mostraron predominio del sistema ATP-CP a los 7 s, una distribución más equilibrada a los 15 s y una mayor contribución glucolítica y aeróbica a los 30 s, evidenciando una transición progresiva entre sistemas. Estos hallazgos permiten optimizar la prescripción del entrenamiento intermitente y las estrategias de recuperación en el básquetbol en función de la duración del esfuerzo.

Palabras clave: baloncesto, sistemas energéticos, VO_2, bioenergética.

INTRODUCTION

Basketball is a high-intensity intermittent sport that demands the repeated execution of explosive actions such as sprints, changes of direction, jumps and physical contact, within a context of constant decision-making. These demands generate high physiological stress and require the integrated and sequential activation of the phosphagen (ATP-CP), anaerobic glycolytic and aerobic energy systems (Archacki et al., 2024). The alternation of maximal efforts and incomplete recoveries makes basketball a suitable model for studying the kinetics of transition between the different metabolic pathways.

During the first few seconds of an explosive effort, ATP resynthesis depends mainly on the phosphagen system, due to the high availability of phosphocreatine and the rapid action of creatine kinase, without the need for oxygen. However, these reserves are rapidly depleted, and the accumulation of metabolic by-products stimulates the early activation of glycogenolysis and anaerobic glycolysis, enabling sustained ATP production during longer-duration efforts (Hargreaves & Spriet, 2020). As the effort continues beyond 15–20 seconds, the contribution of aerobic metabolism becomes more significant. Recent evidence indicates that oxidative phosphorylation is involved from the early stages of exercise, making a significant contribution to efforts lasting up to 30 seconds, as well as facilitating phosphocreatine resynthesis and lactate removal during recovery (Beneke et al., 2021; Buchheit & Laursen, 2013).

In the context of basketball, these bioenergetic transitions occur constantly during the game. Repeated explosive actions, with partial recovery breaks, demand high anaerobic ability and adequate aerobic efficiency to sustain performance and limit fatigue (Stojanović et al., 2018). Although recent reviews have highlighted the importance of the ATP-CP system in decisive game actions (Shalom et al., 2023), there remains limited evidence that objectively quantifies the relative contribution of energy systems as a function of exercise duration in basketball players.

This gap hinders the design of interval training programmes tailored to the sport's actual bioenergetic demands. Therefore, the aim of the present study was to estimate the relative contribution of the ATP-CP, anaerobic glycolysis and aerobic metabolism systems in basketball players subjected to maximal efforts of varying durations (7, 15 and 30 seconds), in order to describe the sequence and predominance of energy systems as a function of exercise duration and to provide physiological grounds for more specific training prescriptions.

METHOD

Participants

A quasi-experimental, analytical study was conducted, employing a cross-sectional design with a comparison between independent groups. The study involved 24 male basketball players (26.5 ± 3.2 years; relative VO_2max: 55.0 ± 7.0 $ml \cdot kg^{-1} \cdot min^{-1}$), selected on a convenience basis according to availability and competitive level. To minimise selection bias, the groups were matched for age, aerobic ability (VO_2max) and sporting experience. The sample size was determined based on the study's experimental design and the feasibility of the protocol. The inclusion of eight players per group is consistent with previous research that has analysed the contribution of energy systems using indirect methods and allows for an adequate assessment of the relative distribution of energy systems according to the duration of maximal effort.

The study was approved by the Scientific Ethics Committee of the University of Santo Tomás (Chile), the institution responsible for the project, under approval number 23136643/2025. The research was conducted in accordance with the ethical principles established in the Declaration of Helsinki for studies involving human subjects and in accordance with current national regulations. All participants were informed verbally and in writing about the objectives, procedures, potential risks and benefits of the study, and gave their written informed consent prior to participation. The confidentiality of the information was guaranteed through the coding and anonymisation of the data, ensuring that only the research team had access to the database, which was used exclusively for scientific purposes.

Inclusion criteria: male players aged between 18 and 35 years, actively competing at regional or national level, with a minimum of 5 years' experience in the sport and $VO_2max \geq 40$ $ml \cdot kg^{-1} \cdot min^{-1}$.

Exclusion criteria: recent musculoskeletal injuries; cardiovascular, metabolic or respiratory conditions; recent use of ergogenic substances or drugs that alter the metabolic response; and/or failure to comply with pre-assessment instructions.

Procedure

The assessments were conducted in a laboratory under controlled environmental conditions (20–22 °C; 50–60% RH). Participants attended in the morning after observing a light fast (≥3 h), adequate hydration, abstention from intense exercise and stimulants for 48 h, and a minimum of 7 hours' night-time rest. On arrival, vital signs were checked and participants were familiarised with the cycle ergometer (Monark 894E) and the metabolic analyser (Cortex Metalyzer 3B-R3). Before each assessment session, the system was calibrated in accordance with the manufacturer's recommendations. The players were divided into three independent groups (n = 8) according to the duration of the maximal effort: 7, 15 and 30 seconds. Prior to the test, a standardised 10-minute warm-up was performed. Subsequently, each group performed a single maximal effort on the cycle ergometer, with a load equivalent to 7.5% of body weight, maintaining maximum cadence throughout the interval.

Measurement of oxygen consumption (VO_2)

Oxygen consumption was recorded continuously for 6 minutes post-exercise using open-circuit ergospirometry. Volume calibration was performed using a 3-litre syringe, whilst calibration of the gas analysers was carried out using standard gases of known concentration for O_2 and CO_2. Furthermore, signal stability, correct flow adjustment and the absence of leaks in the system were verified before the start of each test, ensuring the validity and reliability of the measurements.

Determination of blood lactate

The glycolytic contribution was estimated by measuring capillary lactate, with samples taken from the earlobe 3 and 5 minutes post-exercise. The analysis was performed using a portable lactate tester (Lactate Pro 2), following biosafety protocols.

Estimation of energy contribution

The quantification of the relative contribution of the energy systems (alactic anaerobic, anaerobic glycolysis and aerobic metabolism) was performed using a mixed approach, integrating the measurements of oxygen consumption (VO_2) and blood lactate obtained during the experimental protocol.

System (ATP-CP): The contribution of the anaerobic alactic system was estimated from the rapid component of EPOC, analysed using a biexponential model applied to VO_2 during post-exercise recovery. The equation used was:

$$VO_{2(t)} = VO_{2\,baseline} + A_1 \cdot e^{-\frac{(t-td)}{t_1}} + A_2 \cdot e^{-\frac{(t-td)}{t_2}}$$

where:

A_1: amplitude of the fast component (resynthesis of ATP and phosphocreatine).

t_1: time constant of the fast component.

td: time delay in the response.

VO_2 baseline: oxygen consumption at rest.

The field under the curve of component A_1 reflects the energy cost associated with phosphocreatine resynthesis (ATP-CP), expressed in litres of oxygen consumed, subsequently converted into kilocalories using the metabolic equivalence of 5 $kcal \cdot L^{-1}$ O_2.

The use of fixed values to estimate the contribution of the ATP-CP system is based on the high inter-individual variability observed in the kinetics of phosphocreatine resynthesis when indirect methods based on excess post-exercise oxygen consumption (EPOC) are employed. The available evidence indicates that, during short-duration maximal efforts, the absolute contribution of the phosphagen system remains within relatively narrow ranges, allowing the use of standardised reference values for comparative purposes.

In the present study, the adoption of fixed values (10 kcal for 7 s, 7.5 kcal for 15 s and 5 kcal for 30 s) aimed to reduce the impact of inter-individual variability, facilitate comparison between groups and prioritise the analysis of the relative distribution of energy systems as a function of exercise duration. This approach has previously been used in research estimating energy contribution via indirect models based on EPOC and blood lactate accumulation, particularly in supramaximal exercise protocols, where methodological standardisation is key to the interpretation of results.

Anaerobic Lactic System (Anaerobic Glycolysis): The contribution of anaerobic glycolysis was estimated by combining: The slow component of EPOC (parameters A_2 and t_2), which reflects lactate clearance and homeostatic restoration processes. Blood lactate accumulation, determined at 3 and 5 minutes post-exercise. The glycolytic load was quantified using the following equation:

$$O_{2\,lactato} = (Lactato_{post} - Lactato_{basal}) \times 3\,mL \cdot kg^{-1}$$

where:
Lactate_{post}: post-exercise capillary lactate concentration ($mmol \cdot L^{-1}$).
Lactate_{basal}: baseline value at rest.
$3\ mL \cdot kg^{-1}$: estimated metabolic cost of producing $1\ mmol \cdot L^{-1}$ of lactate.

The equivalent oxygen volume was multiplied by body weight and by $5\ kcal \cdot L^{-1}\ O_2$ to obtain the energy expenditure of anaerobic glycolysis.

Aerobic Metabolism: The contribution of the aerobic system was calculated by integrating net oxygen consumption during maximal exertion (exercise VO_2 – basal VO_2) over the duration of the work period (7, 15 or 30 seconds). This value reflects the direct energy contribution of aerobic metabolism during the exertion.

$$kcal_{aerobico} = (VO_{2\,ejercicio} - VO_{2\,basal}) \times Tiempo \times 5\,kcal \cdot L^{-1}$$

Calculation of Relative Contribution (%): Total energy was calculated as the sum of the contributions from the three systems:

Each system was expressed as a percentage of the total:

$$\%Sistema = \left(\frac{kcal_{Sistema}}{Energia_{total}}\right) \times 100$$

This procedure allowed us to describe the relative distribution of energy systems as a function of the duration of maximum effort (7, 15 and 30 seconds), highlighting the metabolic transitions in basketball players.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics ($p < 0.05$). Descriptive statistics (mean ± SD) and 95% confidence intervals were calculated, and the normality of the data was verified using the Shapiro–Wilk test. Differences in the contribution of energy systems, EPOC components and lactate concentration between the 7-, 15- and 30-second groups were analysed using one-way ANOVA, with Bonferroni post hoc tests where appropriate. The magnitude of the differences was estimated using partial η^2. Finally, the association between post-exercise lactate and the slow component of EPOC was assessed using Pearson's correlation.

RESULTS

Table 1.

Descriptive analysis of the sample (24)

		95% CI						Shapiro-Wilk	
	Mean	Lower	Upper	Median	DE	Minimum	Maximum	W	P
Age	26,542	25,206	27,877	27,000	3,162	19,000	31,000	0,951	0.287
Size	1,797	1,758	1.837	1,780	0.093	1,690	1,980	0.885	0.011
Weight	73,217	67,876	78,558	72,000	12,648	57,000	99,000	0,933	0.117
% Fat	23,887	22,842	24.933	24,000	2,475	18,900	28,200	0.946	0.222
%Mass	41,458	40,462	42,454	41,000	2,359	37,000	46,000	0,974	0.762
Vo2/kg	54,958	52,008	57.909	56,000	6,987	39	67	0,956	0.371
HR	196.125	193,351	198,899	194,000	6,569	182	207	0,931	0.101

Note: %Fat: percentage of body fat. %Mass: percentage of muscle mass. VO_2/kg: relative maximum oxygen consumption. HR: heart rate.

Table 1 describes the descriptive characteristics of the sample, including age, height, weight, body composition (% fat and % lean mass), relative maximum oxygen consumption (VO_2/kg) and maximum heart rate (HR). The values are introduced as mean ± standard deviation (SD), accompanied by their respective 95% confidence intervals (95% CI). Furthermore, the normality of the distributions is reported using the Shapiro-Wilk test.

Table 2.
Energy Intake – Group 7s (8 subjects)

Subject	Weight (kg)	Exercise VO_2 (L/min)	Resting VO_2 (L/min)	kcal Aerobic	kcal Glycolysis	kcal ATP-CP	Total energy (kcal)	% Aerobic	% Glycolysis	% ATP-CP
1	62.2	2.164	0.218	1,135	8,770	10.0	19,906	5.70%	44.06%	50.24%
2	77.0	2.184	0.270	1,117	9,702	10.0	20,819	5.36%	46.60%	48.03%
3	75.0	2,214	0.262	1,138	10,125	10.0	21,263	5.35%	47.62%	47.03%
4	91.0	2.233	0.318	1,117	10,647	10.0	21,764	5.13%	48.92%	45.95%
5	86.0	2,251	0.301	1,138	12,900	10.0	24,038	4.73%	53.67%	41.60%
6	71.0	2,340	0.248	1,220	9,266	10.0	20,486	5.96%	45.23%	48.82%
7	58.0	2,301	0.203	1,224	7,569	10.0	18,793	6.51%	40.28%	53.21%
8	72.0	2.232	0.252	1,155	8,316	10.0	19,471	5.93%	42.71%	51.36%

Note: The estimate for the ATP-CP component was set at 10 kcal for all subjects.

Table 2 shows the absolute and relative contribution of the energy systems during a 7-second maximal effort. The ATP-CP system was the main energy contributor, with a fixed absolute contribution of 10 kcal and a relative contribution of between 41.6% and 53.2%. Anaerobic glycolysis made a significant and variable contribution (40.3–53.7%), indicating early activation even during very brief efforts. In contrast, aerobic metabolism made a marginal contribution, with values below 6.5%. Total energy ranged from 18.8 to 24.0 kcal, being higher in subjects with greater body mass.

Table 3.
Energy Contribution – 15s Group (8 subjects)

Subject	Weight (kg)	Exercise VO_2 (L/min)	Resting VO_2 (L/min)	kcal Aerobic	kcal Glycolysis	kcal ATP-CP	Total energy (kcal)	% Aerobic	% Glycolysis	% ATP-CP
1	99	2.164	0.346	2,272	16,484	7.5	26,255	8.65%	62.78%	28.57%
2	62	2,184	0.217	2,459	11,067	7.5	21,026	11.69%	52.64%	35.67%
3	83	2,214	0.290	2,404	13,197	7.5	23,101	10.41%	57.13%	32.47%
4	65	2,233	0.228	2,507	11,310	7.5	21,317	11.76%	53.06%	35.18%
5	57	2,251	0.200	2,564	9,918	7.5	19,982	12.83%	49.63%	37.53%
6	57	2,340	0.200	2,676	9,576	7.5	19,752	13.55%	48.48%	37.97%
7	63	2,301	0.220	2,601	12,096	7.5	22,197	11.72%	54.50%	33.79%
8	62	2,232	0.217	2,519	11,067	7.5	21,086	11.95%	52.49%	35.57%

Note: The value of 7.5 kcal was selected as a conservative estimate, representing approximately a 25–30% reduction from the 10 kcal set for 7-second efforts. This approximation allows the expected metabolic transition to be reflected, whilst providing a standardised reference for comparison between groups. The adoption of a fixed value facilitates consistency in the analysis, minimising the impact of inter-individual variability on phosphocreatine resynthesis ability

Table 3 presents the absolute and relative contribution of the energy systems during a 15-second maximal effort. Anaerobic glycolysis was the main source of energy, with absolute values ranging from 9.6 to 16.5 kcal and a relative contribution of 48.5% to 62.8%. The ATP-CP system showed a progressive decrease in its contribution, settling at 7.5 kcal, with a relative contribution of between 28.6% and 38.0%, reflecting the metabolic shift towards greater reliance on glycolysis. Aerobic metabolism increased its contribution compared to the 7-second efforts, reaching relative values between 8.7% and 13.6%. Total energy ranged between 19.8 and 26.3 kcal, being higher in subjects with greater body mass.

Table 4.

Energy Contribution – 30s Group (8 complete subjects)

Subject	Weight (kg)	Exercise VO_2 (L/min)	Resting VO_2 (L/min)	kcal Aerobic	kcal Glycolysis	kcal ATP-CP	Total energy (kcal)	% Aerobic	% Glycolysis	% ATP-CP
1	75	2.405	0.263	5,355	16,988	5.0	27,342	19.59%	62.13%	18.29%
2	76	2,449	0.266	5,458	16,302	5.0	26,760	20.40%	60.92%	18.69%
3	81	2,452	0.284	5,420	18,468	5.0	28,888	18.76%	63.93%	17.31%
4	85	2,398	0.298	5,250	17,978	5.0	28,228	18.60%	63.69%	17.71%
5	71	2,482	0.249	5,583	16,720	5.0	27,303	20.45%	61.24%	18.31%
6	58	2,502	0.203	5,748	14,529	5.0	25,276	22.74%	57.48%	19.78%
7	72	2,445	0.252	5,482	15,660	5.0	26,142	20.97%	59.90%	19.13%
8	99	2,436	0.347	5,222	25,691	5.0	35,913	14.54%	71.54%	13.92%

Note: VO_2 exercise = average oxygen consumption recorded during maximum exertion; VO_2 rest = basal oxygen consumption prior to exercise; kcal Aerobic = energy estimated from net oxygen consumption during exercise; kcal Glycolysis = energy estimated from post-exercise blood lactate accumulation; ATP-CP kcal = estimated energy from the phosphagen system, calculated from the fast component of EPOC and set at 5 kcal for all subjects; Total energy = sum of the energy contributions from the three systems; % Aerobic, % Glycolysis and % ATP-CP = relative contribution of each energy system to total energy.

Table 4 presents the absolute and relative contribution of the energy systems during a 30-second maximal effort. Anaerobic glycolysis was the main source of energy, with absolute values ranging from 14.5 to 25.7 kcal and a relative contribution of 57.5% to 71.5%. Aerobic metabolism showed an intermediate contribution, with contributions between 5.2 and 5.7 kcal and relative percentages of 14.5% to 22.7%, indicating progressive activation during longer-duration efforts. The ATP-CP system showed a constant contribution of 5 kcal, with a relative contribution of between 13.9% and 19.8%. Total energy ranged from 25.3 to 35.9 kcal, being higher in subjects with greater body mass.

Figure 1.

Contribution of energy systems at 7, 15 and 30 seconds

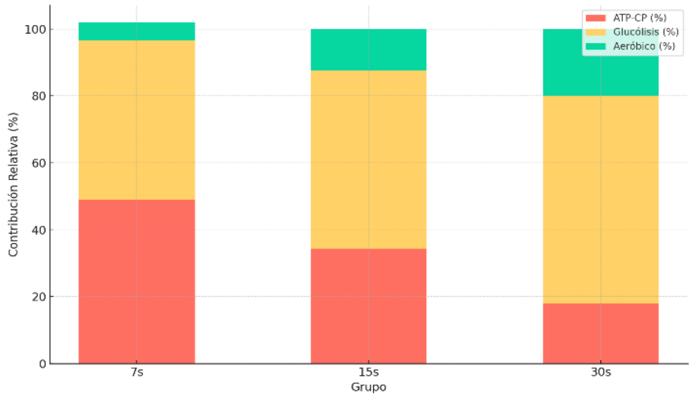

Figure 1 shows the group comparison of the relative contribution of energy systems during maximal efforts of 7, 15 and 30 seconds. A progressive decrease in the contribution of the ATP-CP system is observed, from the 7-second group to the 30-second group, alongside a sustained increase in the glycolytic contribution, which establishes itself as the primary energy pathway in longer-duration efforts. Concurrently, the contribution of aerobic metabolism increases progressively, reaching significant levels at 30 seconds. Total energy expenditure increases with the duration of the exercise, reflecting a higher overall metabolic demand. These results demonstrate a bioenergetic transition dependent on exercise duration, consistent with the physiology of high-intensity exercise.

Figure 2.

Mean maximal lactate and VO_2max at 7, 15 and 30 seconds.

Figure 2 shows the relationship between the duration of maximal exercise and acute metabolic responses, expressed as lactate concentration and oxygen consumption (VO_2). A progressive increase in lactate is observed as the duration of exercise increases, indicating a growing reliance on anaerobic glycolytic metabolism. In contrast, VO_2 shows a moderate increase, indicating a slower activation of aerobic metabolism during high-intensity, short-duration exercise. The ratio of lactate to VO_2 increases with exercise duration, reflecting a progressive predominance of the glycolytic pathway over the oxidative pathway. These results confirm a metabolic response dependent on exercise duration, consistent with the differential kinetics of activation of the energy systems.

Figure 3.
Post-exercise VO_2 recovery at 7, 15 and 30 seconds

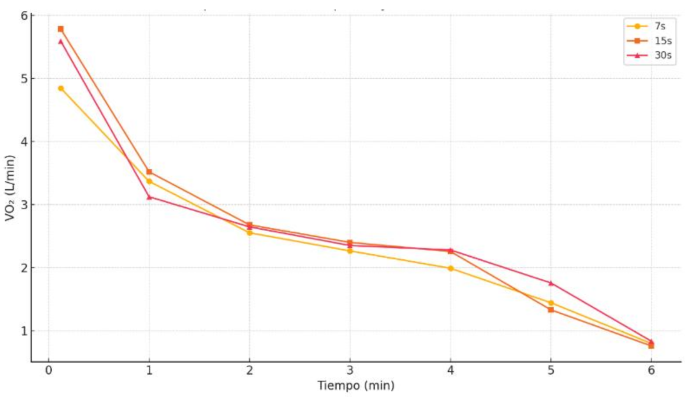

Figure 3 shows the changes in oxygen consumption (VO_2) during post-exercise recovery following maximum efforts lasting 7, 15 and 30 seconds. The 30-second group exhibited the highest initial VO_2 values, reflecting a greater accumulated metabolic load. In all groups, a rapid decrease in VO_2 was observed during the first few minutes of recovery, corresponding to the rapid component of EPOC, followed by a phase of more gradual decline. Throughout recovery, the longer-duration efforts maintained higher VO_2 values, indicating a greater magnitude and persistence of EPOC. These results suggest that the duration of the effort influences the kinetics of metabolic recovery, which is prolonged following efforts with greater glycolytic demand.

Figure 4.
Biexponential fit of EPOC at 7, 15 and 30 seconds

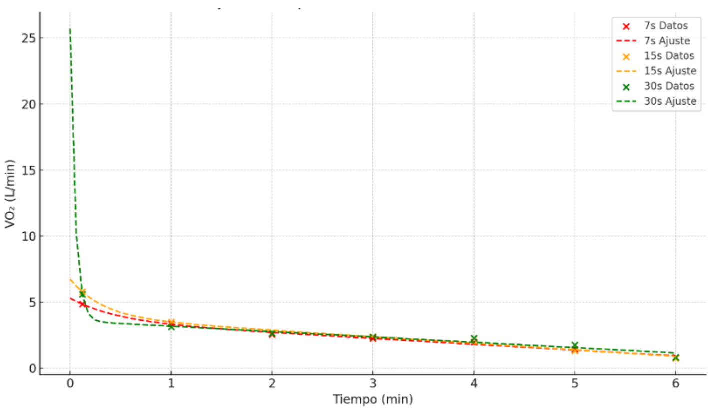

Figure 4 shows the post-exercise recovery kinetics of oxygen consumption (VO_2) using a biexponential fit following maximal efforts of 7, 15 and 30 seconds. Clear differences were observed in the magnitude of EPOC depending on the duration of the effort, with progressively higher values as exercise time increased. The fast component of EPOC exhibited a greater amplitude in longer-duration efforts, reflecting a greater demand for phosphagen resynthesis and a more pronounced metabolic disturbance. In general terms, the 30-second efforts showed a higher initial EPOC and a more prolonged recovery, whilst the 7-second efforts demonstrated a faster recovery. Statistical analysis confirmed significant differences between the groups in lactate concentrations and in the relative contribution of the energy systems, with a greater contribution from the ATP-CP system in the 7-

second efforts and a progressive increase in the glycolytic and aerobic contributions in the longer-duration efforts.

Comparison of results between studies that applied the indirect method.

Table 5.
Comparison of results for 7 to 10 seconds

Study	Time	PCr (%) ± SD	Glycolytic (%) ± SD	Oxidative (%) ± SD
Present study (Cycle ergometer)	7 s	48.28 ± 3.2	46.14 ± 3.2	5.58 ± 1.2
Özbay et al., 2024 (Sprint)	5 s	60.7 ± 3.8	24.9 ± 4.3	14.4 ± 1.3
Tortu et al., 2024 (Taekwondo)	10 s	61.4 ± 4.9	31.1 ± 5.7	7.6 ± 2.3
Gaitanos et al., 1993 (Cycling)	6 s	55.9 ± 4.0	44.1 ± 4.5	0.0 ± 0.0

Note: Estimation of energy contribution using indirect methods based on blood lactate, oxygen consumption and theoretical models of phosphocreatine (PCr) resynthesis.

Table 5 compares the relative contribution of energy systems during short-duration maximal efforts (5–10 s) estimated using indirect methods in various studies. In all cases, the ATP-CP system predominates as the main energy source, with values ranging from 48.3% to 61.4%, followed by a variable glycolytic contribution that increases as the duration of the effort lengthens. The oxidative contribution is low in this time range, although it shows relatively higher values in sprint protocols and in studies with lower relative intensity. The differences observed between studies are mainly explained by the type of exercise, the exact duration of the effort and the characteristics of the subjects evaluated, which reinforces the influence of task specificity and the sporting context on the estimation of energy contribution.

Table 6.
Comparison of results for durations of 15 to 20 seconds

Study	Time	PCr (%)	Glycolytic (%)	Oxidative (%)
Present study (Cycle ergometer)	15 s	34.59 ± 3.2	53.84 ± 3.2	11.57 ± 1.2
Broxterman et al., 2017 (Cycle ergometer)	20 s	28.00 ± 3.5	34.00 ± 1.2	58.00 ± 3.1
Seemann et al., 2022 (Gymnastics)	20 s	50.90 ± 6.6	28.60 ± 4.8	20.50 ± 5.2
Zagatto et al., 2001 (Sprint)	20 s	65.40 ± 1.1	29.50 ± 1.1	5.10 ± 0.5

Note: Estimation of energy contribution using indirect methods based on blood lactate, oxygen consumption and theoretical models of phosphocreatine (PCr) resynthesis.

Table 6 compares studies that estimated the contribution of the ATP-CP, glycolytic and oxidative systems during 15- to 20-second efforts using indirect methods (VO_2, lactate and PCr resynthesis models). The present study shows a predominantly glycolytic profile (53.84%), falling between: Seemann et al., 2022 (anaerobic threshold with 50.9% ATP-CP) and Broxterman et al., 2017, with a clear oxidative predominance (58%). In contrast, it differs from Zagatto et al., 2001, who report a higher contribution from ATP-CP (65.4%) and a lower glycolytic contribution.

The correlations indicate: A strong inverse relationship between time and glycolysis (r = -0.98), as expected. In the present study, the high glycolysis at 15s is explained by the anaerobic ability of the basketball players and the explosive nature of the protocol. The relationship between PCr and oxidative metabolism (r = -0.72) confirms the competition between pathways depending on the specificity of the exercise.

Table 7.
Comparison of results for 30 to 60 seconds

Study	Time	ATP-CP (%)	Glycolytic (%)	Oxidative (%)
Present study (Cycle ergometer)	30 s	17.89 ± 3.2	62.60 ± 3.2	19.51 ± 1.2
Ulupınar et al., 2022 (Football, Sprint)	30 s	42.30 ± 1.1	12.70 ± 1.1	45.00 ± 2.4
Tortu et al., 2024 (Taekwondo, Strikes)	30 s	48.70 ± 6.9	34.50 ± 8.3	16.80 ± 2.6
Beneke et al., 2002 (Cycle ergometer)	30 s	50.30 ± 5.1	31.10 ± 4.6	18.60 ± 2.5
Bussweiler et al., 2012 (Taekwondo)	30 s	52.80 ± 6.0	25.70 ± 3.4	23.40 ± 4.0

Note: Estimation of energy contribution using indirect methods based on blood lactate, oxygen consumption and theoretical models of phosphocreatine (PCr) resynthesis.

Table 7 compares the relative contribution of energy systems during 30-second maximal efforts, estimated using indirect methods. The present study shows a clear predominance of glycolysis (62.6%), accompanied by an intermediate oxidative contribution (19.5%) and a lower contribution from the ATP-CP system (17.9%), reflecting the high glycolytic demand associated with intense and moderate-intensity exercise in basketball players. In contrast, previous studies in football, taekwondo and cycling report more phosphagenic or more oxidative profiles, depending on the sport and the intensity of the protocol. These differences highlight the influence of exercise specificity, the physiological characteristics of the subjects and the relative intensity of the effort on energy distribution, explaining the greater glycolytic activation observed in the present study.

DISCUSSION

The present study analysed the relative contribution of energy systems during maximal efforts of 7, 15 and 30 seconds in basketball players, using indirect methods of metabolic estimation. The results are consistent with the principles of high-intensity exercise physiology, showing a progressive shift in the contribution of the ATP-CP, glycolytic and aerobic systems as the duration of the effort increases. This dynamic reflects the simultaneous and complementary interaction of the energy pathways in ATP resynthesis.

In 7-second efforts, the ATP-CP system predominated (50.24±3.2%), accompanied by significant glycolytic activity (46.14±3.2%), whilst the aerobic contribution was minimal (5.58±1.2%). This pattern coincides with the rapid availability of phosphocreatine during supramaximal efforts, although it confirms an early activation of glycolysis, as previously reported (Gaitanos et al., 1993; Özbay et al., 2024).

At 15 seconds, a clear metabolic transition was observed, with a glycolytic predominance (53.84±3.2%), a decrease in ATP-CP contribution (34.59±3.2%) and a progressive increase in aerobic metabolism (11.57±1.2%). These results are comparable to those described by Seemann et al. (2022), although they differ from protocols of lower relative intensity with a greater oxidative component (Broxterman et al., 2017).

In the 30-second efforts, anaerobic glycolysis emerged as the primary energy pathway (62.60±3.2%), accompanied by an intermediate aerobic contribution (19.51±1.2%) and a lower contribution from the ATP-CP system (17.89±3.2%). Compared with other studies (Beneke et al., 2002; Tortu et al., 2024), a greater reliance on glycolysis was observed, likely associated with the explosive nature of the protocol and the physiological characteristics of basketball players.

Taken together, these results confirm that energy contribution does not depend exclusively on the duration of the effort, but also on the relative intensity and the specificity of the sport, which are determining factors in the bioenergetic dynamics of high-intensity intermittent exercise.

In the basketball players assessed, the intermittent and explosive nature of the game favours a greater reliance on anaerobic pathways, particularly during efforts lasting up to 30 seconds. Understanding these bioenergetic interactions allows for the optimisation of training prescription and periodisation, directing training loads towards the specific development of each energy system according to the player's physiological profile and competitive demands. This approach contributes both to improved performance and to the reduction of premature fatigue and the risk of injuries associated with metabolic imbalances.

The present study employed an indirect estimation approach to assess energy contribution, integrating measurements of blood lactate, oxygen consumption and theoretical models of phosphocreatine resynthesis. Although these methodological approaches are widely accepted, they have limitations, such as the inability to directly measure ATP resynthesis and intramuscular phosphocreatine depletion, as well as the use of a fixed value for the ATP-CP component, which does not account for inter-individual variability. Nevertheless, these methods have been validated in the literature and provide a reliable approximation for analysing energy contribution during short-duration maximal efforts.

In the present study, it was observed that, during 7-second maximal efforts, the ATP-CP system was predominant (50.24%), accompanied by a significant glycolytic contribution (46.14%). These results are consistent with classic and recent studies on supramaximal efforts, such as those by Gaitanos et al. (1993), who reported a 55.9% ATP-CP contribution during 6-second efforts, and Özbay et al. (2024), who observed a 60.7% contribution during 5-second efforts. However, compared with these studies, the present study showed a higher glycolytic contribution, which could be attributed to the characteristics of the basketball players assessed, whose intermittent and explosive profile would favour earlier glycolytic activation under conditions of maximal effort on a cycle ergometer.

Consistent with this, Serresse et al. (1988) reported that the ATP-CP system is the primary energy source in maximal exercises lasting up to 10 seconds, with a contribution of around 55–60%, reinforcing the sequential model of energy activation. However, the high glycolytic contribution observed at 7 seconds in the present study (46.14%) suggests that, under certain conditions of intensity and sport-specificity, glycolysis may be activated earlier than traditionally described for efforts lasting <10 s.

During the 15-second efforts, a clear metabolic transition was observed, characterised by the predominance of anaerobic glycolysis (53.84±3.2%), a decrease in ATP-CP contribution (34.59±3.2%) and a progressive increase in aerobic contribution (11.57±1.2%), in line with the classic physiology of high-intensity intermittent exercise. However, when compared with the literature, differences are observed associated with the exercise modality and the subjects' profile, as reported by Broxterman et al. (2017), who described a greater oxidative component in protocols of lower relative intensity and in populations not specialised in explosive efforts.

In contrast, Seemann et al. (2022) observed in gymnasts a predominance of the ATP-CP system (50.9%) and a lower glycolytic contribution (28.6%), which is explained by the technical, brief nature of floor routines with frequent pauses. Similarly, Zagatto et al. (2001), in 20-second sprints among trained military personnel, reported a high reliance on the ATP-CP system (65.4%), with a moderate glycolytic contribution (29.5%) and a marginal oxidative contribution (5.1%), reflecting the specificity of explosive and cyclic tasks. Overall, comparison with studies in athletics, cycling, gymnastics and combat sports confirms that energy distribution during 15–20-second efforts depends largely on the type of sport, the intensity applied and the characteristics of the athletes. In the basketball players assessed, rapid glycolytic activation is evident as the predominant pathway in efforts of intermediate duration, with direct implications for training planning and the management of competitive fatigue.

In maximum 30-second efforts, anaerobic glycolysis emerged as the primary energy pathway (62.60±3.2%), accompanied by an intermediate oxidative contribution (19.51±1.2%) and a reduced contribution from the ATP-CP system (17.89±3.2%). This pattern is consistent with the classic physiology of high-intensity, intermediate-duration exercises, where glycolysis assumes a central role following the rapid depletion of phosphagens.

These findings are consistent with those reported by Ouergui et al. (2024), who described a glycolytic contribution of around 68% in 30-second Wingate tests in combat sports. However, the greater glycolytic predominance observed in the present study, compared with research in football, cycling and taekwondo, highlights the influence of the sport and the intensity of the protocol applied. For example, Ulupınar et al. (2022) reported a higher oxidative contribution (45%) and a lower glycolytic contribution (12.7%) in footballers, whilst Tortu et al. (2024) observed a more balanced profile between energy systems in taekwondo athletes, characteristic of repeated efforts with pauses between actions.

Beneke et al. (2002) reported in cyclists during Wingate tests a distribution of 50.3% ATP-CP, 31.1% glycolytic and 18.6% oxidative, demonstrating a greater initial reliance on the phosphagen system in cyclic tasks. Similarly, Bussweiler et al. (2012) observed in taekwondo athletes a predominance of the ATP-CP system (52.8%) and a lower glycolytic contribution (25.7%), reinforcing the specificity of energy patterns in combat sports.

Differences in energy contribution between studies are mainly explained by the type of exercise, the physiological characteristics of the athletes, and the relative intensity of the protocol. Whilst cyclic or combat sports exhibit specific bioenergetic profiles, basketball players, due to the repetition of explosive actions, show earlier glycolytic activation during supramaximal efforts. This high glycolytic dependence during 30-second efforts highlights the need for training aimed at improving anaerobic ability, lactate tolerance and recovery between intermittent efforts, in line with the physiological demands of basketball.

Overall, the results confirm the progressive dynamics of energy systems during short-duration efforts and emphasise that the sport, relative intensity and physiological characteristics of the athletes determine the distribution of energy supply. The high glycolytic contribution observed in basketball players up to 30 seconds provides applied evidence for optimising training and performance in high-intensity intermittent sports such as basketball.

PRACTICAL APPLICATIONS

The results of this study provide relevant information for the planning and prescription of training in high-intensity intermittent sports, such as basketball. Characterising the relative contribution of energy systems according to the duration of maximal effort allows coaches and fitness trainers to adjust the duration and density of training stimuli in line with specific physiological objectives.

In short-duration maximal efforts, identifying the predominance of the ATP-CP system and anaerobic glycolysis facilitates the design of tasks aimed at developing power and anaerobic ability, as well as the appropriate selection of recovery breaks. Furthermore, the analysis of aerobic participation during post-exercise recovery provides criteria for optimising the training of recovery ability between repeated high-intensity actions.

From an applied perspective, these findings may contribute to: optimising the timing structure of basketball-specific exercises. Tailoring training loads according to the actual energy demands of maximal efforts. Improving training efficiency and decision-making in competitive contexts.

CONCLUSIONS

The present study demonstrated that the relative contribution of the ATP-CP, glycolytic and aerobic systems varies progressively with the duration of the effort, with the phosphagen pathway being dominant in 7-second efforts, anaerobic glycolysis in 15- and 30-second efforts, and aerobic metabolism increasing its contribution over time. The high glycolytic contribution observed even in short efforts (7–15 seconds) suggests an earlier activation of this pathway in basketball players, compared to disciplines such as cycling or combat sports, reflecting specific adaptations to the explosive and intermittent demands of the sport.

The differences compared to previous studies highlight the importance of considering the sport, relative intensity and physiological profile of athletes when analysing energy contribution, avoiding generalisations based on traditional cyclic models. These findings have direct practical applications in training plann, highlighting the need to enhance glycolytic ability, improve lactate tolerance and optimise recovery between intermittent efforts—key aspects for competitive performance in basketball. Despite the limitations inherent in indirect methods of energy estimation, the results obtained provide a valid approximation consistent with the literature, offering relevant information for specific training strategy design.

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