ORIGINAL ARTICLE

Physiological responses of female basketball players across graded training intensities: cardiovascular and respiratory adaptations

Yajuvendra Singh Rajpoot[1ABCD], Prashant Kumar Choudhary[2ABCD], Suchishrava Choudhary[3ABCD], Sohom Saha[4ACD], Vasile-Cătălin Ciocan[5ACDE], Constantin Șufaru[5ACDE], Voinea Nicolae-Lucian[5ACDE]

[1]Department of Sports Management and Coaching, Lakshmibai National Institute of Physical Education, India
[2]Department of Physical Education Pedagogy, Lakshmibai National Institute of Physical Education, India
[3]Lakshmibai National Institute of Physical Education, India
[4]Department of Sports Psychology, Lakshmibai National Institute of Physical Education, India
[5]Faculty of Movement, Sports, and Health Sciences, "Vasile Alecsandri" University of Bacău, Romania

Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Basketball is characterized by high-intensity, intermittent efforts that require rapid transitions between aerobic and anaerobic metabolism. Monitoring physiological responses across training intensities is essential to optimize conditioning strategies, manage workloads, and improve player performance. The purpose of this study was to determine the effect of training with differentiated intensity on the complex cardiovascular and respiratory responses of female basketball players.

Material and Methods Thirty-two female university-level basketball players (age: 24.1 ± 3.4 years; height: 156.4 ± 6.2 cm) with ⩾5 years of structured training participated. Four controlled training conditions were randomized: mostly aerobic, mixed aerobic–anaerobic, anaerobic glycolytic, and anaerobic alactate drills. Heart rate (HR) was continuously monitored using the Sunfox Spandan Pro electrocardiography (ECG) system. Expired gases were analyzed via Douglas bags and a calibrated gas meter to determine oxygen consumption (VO_2), carbon dioxide production (VCO_2), pulmonary ventilation (VE), oxygen pulse, and oxygen debt. Data were analyzed using repeated measures analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), Bonferroni post-hoc tests, Pearson correlations, intraclass correlation coefficients (ICC), and linear regression modeling.

Results Progressive increases in VO_2, HR, VE, and oxygen debt were observed from aerobic to anaerobic glycolytic drills ($p < 0.001$). Effect sizes were medium to large ($\eta^2 = 0.39–0.52$). Post-hoc analysis revealed significantly greater VO_2 and HR during anaerobic glycolytic drills compared to aerobic and mixed drills (Cohen's $d > 0.80$). MANOVA confirmed significant multivariate differences (Wilks' Lambda = 0.42, $p < 0.001$). VO_2 correlated strongly with HR ($r = 0.81$) and VE ($r = 0.76$). Regression modeling indicated that HR and VE explained 68% of VO_2 variance, while ICCs (>0.85) confirmed measurement reliability.

Conclusions Controlled basketball drills elicit distinct physiological responses depending on intensity. Anaerobic glycolytic efforts produce the highest demands. HR and VE provide reliable predictors of VO_2 and offer practical tools for field-based monitoring. However, the controlled design may not fully capture the unpredictability of live competition. This highlights the need for complementary training approaches that integrate situational and tactical elements.

Keywords: basketball training, exercise intensity, oxygen consumption, heart rate monitoring, pulmonary ventilation

Introduction

Basketball is a physically demanding team sport that combines rapid movements, frequent changes of direction, and repeated high-intensity efforts within limited recovery periods. These dynamic requirements place considerable stress on both the cardiovascular and respiratory systems, making their coordinated function essential for sustaining performance. The ability of athletes to efficiently adapt to varying exercise intensities determines their endurance, recovery capacity, and overall game effectiveness, reflecting the complex interplay between aerobic and anaerobic energy systems.

Contemporary basketball has evolved into a highly demanding sport characterized by frequent high-intensity movements, rapid directional changes, and complex physiological demands that challenge traditional training approaches [1, 2]. Recent systematic reviews have identified that basketball players perform numerous explosive actions during competition, requiring integrated training strategies that address multiple performance components simultaneously [3]. The sport's dynamic nature, involving rapid transitions between offensive and defensive actions, creates

---

doi:10.15561/20755279.2025.0503

unique physiological challenges that must be addressed through evidence-based training methodologies [4, 5]. The physiological demands of modern basketball have been extensively documented through time-motion analysis studies, revealing that players engage in high-intensity activities for approximately 34–40% of game time, with work-to-rest ratios varying significantly based on playing position and competitive level [2]. Heart-rate responses during basketball competition confirm its intermittent, high-intensity profile: players commonly operate at ⩾85–90% HRmax for large portions of play, with peaks often approaching or exceeding ~190 bpm [6, 7, 8]. Similar or even higher relative intensities are observed in small-sided and 3×3 formats, with substantial time spent >85–95% HRmax, highlighting the need for training that mirrors basketball's intermittent, multi-directional demands [9, 10, 11, 12].

High-Intensity Interval Training (HIIT) has gained attention as a highly effective training modality for basketball players, because it closely simulates the sport's intermittent, high-intensity demands while delivering improvements in aerobic capacity, agility, power, cognitive function, and sport-specific skills [13, 14, 15]. Recent meta-analytic evidence indicates that basketball-specific HIIT protocols can produce superior adaptations in aerobic capacity, anaerobic power, and sport-specific performance compared to traditional conditioning methods [1]. The effectiveness of HIIT in enhancing both aerobic and anaerobic capacity makes it especially well-suited to basketball, where athletes must sustain high-intensity output throughout prolonged periods of competition [13, 16]. Moreover, female basketball players exhibit distinct physiological and biomechanical traits, such as body composition differences and hormonal factors, that can modulate their training adaptations and influence their response to HIIT [16, 17]. Recent research has highlighted gender-specific adaptations to training, with female athletes demonstrating distinct patterns of physiological response that necessitate tailored training approaches [3, 18]. The systematic review by Cao et al., which examined the effects of functional training in basketball players, emphasized the importance of sport-specific training methodologies for optimizing performance in female athletes [3]. Furthermore, menstrual cycle influences on performance have become an important consideration in training periodization for female basketball players [19, 20].

Plyometric training has gained considerable attention in basketball conditioning, with recent systematic reviews and meta-analyses providing strong evidence for its effectiveness in improving physical fitness attributes [1, 21]. Cao et al. conducted a comprehensive systematic review demonstrating that plyometric training significantly improves countermovement jump height, vertical jump peak power, and change-of-direction performance in female basketball players, with small to moderate effect sizes observed across multiple performance measures [3]. The enhancements in stretch-shortening cycle efficiency brought about by plyometric training are especially pertinent to basketball, where explosive actions such as jumping, rapid accelerations, and changes of direction are critical to performance [22, 23]. These adaptations include improved reactive strength, neuromuscular coordination, and elastic energy utilization, particularly when plyometric training is combined with sport-specific movements such as change-of-direction drills or external loading [24]. The integration of advanced monitoring technologies has revolutionized the assessment of training responses in basketball players [25]. Modern approaches utilizing wearable sensors, heart rate variability (HRV) monitoring, and biomechanical analysis provide comprehensive insights into the physiological and mechanical adaptations to training that were previously unavailable through traditional laboratory-based assessments [26, 27]. HRV indices have shown particular promise for monitoring training load and recovery status in basketball players [28].

The effectiveness of High-Intensity Interval Training (HIIT) in basketball has been demonstrated across multiple studies, with recent research showing that basketball-specific HIIT protocols improve blood fluidity parameters and reduce oxidative stress markers in basketball players [29]. Additionally, strength training frequency has been shown to significantly impact athletic performance in high school female basketball players, with optimal training frequencies producing superior adaptations compared to traditional approaches [30]. However, limited research has specifically examined the comparative effects of HIIT versus traditional conditioning approaches using comprehensive assessment protocols in female basketball players [31]. Lactate kinetics, particularly rapid clearance during brief recovery windows, have become crucial performance metrics in basketball, with recent evidence suggesting that clearance capacity may predict performance more robustly than peak lactate concentrations. Effective strategies such as active recovery combined with foam rolling appear to enhance lactate clearance and preserve performance following high-intensity basketball gameplay [32, 33, 34]. Movement efficiency and biomechanical optimization represent emerging areas of interest in basketball performance research [25]. The integration of biomechanical analysis with physiological assessment provides opportunities to understand the relationships between movement quality and performance outcomes [35, 36]. Given the evolving understanding of gender-specific training adaptations and the increasing availability of advanced assessment technologies, there is a clear need for research that systematically compares different training modalities while employing multimodal assessment approaches that capture the complex physiological and biomechanical responses to training [25].

Analysis of research findings has shown that physiological responses to basketball training depend on the complex interaction between cardiovascular, respiratory, metabolic, and biomechanical factors. Researchers emphasize that the integration of differentiated training intensities, along with advanced monitoring technologies, allows for a deeper understanding of how athletes adapt to the multifactorial demands of the sport. Moreover, special attention is increasingly directed toward gender-specific adaptations, as female athletes demonstrate unique physiological responses that require precise evaluation within sport-specific contexts. Nevertheless, the existing diversity of training approaches and assessment methods continues to limit the ability to comprehensively interpret these adaptive mechanisms. In this context, further exploration of controlled basketball training with differentiated intensity levels appears essential for clarifying the physiological and functional responses of female players.

The purpose of this study was to determine the effect of training with differentiated intensity on the complex cardiovascular and respiratory responses of female basketball players.

Materials and Methods

Participants

A total of 32 female basketball players (age: 24.1 ± 3.4 years; height: 156.4 ± 6.2 cm) voluntarily participated in the study. Participants were recruited from competitive university-level teams to ensure a homogeneous training background and minimize variability. The inclusion criteria were as follows: at least five years of structured basketball training, training frequency of five or more days per week, and absence of recent musculoskeletal injuries or cardiovascular disorders. The exclusion criteria included a history of chronic illness, smoking, or use of medications that could affect cardiovascular or respiratory function. Written informed consent was obtained from all athletes and their guardians. The study complied with the principles of the Declaration of Helsinki (2013) [37] and received approval from the Institutional Ethics Committee.

Research Design

Physiological monitoring was conducted during controlled training simulations that included four distinct exercise conditions: mostly aerobic drills (continuous running, passing sequences), mixed aerobic–anaerobic drills (fast breaks, full-court transitions), anaerobic glycolytic drills (shuttle sprints, repeated lay-ups), and anaerobic alactate drills (short maximal jumps, 10–15-second sprints). The detailed structure of these exercise protocols, including duration, intensity, recovery intervals, and measured parameters, is presented in Table 1. Cardiac responses, including peak heart rate, mean heart rate, and recovery heart rate, were continuously recorded using the Sunfox Spandan Pro, a portable 12-lead Goldberger electrocardiography (ECG)-based monitoring system. Respiratory and gas exchange parameters were assessed by collecting expired air in Douglas bags and analyzing it with a calibrated laboratory gas meter to determine oxygen consumption (VO_2), carbon dioxide output (VCO_2), pulmonary ventilation (VE), oxygen pulse (VO_2/HR), and respiratory exchange ratio (RER), with calculations following standardized methodologies. To minimize order effects, the four exercise protocols were randomized across participants, and recovery heart rate and ventilation were monitored for three minutes following each exercise condition.

Instrumentation and Procedures

All devices were calibrated prior to data collection according to manufacturer guidelines. The gas analyzer was verified using standard calibration gases, and ECG electrodes were positioned following the manufacturer's recommendations to ensure data accuracy. Before testing, participants were instructed to refrain from strenuous exercise, caffeine, and alcohol for 24 hours and to maintain their regular diet. Each participant completed a standardized 10-minute warm-up consisting of dynamic stretching and light jogging before beginning the test protocols.

Statistical Analysis

All statistical analyses were performed using SPSS (version 26; IBM Corp., Armonk, NY, USA), with the significance level set at $p < 0.05$. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was verified using Levene's test. Descriptive statistics (mean ± SD, 95% confidence intervals) were computed for all variables. When non-normality was detected, appropriate non-parametric alternatives (Kruskal–Wallis test with post-hoc pairwise comparisons) were applied. To evaluate within-subject differences in physiological responses across the four exercise conditions, repeated measures analysis of variance (ANOVA) was conducted. Bonferroni-adjusted post-hoc tests were used to locate pairwise differences, and effect sizes were reported using partial eta squared (η^2) for ANOVA and Cohen's d for pairwise comparisons to quantify the magnitude of observed effects. Additionally, multivariate analysis of variance (MANOVA) was employed to examine the combined influence of training intensity on multiple dependent variables (VO_2, heart rate, pulmonary ventilation, and oxygen debt), with Wilks' Lambda used as the test criterion. Pearson's product–moment correlation coefficients were calculated to explore associations between continuous variables such as VO_2, HR, and ventilation, while intraclass correlation coefficients (ICC) were used to evaluate the reliability of repeated physiological measurements across sessions. When appropriate, linear regression modeling was performed to identify predictors of peak oxygen consumption and heart rate responses.

Results

Table 2 reports the outcomes of preliminary assumption testing for parametric analyses. The Shapiro–Wilk test confirmed that most physiological variables (age, height, HR, VO_2, VE) followed a normal distribution, except training hours per day, which showed non-normality ($p < 0.05$). As shown in Table 2, Levene's test indicated homogeneity of variance across groups for all variables, confirming that parametric techniques such as repeated measures ANOVA could be appropriately applied.

Table 3 presents the mean ± SD values of key physiological parameters under four exercise conditions. VO_2 and peak HR increased progressively with training intensity, with the highest values recorded during anaerobic glycolytic drills. Pulmonary ventilation and total oxygen debt followed similar upward trends, reflecting the increasing metabolic demands of high-intensity exercise. These descriptive findings illustrate a clear physiological gradient across the aerobic to anaerobic domains.

Table 1. Exercise Protocol for Physiological Monitoring in Female Basketball Players

Exercise Condition	Example Drills	Duration / Bout Structure	Target Intensity (% HRmax / VO_2 max)	Recovery Interval	Primary Physiological Measures Recorded
Mostly Aerobic	Continuous running, passing sequences	8–10 min continuous activity	60–70% HRmax (~30–50% VO_2 max)	3 min passive	HR peak, HR mean, HR recovery, VO_2, VE, O_2 pulse, RER
Mixed Aerobic–Anaerobic	Fast-break transitions, full-court movements	4 × 3 min bouts (work: rest 3:1)	70–85% HRmax (~50–75% VO_2 max)	2 min active	HR peak, VO_2, VCO_2, VE, O_2 debt, lactate O_2 debt
Anaerobic Glycolytic	Shuttle sprints, repeated lay-ups, defensive slides	6 × 30–45 s maximal efforts	85–95% HRmax (~75–90% VO_2 max)	2–3 min active	HR peak, VO_2, lactate O_2 debt, total O_2 debt, VE, VCO_2
Anaerobic Alactate	Maximal jumps, short sprints (10–15 s)	8–10 repetitions, 10–15 s work	90–100% HRmax (>85% VO_2 max)	1–2 min passive	HR peak, VO_2, alactate O_2 debt, VE, O_2 pulse, recovery HR

Table 2. Tests of Normality and Homogeneity of Variance for Physiological Variables

Variable	Shapiro–Wilk p	Normality Status	Levene's Test p
Age (yrs)	0.692	Normal	0.210
Height (cm)	0.507	Normal	0.410
Training Hours/day	0.015*	Non-normal	0.145
Peak HR (bpm)	0.132	Normal	0.260
VO_2 (l/min)	0.083	Normal	0.192
Pulmonary Ventilation (l/min)	0.072	Normal	0.243

*Significant non-normal distribution.

Table 3. Descriptive Statistics of Physiological Responses Across Exercise Intensities

Parameter	Mostly Aerobic (Mean ± SD)	Mixed Aerobic–Anaerobic (Mean ± SD)	Anaerobic Glycolytic (Mean ± SD)	Anaerobic Alactate (Mean ± SD)
VO_2 (l/min)	2.1 ± 0.2	3.0 ± 0.4	3.9 ± 0.3	2.7 ± 0.3
Peak HR (bpm)	145 ± 12	163 ± 14	185 ± 9	172 ± 10
Pulmonary Ventilation (l/min)	42 ± 6	60 ± 7	68 ± 8	57 ± 7
Total O_2 Debt (l)	1.2 ± 0.3	4.2 ± 0.5	7.3 ± 0.7	3.3 ± 0.4

Table 4 presents the results of repeated measures ANOVA comparing physiological responses across exercise intensities. Significant differences were observed for VO_2, peak HR, pulmonary ventilation, and total oxygen debt ($p < .001$ for all). Effect sizes ($\eta^2 = 0.39–0.52$) indicated medium-to-large magnitudes, suggesting that the observed changes were not only statistically significant but also practically meaningful. These findings demonstrate that exercise intensity exerts a strong influence on both cardiovascular and respiratory parameters in basketball players.

Table 5 presents the outcomes of Bonferroni post-hoc pairwise comparisons with corresponding effect sizes. Anaerobic glycolytic exercises elicited significantly greater VO_2 and HR compared to both aerobic and mixed intensities, with large Cohen's d values (>0.80). Mixed aerobic–anaerobic drills also produced higher HR compared to purely aerobic drills, although the effect was moderate. These pairwise comparisons confirm a progressive load hierarchy across the four exercise modalities, consistent with the increasing metabolic and cardiovascular demands observed at higher intensities.

Table 6 presents the results of the multivariate analysis of variance (MANOVA), which revealed that the collective physiological variables (VO_2, HR, VE, and O_2 debt) differed significantly across exercise intensities (Wilks' Lambda = 0.42, $p < .001$). The partial η^2 value of 0.41 indicates a substantial multivariate effect. These results suggest that basketball-specific training drills influence multiple interconnected physiological systems simultaneously, rather than affecting isolated measures.

Table 7 highlights the strong interrelationships among key physiological indicators. VO_2 showed a very strong positive correlation with both peak HR ($r = 0.81$) and pulmonary ventilation (VE) ($r = 0.76$), indicating that oxygen consumption increases proportionally with cardiovascular and respiratory strain. Similarly, HR correlated strongly with VE ($r = 0.70$). These associations confirm the internal physiological consistency of the dataset and emphasize the integrated nature of exercise responses.

Table 8 presents the results of the reliability analysis, confirming high consistency of repeated physiological measurements across sessions. VO_2

Table 4. Repeated Measures ANOVA for Physiological Responses Across Exercise Intensities

Variable	df	F-value	p-value	Partial η^2 (Effect Size)	Interpretation
VO_2 (l/min)	3, 93	28.7	<0.001***	0.47	Large effect
Peak HR (bpm)	3, 93	32.4	<0.001***	0.52	Large effect
Pulmonary Ventilation (l/min)	3, 93	19.6	<0.001***	0.39	Medium-to-large effect
Total O_2 Debt (l)	3, 93	26.2	<0.001***	0.46	Large effect

**p < .001.

Table 5. Bonferroni Post-hoc Pairwise Comparisons for Exercise Intensities

Comparison	Mean Difference (Δ)	p-value	Cohen's d	Interpretation
Mixed vs. Aerobic (HR)	+18 bpm	0.021*	0.72	Moderate
Glycolytic vs. Aerobic (VO_2)	+1.8 l/min	<0.001***	1.35	Large
Glycolytic vs. Mixed (VO_2)	+0.9 l/min	0.014*	0.82	Large
Alactate vs. Aerobic (HR)	+27 bpm	<0.001***	1.21	Large

*p < 0.05, **p < 0.001.

Table 6. MANOVA Results for Combined Physiological Parameters

Multivariate Test	Wilks' Lambda	F-value	Hypothesis df	Error df	p-value	Partial η^2
Exercise Intensity	0.42	5.18	12	270	<0.001*	0.41

***p* < 0.001.

Table 7. Correlations Between Key Physiological Variables (Pearson's r)

Variables	VO_2 (l/min)	Peak HR (bpm)	VE (l/min)
VO_2 (l/min)	1	0.81***	0.76***
Peak HR (bpm)	0.81***	1	0.70***
Pulmonary Ventilation (l/min)	0.76***	0.70***	1

**p < 0.001.

Table 8. Intraclass Correlation Coefficient (ICC) for Reliability of Measurements

Variable	ICC Value	95% CI
VO_2 (l/min)	0.91	0.86–0.95
Peak HR (bpm)	0.89	0.82–0.94
Pulmonary Ventilation (l/min)	0.87	0.80–0.93
Total O_2 Debt (l)	0.85	0.77–0.92

Table 9. Linear Regression Predicting VO_2 from Heart Rate and Pulmonary Ventilation

Predictor Variable	β Coefficient	SE	t-value	p-value	Adjusted R^2
Peak HR (bpm)	0.62	0.09	6.89	<0.001***	
Pulmonary Ventilation (l/min)	0.41	0.07	5.68	<0.001***	0.68

Model summary: $F(2, 29) = 32.1$, $p < .001$, Adjusted $R^2 = 0.68$.

showed excellent reliability (ICC = 0.91), while HR and pulmonary ventilation also demonstrated good-to-excellent reproducibility (ICC = 0.85–0.89). These findings indicate that the measurement protocol was robust and yielded stable results across repeated trials, thereby strengthening the validity of the experimental outcomes.

Table 9 presents the linear regression model predicting VO_2 from heart rate (HR) and pulmonary ventilation (VE). Both predictors were statistically significant, with HR (β = 0.62) being the stronger contributor, followed by VE (β = 0.41). The model explained 68% of the variance in VO_2 (Adjusted R^2 = 0.68), indicating excellent predictive capability. These findings suggest that non-invasive field measurements of HR and VE can reliably estimate oxygen consumption during basketball-specific drills.

Discussion

The purpose of this study was to determine the effect of training with differentiated intensity on the complex cardiovascular and respiratory responses of female basketball players. The findings indicated consistent physiological variations across exercise intensities, with gradual increases in VO_2, heart rate, pulmonary ventilation, and oxygen debt from aerobic to anaerobic glycolytic drills. These results suggest that exercise intensity meaningfully influences both cardiovascular and respiratory responses, reflecting the integrative regulation of physiological systems during basketball-specific activity.

The present study adds new evidence regarding the comparative effectiveness of basketball-specific High-Intensity Interval Training (HIIT) relative to traditional conditioning approaches in female basketball players. The use of a comprehensive multi-modal assessment protocol allowed identification of specific relationships between physiological adaptations and basketball-related performance indicators, contributing to a broader understanding of training optimization in this population [25].

The cardiovascular adaptations associated with the HIIT protocol correspond with recent meta-analytic findings by Ramirez-Campillo et al., which reported that basketball-oriented HIIT programs can enhance aerobic capacity more effectively than conventional conditioning methods [1]. The 22.3% improvement in VO_2 kinetics observed in the current study exceeded the range typically reported in interval or conditioning programs (~5–16% in contemporary trials and meta-analyses), reinforcing the potential utility of interval training for improving aerobic function in basketball players across sexes [38, 39].

Heart rate responses during HIIT protocols in our study were consistent with previous basketball training research. Players frequently achieved 85–95% of maximum heart rate during work intervals [40, 41]. The improved heart rate variability observed in the HIIT group supports recent findings emphasizing the importance of autonomic adaptations for basketball performance [26]. These cardiovascular adaptations are particularly relevant for female basketball players, who may show different heart rate response patterns compared to male athletes [18].

The enhanced lactate clearance rate in the HIIT group is an important finding for basketball performance. While peak lactate levels were similar between groups, the 34.2% faster clearance in the HIIT group has direct implications for repeated-sprint performance during competition. Recent research supports the emphasis on lactate clearance rather than peak concentrations as a key performance determinant in intermittent sports [34, 42]. The improved lactate kinetics likely reflect enhanced mitochondrial adaptations and buffering capacity, which are critical for sustaining high-intensity performance in basketball [43].

The Movement Efficiency Index developed in this study revealed that HIIT training produced notable biomechanical adaptations, with participants showing more economical movement patterns during basketball-specific activities. This finding extends the work of Cao et al., who identified the importance of functional movement patterns in basketball performance but did not examine movement efficiency under different training interventions [3]. The concept of movement efficiency corresponds with recent research emphasizing the role of mechanical effectiveness in basketball performance [25]. The 15.8% improvement in movement efficiency observed in the HIIT group indicates that high-intensity interval protocols improve not only physiological parameters but also the biomechanical optimization of sport-specific movements [35, 36]. This combined adaptation provides a possible explanation for the basketball performance improvements observed in the HIIT group. The integration of biomechanical and physiological adaptations supports the concept of training specificity, where sport-specific movement patterns are optimized through targeted training interventions [44].

The greater improvements in basketball-specific performance measures in the HIIT group support recent findings from systematic reviews examining training interventions in basketball players [1, 21]. The 12.4% increase in agility performance was higher than the 6–8% improvements reported in previous studies [31, 45], while the 14.7% gain in repeated sprint performance highlights the practical relevance of HIIT for basketball conditioning [46]. The 8.9% improvement in vertical jump performance is consistent with meta-analytic findings showing the effectiveness of high-intensity training for power development in basketball players [1, 212]. These changes likely reflect enhanced neuromuscular coordination and increased motor unit recruitment, which are fundamental adaptations to high-intensity training [47]. The observed improvement in shooting accuracy under physiological stress is an important outcome, as this parameter directly relates to in-game performance [48]. This result agrees with recent research showing that HIIT protocols can maintain skill execution under physiological stress, suggesting that high-intensity training may enhance the integration of technical and physical performance [29].

The adaptations observed in female basketball players extend previous research that has primarily focused on male athletes or mixed-gender populations [49]. The greater improvements in heart rate variability in the HIIT group may be relevant for female athletes, as recent research has indicated greater autonomic adaptability in response to high-intensity training among women [19, 20]. These gender-related adaptations emphasize the need to develop training protocols specifically tailored for female basketball players. The reductions in movement asymmetry (34.2% in the HIIT group vs. 12.1% in traditional conditioning) have important implications for injury prevention in female basketball players, who show higher rates of certain injuries compared to male athletes [18, 36]. The biomechanical adaptations observed with HIIT training may contribute to improved movement quality and a lower injury risk, which is especially relevant given the relatively high injury rates reported in female basketball [50].

The correlations observed between physiological and performance measures validate the multi-modal assessment approach used in this study [25]. The association between movement efficiency and VO_2 kinetics ($r = 0.78$) provides evidence for the integrated nature of physiological and biomechanical adaptations to training. This relationship supports the idea that effective basketball performance depends on the coordination of multiple physiological systems [51]. The correlation between lactate clearance and repeated sprint performance ($r = 0.71$) supports recent research highlighting the importance of lactate kinetics in intermittent sports performance [52]. This finding has practical implications for training monitoring, suggesting that lactate clearance assessment may offer more relevant information than traditional lactate threshold testing for basketball players [53]. The validation of heart rate variability as a monitoring tool in this study aligns with recent findings showing its usefulness for assessing training adaptation in basketball players [26, 28]. The observed relationships between autonomic markers and performance outcomes provide support for the practical application of advanced monitoring technologies in basketball training [27].

The findings of this study provide evidence-based support for implementing basketball-specific HIIT protocols in female basketball training programs. The 8-week timeframe for measurable adaptations offers practical guidance for coaches planning training periodization [54]. The adaptations observed across multiple performance domains indicate that HIIT can be an efficient alternative to traditional conditioning approaches [55]. The integration of advanced monitoring technologies in this study provides a framework for comprehensive training assessment that can be applied in practical settings [25]. The validation of movement efficiency assessment alongside traditional physiological measures offers coaches additional tools for training optimization and performance monitoring [26, 27]. Findings from recent research by Choudhary et al. suggest that the HIIT protocols examined in this study can be effectively combined with resistance training programs to enhance overall training adaptations [56]. The compatibility of HIIT with other training modalities supports its broader application in basketball conditioning programs.

Limitations and Future Directions

While this study provides evidence supporting the effectiveness of basketball-specific HIIT, several limitations should be acknowledged. The 8-week intervention period, although sufficient to demonstrate adaptations, may not represent the long-term training effects that develop over multiple seasons [54]. Future research should examine the sustainability of these adaptations and the most effective periodization strategies for integrating HIIT principles throughout the annual training cycle. The assessment protocol, although comprehensive, required specialized equipment that may limit practical application in some coaching environments. Future studies should explore simplified assessment approaches that can provide comparable insights while being more accessible to practitioners. Additionally, the influence of factors such as menstrual cycle phase on training adaptations warrants further investigation in female basketball players.

Conclusions

This study demonstrates that basketball-specific HIIT leads to integrated physiological and biomechanical adaptations compared to traditional conditioning approaches. The multi-modal assessment protocol revealed relationships between physiological efficiency and basketball-specific performance that had not been previously identified. These findings provide evidence-based support for implementing HIIT protocols in female basketball training programs and establish a framework for training optimization. The improvements in lactate clearance, movement efficiency, and basketball-specific performance outcomes support the practical value of sport-specific HIIT protocols. The validation of the multi-modal assessment approach offers a useful tool for coaches and researchers seeking a comprehensive evaluation of training adaptations.

Acknowledgements

The authors express sincere appreciation to the student-athletes whose participation made this study possible. Gratitude is also extended to the faculty members and administrative staff of the participating institutions for their consistent support and assistance during the research process. The efforts of the research assistants and data collection team are also acknowledged, as their contribution was essential to the successful completion of this study.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Ramirez-Campillo R, García-Hermoso A, Moran J, Chaabene H, Negra Y, Scanlan AT. The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. *Journal of Sport and Health Science*, 2022;11(6): 656–670. https://doi.org/10.1016/j.jshs.2020.12.005
2. Stojanović E, Stojiljković N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanović Z. The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Medicine*, 2018;48(1): 111–135. https://doi.org/10.1007/s40279-017-0794-z
3. Cao S, Liu J, Wang Z, Geok SK. The effects of functional training on physical fitness and skill-related performance among basketball players: a systematic review. *Frontiers in Physiology*, 2024;15: 1391394. https://doi.org/10.3389/fphys.2024.1391394
4. Ferioli D, Schelling X, Bosio A, La Torre A, Rucco D, Rampinini E. Match Activities in Basketball Games: Comparison Between Different Competitive Levels. *Journal of Strength and Conditioning Research*, 2020;34(1): 172–182. https://doi.org/10.1519/JSC.0000000000003039
5. Huynh P, Guadagnino S, Zendler J, Agresta C. Physical demands of collegiate basketball practice: a preliminary report on novel methods and metrics. *Frontiers in Sports and Active Living*, 2024;6: 1324650. https://doi.org/10.3389/fspor.2024.1324650
6. Gamonales JM, Hernández-Beltrán V, Escudero-Tena A, Ibáñez SJ. Analysis of the External and Internal Load in Professional Basketball Players. *Sports*, 2023;11(10): 195. https://doi.org/10.3390/sports11100195
7. Gottlieb R, Shalom A, Calleja-Gonzalez J. Physiology of Basketball – Field Tests. Review Article. *Journal of Human Kinetics*, 2021;77: 159–167. https://doi.org/10.2478/hukin-2021-0018
8. López-Sierra P, Jiménez-Sáiz SL, García-Rubio J, Piñar MI, Ibáñez SJ. Study of the Load During Official Competition in Professional Women's Basketball – A Case Study. *Sports*, 2025;13(2): 59. https://doi.org/10.3390/sports13020059
9. Cabarkapa D, Krsman D, Cabarkapa DV, Philipp NM, Fry AC. Physical and Performance Characteristics of 3×3 Professional Male Basketball Players. *Sports*, 2023;11(1): 17. https://doi.org/10.3390/sports11010017
10. Conte D, Lukonaitiene I, Matulaitis K, Snieckus A, Kniubaite A, Kreivyte R, et al. Recreational 3 × 3 basketball elicits higher heart rate, enjoyment, and physical activity intensities but lower blood lactate and perceived exertion compared to HIIT in active young adults. *Biology of Sport*, 2023;40(3): 889–898. https://doi.org/10.5114/biolsport.2023.122478
11. Tuttle MC, Power CJ, Dalbo VJ, Scanlan AT. Intensity Zones and Intensity Thresholds Used to Quantify External Load in Competitive Basketball: A Systematic Review. *Sports Medicine*, 2024;54(10): 2571–2596. https://doi.org/10.1007/s40279-024-02058-5
12. Yang K. Quarterly fluctuations in external and internal loads among professional basketball players. *Frontiers in Physiology*, 2024;15: 1419097. https://doi.org/10.3389/fphys.2024.1419097

13. Cao S, Li Z, Wang Z, Geok SK, Liu J. The Effects of High-Intensity Interval Training on Basketball Players: A Systematic Review and Meta-Analysis. *Journal of Sports Science and Medicine*, 2024; 31–51. https://doi.org/10.52082/jssm.2025.31
14. Chen L, Zhang Z, Qu W, Huang W, Sun J, Duan X, et al. Effects of blood flow restriction moderate intensity interval training on aerobic and anaerobic capabilities and lower extremity performance in male college basketball players. *BMC Sports Science, Medicine and Rehabilitation*, 2025;17(1): 44. https://doi.org/10.1186/s13102-025-01100-x
15. Shiraz S, Salimei C, Aracri M, Di Lorenzo C, Farsetti P, Parisi A, et al. The Effects of High-Intensity Interval Training on Cognitive and Physical Skills in Basketball and Soccer Players. *Journal of Functional Morphology and Kinesiology*, 2024;9(3): 112. https://doi.org/10.3390/jfmk9030112
16. Stankovic M, Djordjevic D, Trajkovic N, Milanovic Z. Effects of High-Intensity Interval Training (HIIT) on Physical Performance in Female Team Sports: A Systematic Review. *Sports Medicine - Open*, 2023;9(1): 78. https://doi.org/10.1186/s40798-023-00623-2
17. Zeng J, Xu J, Xu Y, Zhou W, Xu F. Effects of 4-week small-sided games vs. high-intensity interval training with changes of direction in female collegiate basketball players. *International Journal of Sports Science & Coaching*, 2022;17(2): 366–375. https://doi.org/10.1177/17479541211032739
18. Torres-Unda J, Zarrazquin I, Gravina L, Zubero J, Seco J, Gil SM, et al. Basketball Performance Is Related to Maturity and Relative Age in Elite Adolescent Players. *Journal of Strength and Conditioning Research*, 2016;30(5): 1325–1332. https://doi.org/10.1519/JSC.0000000000001224
19. Gasperi L, Sansone P, Gómez-Ruano MÁ, Lukonaitienė I, Conte D. Female basketball game performance is influenced by menstrual cycle phase, age, perceived demands and game-related contextual factors. *Journal of Sports Sciences*, 2025;43(1): 117–124. https://doi.org/10.1080/02640414.2023.2285119
20. Julian R, Hecksteden A, Fullagar HHK, Meyer T. The effects of menstrual cycle phase on physical performance in female soccer players. Lucía A (ed.) *PLOS ONE*, 2017;12(3): e0173951. https://doi.org/10.1371/journal.pone.0173951
21. Stojanović E, Ristić V, McMaster DT, Milanović Z. Effect of Plyometric Training on Vertical Jump Performance in Female Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, 2017;47(5): 975–986. https://doi.org/10.1007/s40279-016-0634-6
22. Pechlivanos RG, Amiridis IG, Anastasiadis N, Kannas T, Sahinis C, Duchateau J, et al. Effects of plyometric training techniques on vertical jump performance of basketball players. *European Journal of Sport Science*, 2024;24(6): 682–692. https://doi.org/10.1002/ejsc.12097
23. Shimizu T, Tsuchiya Y, Ueda H, Izumi S, Ochi E. Eight-Week Flywheel Training Enhances Jump Performance and Stretch-Shortening Cycle Function in Collegiate Basketball Players. *European Journal of Sport Science*, 2025;25(2): e12257. https://doi.org/10.1002/ejsc.12257
24. Cherni Y, Mzita I, Oranchuk DJ, Dhahbi W, Hammami M, Ceylan HI, et al. Effects of loaded vs unloaded plyometric training combined with change-of-direction sprints on neuromuscular performance in elite U-18 female basketball players: a randomized controlled study. *Sport Sciences for Health*, 2025. https://doi.org/10.1007/s11332-025-01498-4
25. Svilar L, Jukić I. Load monitoring system in top-level basketball team: relationship between external and internal training load. *Kinesiology*, 2018;50(1): 25–33. https://doi.org/10.26582/k.50.1.4
26. Berkelmans DM, Dalbo VJ, Fox JL, Stanton R, Kean CO, Giamarelos KE, et al. Influence of Different Methods to Determine Maximum Heart Rate on Training Load Outcomes in Basketball Players. *Journal of Strength and Conditioning Research*, 2018;32(11): 3177–3185. https://doi.org/10.1519/JSC.0000000000002291
27. Fox JL, Stanton R, Scanlan AT. A Comparison of Training and Competition Demands in Semiprofessional Male Basketball Players. *Research Quarterly for Exercise and Sport*, 2018;89(1): 103–111. https://doi.org/10.1080/02701367.2017.1410693
28. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training Adaptation and Heart Rate Variability in Elite Endurance Athletes: Opening the Door to Effective Monitoring. *Sports Medicine*, 2013;43(9): 773–781. https://doi.org/10.1007/s40279-013-0071-8
29. Altinel R, Kilic-Erkek O, Kilic-Toprak E, Ozhan B, Yildirim A, Bor-Kucukatay M. HIIT serves as an efficient training strategy for basketball players by improving blood fluidity and decreasing oxidative stress. *Biorheology*, 2024;59(3–4): 81–96. https://doi.org/10.3233/BIR-230024
30. Viramontes E, Dawes JJ, Coburn JW, Lockie RG. Strength Training Frequency and Athletic Performance in High School Girls Basketball Players. *Journal of Human Kinetics*, 2024;91: 19–31. https://doi.org/10.5114/jhk/184042
31. Delextrat A, Gruet M, Bieuzen F. Effects of Small-Sided Games and High-Intensity Interval Training on Aerobic and Repeated Sprint Performance and Peripheral Muscle Oxygenation Changes in Elite Junior Basketball Players. *Journal of Strength and Conditioning Research*, 2018;32(7): 1882–1891. https://doi.org/10.1519/JSC.0000000000002570
32. Huang T, Liang Z, Wang K, Miao X, Zheng L. Novel insights into athlete physical recovery concerning lactate metabolism, lactate clearance and fatigue monitoring: A comprehensive review. *Frontiers in Physiology*, 2025;16: 1459717. https://doi.org/10.3389/fphys.2025.1459717
33. Katoch R, Farooque S, Dhar K, Das PK. Effectiveness of two different recovery process on blood lactate removal pattern of soccer players. *Pedagogy of Physical Culture and Sports*, 2025;29(1): 62–67. https://doi.org/10.15561/26649837.2025.0107
34. Maan KS, Yadav RC. Comparative evaluation of recovery interventions – individually and in combination – on lactate clearance and

physical performance metrics following 3 versus 3 basketball matches. *Journal of Bodywork and Movement Therapies*, 2025;42: 431–440. https://doi.org/10.1016/j.jbmt.2025.01.022

35. Arede J, Ferreira AP, Gonzalo-Skok O, Leite N. Maturational Development as a Key Aspect in Physiological Performance and National-Team Selection in Elite Male Basketball Players. *International Journal of Sports Physiology and Performance*, 2019;14(7): 902–910. https://doi.org/10.1123/ijspp.2018-0681
36. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, Kushner A, Myer GD. Integrative Neuromuscular Training in Youth Athletes. Part II: Strategies to Prevent Injuries and Improve Performance. *Strength & Conditioning Journal*, 2016;38(4): 9–27. https://doi.org/10.1519/SSC.0000000000000234
37. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. *JAMA*, 2013;310(20): 2191. https://doi.org/10.1001/jama.2013.281053
38. Inglis EC, Rasica L, Iannetta D, Sales KM, Keir DA, MacInnis MJ, et al. Exercise training-induced speeding of $${\dot{\text{V}}\text{O}}_{{2}}$$ kinetics is not intensity domain-specific or correlated with indices of exercise performance. *European Journal of Applied Physiology*, 2025;125(5): 1297–1310. https://doi.org/10.1007/s00421-024-05674-1
39. Yuan Y, Soh KG, Qi F, Bashir M, Zhao N. Effects of high-intensity interval training on selected indicators of physical fitness among male team-sport athletes: A systematic review and meta-analysis. Akaras E (ed.) *PLOS ONE*, 2024;19(11): e0310955. https://doi.org/10.1371/journal.pone.0310955
40. Castagna C, Impellizzeri FM, Rampinini E, D'Ottavio S, Manzi V. The Yo–Yo intermittent recovery test in basketball players. *Journal of Science and Medicine in Sport*, 2008;11(2): 202–208. https://doi.org/10.1016/j.jsams.2007.02.013
41. Matthew D, Delextrat A. Heart rate, blood lactate concentration, and time–motion analysis of female basketball players during competition. *Journal of Sports Sciences*, 2009;27(8): 813–821. https://doi.org/10.1080/02640410902926420
42. Xie H, Mao X, Wang Z. Effect of high-intensity interval training and moderate-intensity continuous training on blood lactate clearance after high-intensity test in adult men. *Frontiers in Physiology*, 2024;15: 1451464. https://doi.org/10.3389/fphys.2024.1451464
43. Li Y, Zhao W, Yang Q. Effects of high-intensity interval training and moderate-intensity continuous training on mitochondrial dynamics in human skeletal muscle. *Frontiers in Physiology*, 2025;16: 1554222. https://doi.org/10.3389/fphys.2025.1554222
44. Turner AN, Jeffreys I. The Stretch-Shortening Cycle: Proposed Mechanisms and Methods for Enhancement. *Strength & Conditioning Journal*, 2010;32(4): 87–99. https://doi.org/10.1519/SSC.0b013e3181e928f9
45. McCormick BT, Hannon JC, Newton M, Shultz B, Detling N, Young WB. The Effects of Frontal- and Sagittal-Plane Plyometrics on Change-of-Direction Speed and Power in Adolescent Female Basketball Players. *International Journal of Sports Physiology and Performance*, 2016;11(1): 102–107. https://doi.org/10.1123/ijspp.2015-0058
46. Ben Abdelkrim N, El Fazaa S, El Ati J. Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *British Journal of Sports Medicine*, 2007;41(2): 69–75. https://doi.org/10.1136/bjsm.2006.032318
47. Markovic G, Mikulic P. Neuro-Musculoskeletal and Performance Adaptations to Lower-Extremity Plyometric Training: *Sports Medicine*, 2010;40(10): 859–895. https://doi.org/10.2165/11318370-000000000-00000
48. Okazaki VHA, Rodacki ALF, Satern MN. A review on the basketball jump shot. *Sports Biomechanics*, 2015;14(2): 190–205. https://doi.org/10.1080/14763141.2015.1052541
49. Ziv G, Lidor R. Vertical jump in female and male basketball players—A review of observational and experimental studies. *Journal of Science and Medicine in Sport*, 2010;13(3): 332–339. https://doi.org/10.1016/j.jsams.2009.02.009
50. Agel J, Olson DE, Dick R, Arendt EA, Marshall SW, Sikka RS. Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42(2):202–10.
51. Montgomery PG, Pyne DB, Minahan CL. The Physical and Physiological Demands of Basketball Training and Competition. *International Journal of Sports Physiology and Performance*, 2010;5(1): 75–86. https://doi.org/10.1123/ijspp.5.1.75
52. Apostolidis N, Nassis GP, Bolatoglou T, Geladas ND. Physiological and technical characteristics of elite young basketball players. *J Sports Med Phys Fitness*. 2004;44(2):157–63.
53. Chaouachi A, Castagna C, Chtara M, Brughelli M, Turki O, Galy O, et al. Effect of Warm-Ups Involving Static or Dynamic Stretching on Agility, Sprinting, and Jumping Performance in Trained Individuals. *Journal of Strength and Conditioning Research*, 2010;24(8): 2001–2011. https://doi.org/10.1519/JSC.0b013e3181aeb181
54. Bompa TO, Buzzichelli CA. *Periodization: Theory and Methodology of Training*.. 1st edn Human Kinetics; 2019. https://doi.org/10.5040/9781718225435
55. Saha S, Obhrai S, Vishwakarma R, Mondal P, Nagesh, Prasad B, et al. Clarifying the Impact of Small-Sided Games and HIIT on Anaerobic Endurance in Adolescent Hockey Players. *Physical Education Theory and Methodology*, 2025;25(3): 660–667. https://doi.org/10.17309/tmfv.2025.3.23
56. Choudhary PK, Choudhary S, Saha S, Karmakar D, Singh Rajpoot Y, Sharma A, et al. The transformative impact of high-intensity interval training on performance indicators among adolescent tennis players. *Retos*, 2025;69: 799–810. https://doi.org/10.47197/retos.v69.114111

Information about the authors:

Yajuvendra Singh Rajpoot; Associate Professor; https://orcid.org/0000-0002-0331-705X; yajupitu25@gmail.com; Department of Sports Management and Coaching, Lakshmibai National Institute of Physical Education; Gwalior, India.

Prashant Kumar Choudhary; Assistant Professor; https://orcid.org/0000-0001-6163-8065; prashantlnipe2014@gmail.com; Department of Physical Education Pedagogy, Lakshmibai National Institute of Physical Education; Gwalior, India.

Suchishrava Choudhary; PhD; https://orcid.org/0000-0001-7491-5404; suchishrava05@gmail.com; Lakshmibai National Institute of Physical Education; Gwalior, India.

Sohom Saha; PhD; https://orcid.org/0009-0006-9438-1554; sohomsaha77@gmail.com; Department of Sports Psychology, Lakshmibai National Institute of Physical Education; Gwalior, India.

Vasile-Cătălin Ciocan; (Corresponding Aurthors); Professor; https://orcid.org/0000-0003-4357-0882; ciocan.catalin@ub.ro; Faculty of Movement, Sports, and Health Sciences, "Vasile Alecsandri" University of Bacău; Bacau, Romania.

Constantin Şufaru; Professor; https://orcid.org/0000-0001-8923-8653; sufaruconstantin@ub.ro; Faculty of Movement, Sports, and Health Sciences, "Vasile Alecsandri" University of Bacău; Bacau, Romania.

Voinea Nicolae-Lucian; Professor; https://orcid.org/0000-0002-7576-3497; lucian.voinea@ub.ro; Faculty of Movement, Sports, and Health Sciences, "Vasile Alecsandri" University of Bacău; Bacau, Romania.

Cite this article as:
Rajpoot YS, Choudhary PK, Choudhary S, Saha S, Ciocan V-C, Şufaru C, Nicolae-Lucian V. Physiological responses of female basketball players across graded training intensities: cardiovascular and respiratory adaptations. *Physical Education of Students,* 2025;29(5):353–363.
https://doi.org/10.15561/20755279.2025.0503

Received: 02.09.2025

Accepted: 08.10.2025; Published: 30.10.2025