applied sciences

MDPI

Review

Heart Rate Variability in Basketball: The Golden Nugget of Holistic Adaptation?

Rubén Portes Sánchez [1], Enrique Alonso-Pérez-Chao [2,3], Julio Calleja-González [4] and Sergio L. Jiménez Sáiz [5,*]

1 Valencia Basket Performance Department, Pabellón Fuente de San Luis, Avenida dels Germans Maristes 16, Quatre Carreres, 46013 Valencia, Spain; rubenportes@yahoo.es
2 Department of Physical Activity and Sports Science, University Alfonso X el Sabio, 28691 Madrid, Spain; ealonsoperezchao@gmail.com
3 Faculty of Sports Science, European University of Madrid, 28670 Villaviciosa de Odón, Spain
4 Department of Physical Education and Sports, Faculty of Education and Sport, University of the Basque Country, (UPV/EHU), 01007 Vitoria-Gasteiz, Spain; julio.calleja@ehu.eus
5 Sport Sciences Research Centre, Universidad Rey Juan Carlos, 28943 Madrid, Spain
* Correspondence: sergio.jimenez.saiz@urjc.es

Abstract: The main aim of this narrative review is to assess the existing body of scientific literature on heart rate variability (HRV) in relation to basketball, focusing on its use as a measure of internal load and vagal nerve responses. Monitoring HRV offers insights into the autonomic function and training-induced adaptations of basketball players. Various HRV measurement protocols, ranging from short-term to longer durations, can be conducted in different positions and conditions, such as rest, training, and sleep, to determine this key metric. Consistency and individualization in measurement protocols, responding to the athlete's specific characteristics, is crucial for reliable HRV data and their interpretation. Studies on HRV in basketball have explored psychological adaptation, training effects, individual differences, recovery, and sleep quality. Biofeedback techniques show positive effects on HRV and anxiety reduction, potentially enhancing performance and stress management. The scientific literature on HRV in basketball could benefit from studies involving longer monitoring periods to identify significant trends and results related to training and recovery. Longitudinal HRV monitoring in teams with intense travel schedules could reveal the impact on athletes of all levels and ages, and, in this regard, individualized interpretation, considering the subjective recovery and fitness levels of athletes, is recommended to optimize training programs and performance. HRV provides insights into training and competitive loads, aiding in determining exercise intensities and training status. Additionally, HRV is linked to recovery and sleep quality, offering valuable information for optimizing player performance and well-being. Overall, HRV is a reliable tool for adjusting training programs to meet the specific needs of basketball players.

Keywords: HRV; basketball; recovery; adaptation; heart rate

check for updates

Citation: Sánchez, R.P.; Alonso-Pérez-Chao, E.; Calleja-González, J.; Jiménez Sáiz, S.L. Heart Rate Variability in Basketball: The Golden Nugget of Holistic Adaptation? *Appl. Sci.* **2024**, *14*, 10013. https://doi.org/10.3390/app142110013

Academic Editors: Dana Badau, Adela Badau and Philip X. Fuchs

Received: 25 August 2024
Revised: 14 October 2024
Accepted: 21 October 2024
Published: 2 November 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Heart rate variability (HRV) measures the fluctuation in time intervals between heartbeats [1] and is associated with adaptability and resilience. Therefore, high HRV can enhance executive function performance [2]. In particular, a 5 min HRV measurement at rest effectively interprets responses to training [3]. In fact, sympathetic activity increases heart rate (HR), while parasympathetic activity decreases it (Figure 1), leading to psychophysiological changes in HRV [2]. After exercise, the autonomic nervous system (ANS) shifts towards sympathetic activity to manage training stress, reducing parasympathetic activity and HRV [4]. Consequently, monitoring HRV can effectively determine the crucial balance between these two ANS responses [5]. In this regard, circadian variations in metabolism, sleep cycles, and body temperature affect HRV measurements [6]. Specifically,

changes in athletes' ANS patterns can alter HRV patterns [7], aiding training professionals in managing fatigue and adjusting the exercise intensity [7], thus enabling dynamic periodization [8].

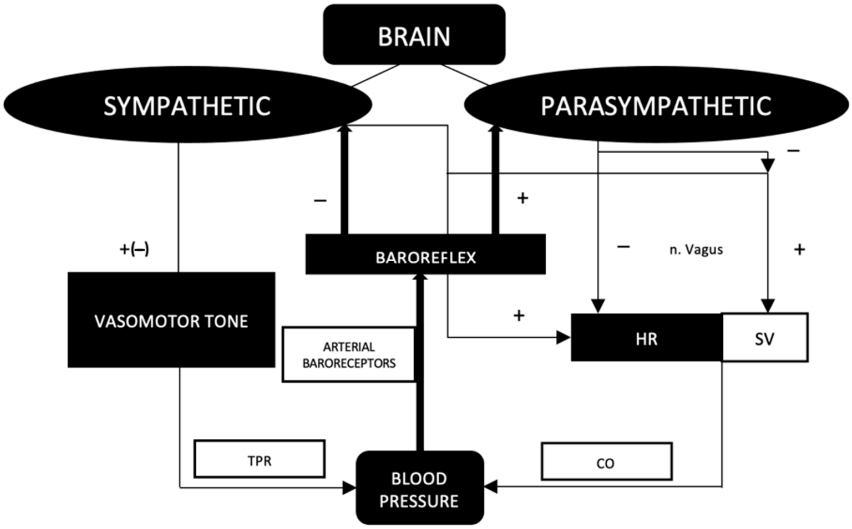


Figure 1. Adapted from (Aubert, 2003) [2]. BP = blood pressure; CO = cardiac output; HR = heart rate; n. vagus = nervus vagus; SV = stroke volume; TPR = total peripheral resistance.

HRV monitoring has gained significant interest in team sports for reflecting changes in the autonomic function and training adaptations during the competitive season [9]. In basketball [10], a sport characterized by high-intensity efforts [11], HRV is crucial for managing executive functions during practice and competition [12], considering that effective basketball training aims to improve the physical and physiological condition of athletes by accurately recording, interpreting, and adjusting training loads [13].

Concretely, load demands can be categorized as the external load (EL), related to the volume and intensity, and the internal load (IL), which is the athlete's physiological response to these demands [14]. Specifically, the IL measures can be classified as subjective (the athletes' mental interpretation of stress) and objective (the monitored physiological responses) [15]. Among them, HRV (an objective measure) is typically monitored using HR sensors, straps, watches, wristbands, or rings that register beat-to-beat timing [16], indicating how athletes adapt to training, and has gained attention due to technological advancements in data collection. As a consequence, consistent and validated protocols are essential for effective decision-making using these data [17].

The impact of physical activity on HRV is well documented in numerous team sports [18–28]. Previous studies have investigated the role of HRV on recovery and readiness and as a load indicator. For instance, Ayuso-Moreno et al. [18] found differences in the HRV of female soccer players before high-demand matches. On the other hand, D'ascenzi et al. [19] observed increased HRV in female volleyball players in the days leading up to competition. Conversely, Holguín-Ramírez et al. [21] found no effect of mindfulness training on the HRV of female soccer players. Laborde et al. [22] linked well-being to baseline HRV in female handball players. Móra et al. [23] found decreased HRV after psychological stress in soccer players, suggesting strategies to enhance athletic performance. In another study, centered on field sport, Parrado et al. [25] identified a negative correlation between perceived tiredness and HRV. Finally, Ke-Tien et al. [29] found correlations between POMS questionnaires and HRV in rugby players. In summary, the variability in studies highlights the need for specificity and contextualization when interpreting HRV data across different athlete groups.

In a concrete way, to the best of the author's knowledge, research on HRV in basketball is limited. Current existing studies have mainly focused on HRV responses to basketball-specific stress activities [9,10,30–32] and physical tests [33–35], but no previous specific

reviews have been published on the outcomes of these studies. Therefore, this narrative review aims to examine the scientific literature on HRV in basketball to assess the evidence related to internal load and vagal nerve responses.

2. HRV Measurement Protocols in Basketball

Measurements of HRV in the basketball-related literature include short term measurements (ST, 5 min) [10,36–41], specific test and in-session measures [31,32,36,42], sleep measures [43,44], and ultra-short-term measures [30,45]. Messina et al. [37] measured the PSA of HRV through an electrocardiogram (ECG) for 5 min, analyzing the signal through an electrocardiograph connected to a PC (Personal Computer) at 100 s/s and analyzing the obtained data through specific software. In addition, Paul et al. [38] analyzed the role of biofeedback in training through the measurement of HRV in a seated position, with the participants seated on a chair with their eyes closed, while Moreno et al. [39] measured ACB (Spain's First League) players over the same time duration but in a different body position; in this case, the participants were resting in a supine position for the measurement, a protocol that the same author later used for a posterior study with LEB Gold (Spain's Second Division) players [40]. Khan et al. [46] used the same time frame (5 min) to measure the HRV of collegiate players, but in this case, the measurements were recorded during an incremental running protocol, as well as after the test. García-Ceberino et al. [33] studied the HRV in a younger population (U-16), with a protocol of 5 min in a seated position before and after competition. The 5 min protocol can be placed within the short-term group of HRV measurements [6], which are the product of two processes: (a) mainly concerns the complex and dynamic relationship between the sympathetic and parasympathetic branches, while (b) relates to the regulatory mechanisms that control HR via respiratory sinus arrythmia (RSA) and the baroreceptor reflex and rhythmic changes in the vascular tone [47]. Longer periods of recording provide information about cardiac variations in response to a wider variety of environmental and stress factors [6], such as training load variations produced by conditioning tests or training sessions.

Longer durations of measurement were utilized by Morales et al. [34] in a study where participants were assessed in an orthostatic position for 10 min, both before and after a vertical jump assessment. Similarly, Abad et al. [35] employed the same duration to investigate the effects of sub-maximal tests and a Yo-Yo IR1 test on participants positioned in a resting posture, as outlined by the authors, to gather HR data. In another study focusing on workload effects, Ramos-Campo et al. [36] conducted an incremental test to volitional fatigue while simultaneously recording gas-exchange measurements and the HRV of the subjects during the tests. Additionally, Nakamura et al. [9] utilized 10 min measurements in a seated position, before and after practice, to examine the impact of training sessions. Piedra et al. [42], Zamora et al. [32], and Jin et al. [10] collected HRV measurements of amateur basketball players during training sessions and specific ball drills (5 vs. 5) to assess their response to training. Moreover, García et al. [33] and Senbel at el. [44] analyzed HRV measurements obtained during sleep, using wearable devices to understand the variations influenced by factors affecting sleep quality. Regarding ultra-short-term measures, Lukonaitiene et al. [30] studied female under-18 and under-20 players before a European championship, using a 90 seconds morning measurement in a seated position.

In conclusion, various protocols have been used in basketball studies, with different results found. Nevertheless, to ensure the validity and applicability of the results obtained when monitoring the heart rate responses within a group of athletes, consistency in measurement protocols is needed for the reliability and subsequent interpretation of the results obtained.

3. Impact of HRV on Fatigue and Recovery

Recovery is an essential component of any training program, facilitating the body's adaptation and enhancement. An athlete's ability to recover is influenced by various factors, the foremost among them being fatigue [48,49]. Fatigue is defined as a suboptimal

psychophysiological state, encompassing mental and physical mechanisms, concurrent to physical exertion [15].

Multiple factors contribute to fatigue, including glycogen depletion, muscle damage, action potential interruption, and excitation–contraction coupling failure [50–52]. These factors, resulting from basketball activity, can impede a player's capacity to maintain high-intensity activity levels during games [51]. Additionally, since exercise performance is centrally regulated by the central nervous system (CNS), fatigue should no longer be perceived solely as a physical event. Instead, it should be seen as a sensation or emotion, distinct from any overt physical manifestation, such as the reduction in the force output of active muscles [53]. Physical activity is controlled by a central governor in the brain, with the human body operating as a complex system during exercise. Using feed-forward control in response to afferent feedback from various physiological systems, the extent of skeletal muscle recruitment is modulated as part of a pacing strategy. The sensation of fatigue represents the conscious interpretation of these homoeostatic central governor control mechanisms [52]. Given that studying muscle fatigue in isolation, without CNS control [52], is unlikely to advance the understanding of this phenomenon, HRV emerges as a measure that can effectively monitor an athlete's recovery and fatigue levels [50].

The autonomic nervous system regulates numerous physiological processes, including heart rate, respiration, and blood pressure [6]. HRV serves as an indirect gauge of autonomic nervous system activity, with higher HRV indicating a healthier and more adaptable nervous system. Therefore, HRV is invaluable in monitoring an athlete's fatigue level [17]. A decrease in HRV could be a sign of fatigue in the athlete, also signifying reduced activity in the parasympathetic nervous system, which is responsible for rest and recovery [50,54]. Conversely, an increase in HRV suggests that the parasympathetic nervous system is more active when an athlete is well rested. A low HRV in an athlete may signal the need for a training break or adjustments to the training program to allow adequate recovery time [55]. Consequently, HRV serves as a valuable tool in monitoring an athlete's recovery and fatigue levels. By tracking HRV, athletes and their coaches can make well-informed decisions regarding training and recovery strategies [10,50,56]. Future studies on recovery should consider these variables in other basketball populations.

4. Discussion of the Present Evidence

This narrative review aimed to explore the scientific literature on HRV in basketball to assess the evidence related to internal load and vagal nerve responses. The main conclusions described that HRV provides insights into training and competitive loads, aiding in determining exercise intensities and training status. Additionally, HRV is linked to recovery and sleep quality, offering valuable information for optimizing player performance and well-being. Overall, HRV is a reliable tool for adjusting training programs to meet the specific needs of basketball players. A summary of the main investigations can be seen in Table 1.

Many diverse coaching strategies should be adapted by players, and, consequently, performance coaches must adapt to these. The monitorization and interpretation of HRV in basketball can provide these professionals with a comprehensive and holistic understanding of the shift from vagal to sympathetic cardiac modulation [7]. This insight allows coaches to tailor workloads and rest periods to better match the individual needs of each player.

Given the nature of basketball as a high-intensity intermittent physical activity, which is highly dependent on both the aerobic and anaerobic components [57], preparation for these actions and the recovery [58] from exposure to them seems crucial to a well-developed training program. In this sense, studies related to HRV in basketball have aimed for different goals and objectives, as previously mentioned in this review, but the main and overall interest seems to be the different and specific branches or components that this variable can provide to interpret a holistic adaptation to the training process [59,60].

One of these specific branches of adaptation is the psychological one [37,61], where studies investigated the subjective or emotional status of an athlete to find out its impact

on HRV. Authors found that biofeedback had a positive effect on HRV by a reduction in both the trait and state anxiety, probably due to the stimulation of baroreflexes through the regulation of breathing, which occurred due to specific HRV biofeedback [37]. Results showed a reduction in the reaction and movement time after biofeedback training, as was confirmed by another study about the effect of biofeedback on HRV [61]. It is possible that these results are due to a greater balance between the sympathetic and parasympathetic systems. However, additional evidence related to these protocols is needed to confirm their efficacy for a broader spectrum of the population. These findings are of high relevance to practitioners who want to improve specific athlete training programs related to situations of high stress, resembling competition, as the high levels of arousal that are produced during competitive events could lead to a performance reduction [62]. Thus, by improving the control of these variables, performance could be positively affected. Paced breathing could help athletes to cope with stress through the production of high-amplitude oscillations in the cardiovascular system. In addition, this will help maintain focus and improve decision-making during these specific moments, characteristic of competition [60]. The addition of psychological measures could also help to interpret HRV measures and vice versa in elite basketball players [38]. This could bring a more holistic approach to psychophysiological measures and our understanding of the training process by considering the intangible load affecting the players through the psychological taxation of travel or team results. Further studies are required to gather more evidence regarding this topic.

Training adaptation has also gathered interest through the HRV-related studies in basketball. Physical activity seems to have a positive impact in basketball players, as female professional basketball players seemed to improve their parasympathetic activity through basketball training compared to a sedentary group [36]. Although these results might be specific, since gender, age, and athletic conditioning influence an athlete's autonomic control [7], it is confirmed that team-based athletic activities induce parasympathetic modulation [63], therefore improving HRV in athletes involved in such activities. Maximum jumps seem to reduce HRV and 5′ seems to be a resting time that can onset the vagal tone in elite basketball players [33]. This could also be confirmation of the cardiac flexibility of highly trained participants, a fact that could affect the considerations for recovery in these populations [64,65].

Although there are some common considerations regarding the monitoring of HRV, the personalization of the monitoring process seems to be recommended for athletes; in particular, professional basketball players seem to present significant differences between individuals regarding subjective recovery and HRV data [39]. For example, HRV measures in basketball players are related to the subjects' athletic fitness [66] and can be influenced by the intensity, duration, and content of the exercise intervention [40], which suggests the need for personalization in the interpretation of heart rate-derived data. On account of this, the implementation of both subjective and objective methods in the evaluation of recovery will bring more individualized results to practitioners. Female basketball players have shown disparities in subjective well-being measures and HRV monitoring data, with both of these methods recommended to determine player status [30]. These principles could also be applied when monitoring stress in basketball players, as a multivariable model seems to be more desirable to determine the effect of the stress imposed during training periods, even at the amateur level [36].

Table 1. Summary of the studies analyzed regarding HRV in basketball.

Title	Journal	Year/Quartil	Authors	Participants/ Level	Methodology	Dependent Variables	Methodological Procedures	Results	Conclusions	Practical Applications	Study Strengths	Study Limitations
The Effect of Heart Rate Variability Biofeedback on Performance Psychology of Basketball Players	Applied Psychophysiology biofeedback	2012	Paul & Garg [38]	17 M and 13 F Different levels of competition (university, state, national)	Experimental double-blind	HRV	HRV, RR analyzed with BFB software	Variation anxiety/time significant ($F = 66.503$, p\0.001).	HRV improves with biofeedback training	Biofeedback training → > performance "zone of excellence"	Placebo group, inclusion male/female	Small sample group
Enhanced parasympathetic activity of sportive women is paradoxically associated to enhanced resting energy expenditure	Basic & Clinical neuroscience	2012/Q3	Messina et al. [37]	20 F/10 Sedentary & 10 Professional	Observational retrospective	PSA of HRV (LF, HF, LF/HF)	HRV evaluated through electrocardiogram during 5′	Significant differences between groups on HF of HRV	Increases of parasympathetic activity at rest induced by training	Basketball does not modify the sympathetic discharge as no changes were observed in LF in this population	Number of physiological measures included in the study	No performance results included in study, limited age range of the sample
Role of biofeedback in optimizing psychomotor performance in sports	Asian Journal of Sport Medicine	2012/Q4	Paul et al. [61]	16 M & 14 F/University, State, National level (China)	Experimental double blind	HRV, RR, LF, HF, Concentration (60 seconds), Choice Reaction Time, Movement Time, Shooting (number shots in 90″)	HRV (5′ seated with closed eyes on a chair)	Significant variation in HRV in both groups	Changes in HRV are sensitive to emotional state	Biofeedback helps regulate HRV and positively impacts physiological and psychological states of the athlete	Inclusion of placebo group	Small sample size
Heart Rate Variability and Psychophysiological Profiles in High-Performance Team Sports	Revista de Psicología del Deporte	2013/Q3	Moreno et al. [39]	53 M (14 basketball players)/ACB (Spain), Grass Hockey, Football	Observational retrospective and descriptive	HRV, POMS	HRV measured 5′ resting in supine position	Basketball and grass hockey players present higher HRV than football players	POMS and HRV variables together could be used to determine psychophysiological profiles in elite athletes	Addition of psychological measures to HRV interpretation could help on the understanding of both parameters	Elite level and number of the subjects selected for the study	Only one evaluation of the selected athletes
Heart Rate Variability Responses in Vertical Jump Performance of Basketball Players	International Journal of Sports Science	2014/Q3	Morales et al. [34]	8 M/National Basketball League (Brazil)	Observational, retrospective, and descriptive	HRV & VJ	HRV (10′ standing orthostatic position before and after the vertical jump assessment)	Relationships VJ Symp-Parasymp modulation	Sympathetic modulation (LF; LF: HF) = 5VJ test> 60SVJ protocol. 5′rest ≠ onset of vagal tone→ higher fatigue	>5′ rest for onset of vagal tone	Sample playing level, comparison of external and internal measures	Results related only to high training load

Table 1. *Cont.*

Title	Journal	Year/Quartil	Authors	Participants/ Level	Methodology	Dependent Variables	Methodological Procedures	Results	Conclusions	Practical Applications	Study Strengths	Study Limitations
Individual Recovery Profiles in Basketball Players	Spanish Journal of Psychology	2015/Q3	Moreno et al. [40]	6 M/LEB Oro (Spain)	Experimental, retrospective descriptive	HRV & Subjective Recovery	TQart (6-20) & HRV (5′ in supine lying)	Significant differences between subjects	No consistent relationship between TQart & HRV	Individual recovery profiles are recommended	Objective/ subjective measurements	Interdisciplinary perspective
Heart rate and heart rate variability of Yo-Yo IR1 and simulated match in young female basketball athletes: A comparative study	International Journal of Performance Analysis in Sport	2016/Q3	Abad et al. [35]	15 F (Voluntary participants 3–4 years of playing experience)	Quantitative, descriptive, and comparative study	Yo-Yo IR1, Submaximal efforts (SM), HRmax & HRV	HRV measured in resting condition for 10´ (last 5´only registered for the measurement) after the Yo-Yo IR1 and the SM tests	Small effect size of HR yo-yo IR1 & SM (177 ± 9 and 173 ± 10 beats.min^{-1}; ES = 0.2)	SM > HRmax, Yo-Yo IR1 < HRV	Specificity of stimulus to enhance players performance	Stableness, related to fatigue and fitness levels, of the sample	Long term adaptations not studied
Heart Rate Variability to Assess Ventilatory Thresholds in Professional Basketball Players	Journal of Sport and Health Science	2017/Q1	Ramos-Campo et al. [36]	24 M/ACB league (Spain)	Experimental, descriptive, and comparative	HRV & VTs (1&2)	Incremental test to exhaustion collecting gas exchange (breath by breath analysis) and HR (R-R intervals)	VT1 = Speed>HRV VT2 = No differences VO2/HR/Speed	HRV→ VT2 estimation	HRV→ exercise intensity	Objective and qualitative data collection	Small group of subjects, specific timing < applicability
Adequacy of the Ultra-Short-Term HRV to Assess Adaptive Processes in Youth Female Basketball Players	Journal of Human Kinetics	2017/Q3	Nakamura et al. [67]	17 F/Brazil State U-17 & U-19	Observational, retrospective and descriptive	HRV (1nRMSSD)	HRV pre and post training 10´ in seated position	Agreement of 1nRMSSD between ultra-short term 1′ and criterion 5′ measures	1nRMSSD→ 2´ measurement protocol (1st minute discarded)	Ultra-short-term HRV measure responds to training→ simplifies adaptation monitoring	Validation of ultra-short-1nRMSSD measures	Isolated 1nRMSSD Measures
Non-invasive assessment of internal and external player load: implications for optimizing athletic performance	The Journal of Strength and Conditioning Research	2018/Q1	Heishman et al. [68]	10 M/NCAA (USA)	Retrospective analysis	HRV, TRIMP, PL	HRV measured in supine position with by mobile app	All performance indicators improved with higher CNS readiness values	Lower training loads correlate with higher physical performance indicators	Non-invasive strategies can effectively monitor internal and external stress	Technology utilized, inclusion of internal and external load measures	Period of measurement affects interpretation of PL and consequent results derived from it

Table 1. *Cont.*

Title	Journal	Year/Quartil	Authors	Participants/ Level	Methodology	Dependent Variables	Methodological Procedures	Results	Conclusions	Practical Applications	Study Strengths	Study Limitations
Investigating the workload, readiness and physical performance changes during intensified 3-week preparation periods in female national Under18 and Under20 basketball teams	Journal of Sport Sciences	2020/Q2	Lukonaitienė et al. [45]	24 F/U18 & U20 Lithuanian league	Observational, retrospective and descriptive	PL, TRIMP, sRPE-TL, HRV, 20mSprt, CMJ, Yo-Yo IRT1	HRV 90″ morning measurement in seated position	Differences between groups in all variables (workload, readiness, WB)	Short overload and taper periods → <HRV during short and intensified training periods	Adopting constant and adequate workload→ >HRV values in short and intensified training periods	Level of competition of sample, measures during official competition	Tests limited to physical qualities, different time-lapse of players exposure
Investigation of readiness and perceived workload in junior female basketball players during a congested match schedule	Biology of Sport	2021/Q1	Lukonaitienė et al. [30]	24 F/U18 & U20 Lituanian national teams (European national tournaments)	Observational, retrospective and descriptive	HRV, sRPE, WB, Match Performance (box score)	HRV 90″ morning measurement in seated position	Significant between-day differences in all variables	HRV (constant)≠ WB (decreased) during tournament	Objective & subjective methods→ determine player status	Level of competition of sample, measures during official competition	No objective external load measures or internal biochemical markers
Internal and External Load Control in Team Sports through a Multivariable Model	Journal of Sport Science and Medicine	2021/Q2	Piedra et al. [42]	10 M/EBA League (Spain)	Observational, retrospective and descriptive	HRV (RMSSD), CMJ, SHRZ, RPE, Total Acc. & Dec.	HRV obtained during the session	Physiological markers related to the onset of neuromuscular physiological fatigue	Multivariable model seems to be reliable for the measurement of physiological stress on this level	Applying internal and external load variables to the monitoring process increases reliability of decision making based on the data obtained	The objective multivariable approach of the study	Specific competition context, small sample
Heart Rate Variability and Accelerometry: Workload Control Management in Men's Basketball	Apunts	2021/Q2	Zamora et al. [32]	12 M/Copa Catalunya (Spain)	Observational, retrospective and descriptive	IL(HRV), EL(Acc-Dec)	10 sessions HRV 10 sessions Acc-Dec	Causation correlation between RR mean & EL, % SHRZ and specificity of exercises	IL correlations with EL	Predictability of load variables registering one of them	Measurements of IL & EL of specific drills	Different time recordings of IL and El

Table 1. *Cont.*

Title	Journal	Year/Quartil	Authors	Participants/ Level	Methodology	Dependent Variables	Methodological Procedures	Results	Conclusions	Practical Applications	Study Strengths	Study Limitations
Effects of visual search task on attentional bias and stress response under pressure	WORK	2021	Jin et al. [69]	62 M/ Shenyang Sports Institute, State and National level (China)	Experimental double blind	HRV (TP, VLF, LF, HF, LF/HF)	HRV recorded during a selective attention test	No significant differences in HRV before and after training	VST improved AB of the subjects	VST monitored through HRV can help improve athletes' decision making	Large sample, physiological-psychological measures included	No follow up measures for the athletes
Intermittent pneumatic compression changes heart rate recovery and heart rate variability after short term submaximal exercise in collegiate basketball players: a cross-over study	Sport Sciences for Health	2021/Q4	Khan et al. [46]	16 M/ Collegiate level (India)	Randomized cross-over experimental design	HR, HRV & IPC	5′ HRV protocol HR incremental running test protocol IPC therapy 15′ after (5′) incremental test	No significant differences found between pre and post IPC group in session one to pre and post IPC group in session two, respectively, for all measures of HRV	IPC = effective o lowering HR in 1st min of recovery & + effect on HRV	IPC→ + effects on recovery	Two group intervention	Small sample size, no sympathetic activity measures
A validation study of heart variability index in monitoring basketball training load	Frontiers In Physiology	2022/Q1	Jin et al. [10]	10 M/ Collegiate level (China)	Observational within-subjects	HRV(TLHRV), TRIMP, RPE, Speed & Distance	All variables recorded during 5 half-court ball-drills	Significant TL differences between the five drills	TLHRV valid objective TL measure	Usage of TLHRV as valid tool for training adaptation	Measurement based on specific ball drills	No biochemical indicators, validity of TLHRV
Impact of Basketball Match on the Pre-Competitive Anxiety and HRV of Youth Female Players	IJERPH	2022/Q2	Garcia-Ceberino et al. [33]	12 F/U-16 (Spain)	Cross sectional study	HRV	5′ HRV seated protocol measurement pre and post competition was followed	<HRV post-competition → baseline & pre-competition	No > of pre-competitive anxiety, No change in HRV or cognitive-somatic anxiety between baseline and pre-match measures, <HRV after match	Monitoring of variables can bring <anxiety & >joy→ competition→ -<sport quitting in young females	Exploring effects of pre- and post-competition	Small sample size

Table 1. *Cont.*

Title	Journal	Year/Quartil	Authors	Participants/ Level	Methodology	Dependent Variables	Methodological Procedures	Results	Conclusions	Practical Applications	Study Strengths	Study Limitations
Sports training to detect heart rate and body temperature in teenagers	Revista Brasileira Medicina de Esporte	2022/Q4	Pan, Song, & Pan [41]	12 M	Experimental and comparative	HRV	5′ of ECG measurements	Changes in HRV and body temperature post-exercise vs. pre-exercise	Physical function training can improve HRV	HRV responds to subjects' age, exercise intervention time, exercise intervention intensity, exercise intervention amount, and exercise content and items	Reliable technology used to determine results, longitudinal measurements	Playing level of subjects, small sample size
Recovery of the physiological status in professional basketball players using NESA neuro-modulation treatment during different types of microcycles in season: A preliminary randomized clinical trial	Frontiers in Physiology	2022/Q1	García et al. [43]	12 M/LEB Plata (Spain)	Randomized Clinical trial	HRV (RMSSD)	OURA (During sleep measurements)	No significant differences were found between one game or two games per week	Players who underwent NNT protocol tended to improve their sleep quality	Non-invasive protocols like NNT can be implemented to improve players sleep and therefore overall recovery	First study to be conducted with NESA	Small sample size, 2 days of data collection, only player response variables
Impact of Sleep and Training on Game Performance and Injury in Division-1 Women's Basketball Amidst the Pandemic	IEEE Access	2022/Q1	Senbel et al. [44]	16 F/Collegiate level NCAA (USA)	Observational, retrospective and descriptive	HRV, sRPE, perception questionaries, game performance	WHOOP Strap during sleep measuring of HRV	Lower than recommended sleep averages of the subjects	Team averages RHR and fluctuations in HRV could be reflective of the stress placed on the subjects during the measuring period	A compressed competition schedule and irregularities in training schedule might increase injury rate in collegiate players	Multivariable approach to the study to determine injury prediction model	Limited number of subjects in the study and specific applicability due to their specific characteristics

Studies have also analyzed the effect of conditioning tests on HRV by comparing simulated basketball games to Yo-Yo IR1; during the former, players seemed to have a higher cardiac autonomic depression and showed the ability to reach max heart rate, while during the latter, they seemed to have a higher cardiac autonomic response [34]. In elite professional players, the responses could be different than in other populations due to the higher demand of the efforts performed during competitive activity and the physical capacity of the participants. In this sense, an incremental test performed on elite basketball players confirmed that HRV can identify exercise-intensity differences between lower and higher sympathetic activity [37], which could simplify the determination of exercise intensities without the use of expensive equipment to determine these parameters.

HRV can also provide valuable information regarding competitive and training loads. Some studies investigating different playing levels have analyzed and monitored internal loads, through HRV, and external loads to determine the impact of these variables; non-invasive methods of measuring internal (including HRV) and external loads were able to determine the training status in collegiate basketball players [68], again validating the use of HRV for the evaluation of player status in this population. Regarding the vagal regulation of HR related to training loads, basketball players could benefit from lower loads, related to lower training volumes during training periods, to improve performance indicators [68]. If we refer to specific, short training periods, overload and taper periods seem to decrease HRV in young female basketballers, while a constant load seems to improve it [45]. Novel measures regarding HRV and its response to training adaptations have been validated by authors in recent years to update the practitioners' toolbox, with TL_{HRV} having shown reliability in interpreting the adaptation of basketball players to the training stimulus [32].

HRV has also been shown to bring valuable information regarding the recovery and sleep quality of basketball players, who, at least at the collegiate level, seem to show lower than recommended sleep levels, especially during compressed competition schedules [44]. Using non-invasive monitoring technology, neuromodulation technology has also shown promising results regarding the improvement of sleep and therefore in the recovery of basketball players involved in competitive schedules [43]. Overall, HRV seems to be related to the adaptations and recovery of basketball players, and, therefore, could be used as a reliable tool to monitor a player's physical status, reflecting information that may allow coaching staff to adapt training programs to the demands needed by a specific group of players.

5. Practical Applications

The HRV approach offers valuable potential applications for basketball practitioners. These include monitoring the training load and recovery, assessing stress and recovery during competition, and potentially predicting the performance and injury risk in basketball players. Additionally, the practical applications of HRV should be aligned with contextual variables, such as the individual needs, individual stress tolerance, objectives, stage of the season, age, sex, number of games per week, and team resources [70]. Hence, when choosing the practical applications of HRV in basketball players, it is crucial to consider the context in which the measurements are taken and tailor the interpretation and use of these measurements accordingly [50].

5.1. Monitoring Training Load and Recovery

One practical application of HRV in basketball players is monitoring their training load and recovery. By measuring HRV, coaches and basketball practitioners can assess the athlete's physiological readiness for training and adjust the training loads accordingly [5,71]. For instance, Jin et al. [10] showed that HRV during different basketball drills (1v1, 1v2, 3v3, 4v4, and 5v5) gradually decreased as the number of athletes in each group increased. Thus, fewer players on the court correlated with a higher HRV between athletes during drills [10]. This trend may be attributed to the impact of player numbers on the physical demands of basketball. Such demands stimulate the parasympathetic nerves to innervate

the arteries and myocardium by releasing acetylcholine, prompting corresponding and adaptive physiological changes [10]. Consequently, having fewer players on the court affords each player more opportunities to engage with the ball, leading to an increase in the individual physical contacts, technical actions, and relative court area per player. These factors alter the physical requirements of the exercise.

5.2. Assessing Stress and Recovery During Competition

In recent years, the demands of modern sport have led to an increase in the number of competitions and games, resulting in more congested schedules and frequent travel [72,73]. This can negatively impact an athlete's readiness to train and compete, as it can disrupt their sleep patterns, increase fatigue, and contribute to an overtraining status [73]. To mitigate these effects, individualization in the interpretation of HRV data is crucial during load management in competition, given the many characteristics that an athlete may respond to. Establishing an individual baseline for HRV readings and combining HRV data with other indicators can help coaches and athletes optimize competitive performance. Once a baseline has been established, HRV readings can be used to monitor the athlete's recovery status and adjust their training load accordingly. For example, if an athlete's HRV readings are consistently low, it may indicate that they are not fully recovered from their previous training session or competition, and that their training load may need to be reduced.

In this regard, if a player presents high HRV values, it is important to detect the main reason for this and implement various recovery strategies to help them maintain optimal performance. Therefore, it is essential to capitalize on this opportunity by implementing proper sleep hygiene practices [74], training, hydration [75], and nutrition [76,77] and to use different recovery strategies, such as foam rolling [78,79], yoga [80], massage therapy [81,82], cold water immersion [83] or cryotherapy [58,83], compression garments [58], active recovery exercises or low-intensity cardio exercise [58], nutritional supplements [65,76], or joint mobilization [84] to help the player optimize their performance.

5.3. Predicting Performance and Injury Risk

A key determinant for successful teams in basketball is limiting the number of injuries sustained by players and the subsequent sideline time [85]. Basketball performance should be assessed from a holistic approach and consider more than just isolated variables to better understand the players' performance during basketball competition [86].

Monitoring HRV can be an efficient and cost-effective way to gather valuable information about an athlete's physical readiness for training and competition. Compared to other methods of assessing an athlete's physiological state, such as laboratory testing, monitoring HRV requires minimal resources in terms of time and money. With the use of wearable technology and smartphone applications (e.g., HRV4training or Elite HRV), HRV monitoring can be completed quickly and easily, making it a practical solution for basketball practitioners. Despite its simplicity, HRV has been shown to be a valuable tool for assessing the athlete's physiological state and predicting their readiness to perform [53,55]. HRV monitoring can help coaches and trainers identify athletes who are not coping with the stress they are being exposed to and, consequently, athletes who are at risk of underperforming or present a higher risk of injury, all while investing minimal resources. Some key findings regarding HRV should be considered as follows:

- A multivariable approach incorporating subjective and objective internal, as well as external, load measures, appears advisable for interpreting HRV data in basketball players.
- Biofeedback emerges as a viable tool for regulating HRV and associated performance markers in basketball players.
- The addition of psychological insights into HRV interpretation can offer valuable context to the data. Personalizing the interpretation of HRV data is recommended, due to the diverse responses athletes may exhibit.

- TL_{HRV} could serve as a useful tool for monitoring the training load and adaptation in basketball players.
- HRV analysis can aid in assessing the holistic adaptation of athletes to training programs or their recovery from the effects of the program.
- Protocols for HRV measurement are sensitive to changes in the measurement process, which can compromise data reliability.
- Consistency in the measurement process and protocol is crucial for validating the collected data.
- Considering the context in which the measurements are taken, and tailoring the interpretation and use of data accordingly, is crucial.

6. Future Directions

The scientific literature regarding HRV in basketball could benefit from studies with longer monitoring periods to illustrate the significant changes, trends, and outcomes of vagally mediated heart rate measures associated with training and recovery. Additionally, the utilization of longitudinal HRV monitoring in teams subjected to intense travel schedules could provide insights into the impact of these performance constraints on athletes of all levels and ages. Such research efforts would deepen our understanding of the interplay between HRV, training, recovery, and the demands of competitive basketball, leading to the creation of more effective strategies for enhancing athlete performance and well-being.

7. Conclusions

The monitoring and interpretation of HRV in basketball offers valuable insights for coaches and trainers. HRV can assist in adjusting workloads and rest periods to optimize performance. Training adaptation in basketball enhances parasympathetic activity and impacts HRV, underscoring the importance of individualized monitoring due to variations in subjective recovery and fitness levels. Therefore, HRV emerges as a reliable tool for monitoring a player's physical status and can inform the development of tailored training programs for basketball players. Nevertheless, an athlete's health and readiness should always be interpreted together with other variables of internal and external load to ensure a more solid consideration of the athlete's overall status.

Author Contributions: R.P.S. conceived and designed the investigation, reviewed, and collected the present evidence. E.A.-P.-C. contributed with writing and the design of the article. J.C.-G. and S.L.J.S. drafted the paper and critically reviewed and approved the final version submitted for publication. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Mccraty, R.; Shaffer, F. Heart rate variability: New perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. *Glob. Adv. Health Med.* **2015**, *4*, 46–61. [CrossRef] [PubMed]
2. Aubert, A.E.; Seps, B.; Beckers, F. Heart Rate Variability in Athletes. *Sports Med.* **2003**, *33*, 889–919. [CrossRef] [PubMed]
3. Buchheit, M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front. Physiol.* **2014**, *5*, 73. [CrossRef] [PubMed]
4. Leti, T.; Bricout, V.A. Interest of analyses of heart rate variability in the prevention of fatigue states in senior runners. *Auton. Neurosci.* **2013**, *173*, 14–21. [CrossRef]
5. Schmitt, L.; Regnard, J.; Millet, G.P. Monitoring fatigue status with HRV measures in elite athletes: An avenue beyond RMSSD? *Front. Physiol.* **2015**, *6*, 343. [CrossRef]
6. Shaffer, F.; Ginsberg, J.P. An Overview of Heart Rate Variability Metrics and Norms. *Front. Public Health* **2017**, *5*, 258. [CrossRef]
7. Dong, J.G. The role of heart rate variability in sports physiology (Review). *Exp. Ther. Med.* **2016**, *11*, 1531–1536. [CrossRef]
8. Mateo-March, M.; Moya-Ramón, M.; Javaloyes, A.; Sánchez-Muñoz, C.; Clemente-Suárez, V.J. Validity of detrended fluctuation analysis of heart rate variability to determine intensity thresholds in elite cyclists. *Eur. J. Sport Sci.* **2022**, *23*, 580–587. [CrossRef]

9. Nakamura, F.Y.; Flatt, A.A.; Pereira, L.A.; Ramirez-Campillo, R.; Loturco, I.; Esco, M.R. Ultra-Short-Term Heart Rate Variability is Sensitive to Training Effects in Team Sports Players. *J. Sports Sci. Med.* **2015**, *14*, 602–605.
10. Jin, N.; Tian, J.; Li, Y.; Mi, J. A Validation Study of Heart Rate Variability Index in Monitoring Basketball Training Load. *Front. Physiol.* **2022**, *13*, 881927. [CrossRef]
11. Drinkwater, E.J.; Pyne, D.B.; McKenna, M.J. Design and Interpretation of Anthropometric and Fitness Testing of Basketball Players. *Sports Med.* **2008**, *38*, 565–578. [CrossRef] [PubMed]
12. Petway, A.J.; Freitas, T.T.; Calleja-González, J.; Leal, D.M.; Alcaraz, P.E. Training load and match-play demands in basketball based on competition level: A systematic review. *PLoS ONE* **2020**, *15*, e0229212. [CrossRef] [PubMed]
13. Fox, J.L.; Scanlan, A.T.; Stanton, R. A Review of Player Monitoring Approaches in Basketball: Current Trends and Future Directions. *J. Strength Cond. Res.* **2017**, *31*, 2021–2029. [CrossRef] [PubMed]
14. McLaren, S.J.; Macpherson, T.W.; Coutts, A.J.; Hurst, C.; Spears, I.R.; Weston, M. The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. *Sports Med.* **2018**, *48*, 641–658. [CrossRef] [PubMed]
15. Halson, S.L. Monitoring training load to understand fatigue in athletes. *Sports Med.* **2014**, *44* (Suppl. S2), 139–147. [CrossRef]
16. Stone, J.D.; Ulman, H.K.; Tran, K.; Thompson, A.G.; Halter, M.D.; Ramadan, J.H.; Stephenson, M.; Finomore, V.S.; Galster, S.M.; Rezai, A.R.; et al. Assessing the Accuracy of Popular Commercial Technologies That Measure Resting Heart Rate and Heart Rate Variability. *Front. Sports Act. Living* **2021**, *3*, 37. [CrossRef]
17. Mosley, E.; Laborde, S. A scoping review of heart rate variability in sport and exercise psychology. *Int. Rev. Sport Exerc. Psychol.* **2022**, 1–75. [CrossRef]
18. Ayuso-Moreno, R.; Fuentes-García, J.P.; Collado-Mateo, D.; Villafaina, S. Heart rate variability and pre-competitive anxiety according to the demanding level of the match in female soccer athletes. *Physiol. Behav.* **2020**, *222*, 112926. [CrossRef]
19. D'Ascenzi, F.; Alvino, F.; Natali, B.M.; Cameli, M.; Palmitesta, P.; Boschetti, G.; Bonifazi, M.; Mondillo, S. Precompetitive assessment of heart rate variability in elite female athletes during play offs. *Clin. Physiol. Funct. Imaging* **2013**, *34*, 230–236. [CrossRef]
20. Gantois, P.; Ferreira, M.E.C.; de Lima-Junior, D.; Nakamura, F.Y.; Batista, G.R.; Fonseca, F.S.; Fortes, L.d.S. Effects of mental fatigue on passing decision-making performance in professional soccer athletes. *Eur. J. Sport Sci.* **2020**, *20*, 534–543. [CrossRef]
21. Holguín-Ramírez, J.; Ramos-Jiménez, A.; Quezada-Chacón, J.T.; Cervantes-Borunda, M.S.; Hernández-Torres, R.P. Effect of Mind-fulness on the Stress–Recovery Balance in Professional Soccer Players during the Competitive Season. *Sustainability* **2020**, *12*, 7091. [CrossRef]
22. Laborde, S.; Brüll, A.; Weber, J.; Anders, L.S. Trait emotional intelligence in sports: A protective role against stress through heart rate variability? *Personal. Individ. Differ.* **2011**, *1*, 23–27. [CrossRef]
23. Móra, Á.; Komka, Z.; Végh, J.; Farkas, I.; Kocsisné, G.S.; Bosnyák, E.; Szmodis, M.; Ligetvári, R.; Csöndör, É.; Almási, G.; et al. Comparison of the Cardiovascular Effects of Extreme Psychological and Physical Stress Tests in Male Soccer Players. *Int. J. Environ. Res. Public Health* **2022**, *19*, 715. [CrossRef] [PubMed]
24. Morales, J.; Roman, V.; Yáñez, A.; Solana-Tramunt, M.; Álamo, J.; Fíguls, A. Physiological and Psychological Changes at the End of the Soccer Season in Elite Female Athletes. *J. Hum. Kinet.* **2019**, *66*, 99–109. [CrossRef]
25. Parrado, E.; Cervantes, J.; Pintanel, M.; Rodas, G.; Capdevila, L. Perceived tiredness and heart rate variability in relation to overload during a field hockey world cup. *Percept. Mot. Ski.* **2010**, *110*, 699–713. [CrossRef]
26. Perry, J.; Hansen, A.; Ross, M.; Montgomery, T.; Weinstock, J. Effectiveness of Athletes' Mental Strategies in Maintaining High Heart Rate Variability: Utility of a Brief Athlete-Specific Stress Assessment Protocol. *J. Clin. Sport Psychol.* **2019**, *13*, 41–55. [CrossRef]
27. Rusciano, A.; Corradini, G.; Stoianov, I. Neuroplus biofeedback improves attention, resilience, and injury prevention in elite soccer players. *Psychophysiology* **2017**, *54*, 916–926. [CrossRef]
28. Vaz, M.S.; Ribeiro, Y.S.; Pinheiro, E.S.; Del Vecchio, F.B. Psychophysiological profile and prediction equations for technical performance of football players. *Rev. Bras. Ciências Esporte* **2019**, *41*, 215–221. [CrossRef]
29. Ke-Tien, Y. Effects of Cardiovascular Endurance Training Periodization on Aerobic performance and Stress Modulation in Rugby Athletes. *Life Sci. J.* **2012**, *9*, 1218–1225.
30. Lukonaitienė, I.; Conte, D.; Paulauskas, H.; Pliauga, V.; Kreivytė, R.; Stanislovaitienė, J.; Kamandulis, S. Investigation of readiness and perceived workload in junior female basketball players during a congested match schedule. *Biol. Sport* **2021**, *38*, 341–349. [CrossRef]
31. Sansone, P.; Tessitore, A.; Paulauskas, H.; Lukonaitiene, I.; Tschan, H.; Pliauga, V.; Conte, D. Physical and physiological demands and hormonal responses in basketball small-sided games with different tactical tasks and training regimes. *J. Sci. Med. Sport* **2019**, *22*, 602–606. [CrossRef] [PubMed]
32. Zamora, V.; Capdevila, L.; Lalanza, J.F.; Caparrós, T. Heart rate variability and accelerometry: Workload control management in men's basketball. *Apunt. Educ. Fis. Y Deport.* **2021**, *143*, 44–51. [CrossRef]
33. García-Ceberino, J.M.; Fuentes-García, J.P.; Villafaina, S. Impact of Basketball Match on the Pre-Competitive Anxiety and HRV of Youth Female Players. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7894. [CrossRef] [PubMed]
34. Morales, A.P.; Sampaio-Jorge, F.; Rangel, L.D.C.; Coe1ho, G.M.O.; Leite, T.C.; Ribeiro, B.G. Heart Rate Variability Responses in Vertical Jump Performance of Basketball Players. *Int. J. Sports Sci.* **2014**, *4*, 72–78. [CrossRef]

35. Abad, C.C.C.; Pereira, L.A.; Kobal, R.; Kitamura, K.; Cruz, I.F.; Loturco, I.; Nakamura, F.Y. Heart rate and heart rate variability of Yo-Yo IR1 and simulated match in young female basketball athletes: A comparative study. *Int. J. Perform. Anal. Sport* **2016**, *16*, 776–791. [CrossRef]
36. Ramos-Campo, D.J.; Rubio-Arias, J.A.; Ávila-Gandía, V.; Marín-Pagán, C.; Luque, A.; Alcaraz, P.E. Heart rate variability to assess ventilatory thresholds in professional basketball players. *J. Sport Health Sci.* **2017**, *6*, 468–473. [CrossRef]
37. Messina, G.; Vicidomini, C.; Viggiano, A.; Tafuri, D.; Cozza, V.; Cibelli, G.; Devastato, A.; De Luca, B.; Monda, M. Enhanced parasympathetic activity of sportive women is paradoxically associated to enhanced resting energy expenditure. *Auton. Neurosci.* **2012**, *169*, 102–106. [CrossRef]
38. Paul, M.; Garg, K. The effect of heart rate variability biofeedback on performance psychology of basketball players. *Appl. Psychophysiol. Biofeedback* **2012**, *37*, 131–144. [CrossRef]
39. Moreno Sanchez, J.; Parrado Romero, E.; Capdevila Ortis, L. Heart Rate Variability and Psychophysiological Profiles in High-Performance Team Sports. *Rev. Psicol. Deporte* **2013**, *22*, 345–352.
40. Moreno, J.; Ramos-Castro, J.; Rodas, G.; Tarragó, J.R.; Capdevila, L. Individual recovery profiles in basketball players. *Span. J. Psychol.* **2015**, *18*, E24. [CrossRef]
41. Pan, X.; Song, M.; Pan, X. Sports training to detect heart rate and body temperature in teenagers. *Rev. Bras. Med. Esporte* **2022**, *28*, 830–833. [CrossRef]
42. Piedra, A.; Caparrós, T.; Vicens-Bordas, J.; Peña, J. Internal and external load control in team sports through a multivariable model. *J. Sports Sci. Med.* **2021**, *20*, 751–758. [CrossRef] [PubMed]
43. García, F.; Fernández, D.; Vázquez-Guerrero, J.; Font, R.; Moreno-Planas, B.; Álamo-Arce, D.; Medina-Ramírez, R.; Mallol-Soler, M. Recovery of the physiological status in professional basketball players using NESA neuromodulation treatment during different types of microcycles in season: A preliminary randomized clinical trial. *Front. Physiol.* **2022**, *13*, 1032020. [CrossRef] [PubMed]
44. Senbel, S.; Sharma, S.; Raval, M.S.; Taber, C.; Nolan, J.; Artan, N.S.; Ezzeddine, D.; Kaya, T. Impact of Sleep and Training on Game Performance and Injury in Division-1 Women's Basketball Amidst the Pandemic. *IEEE Access* **2022**, *10*, 15516–15527. [CrossRef]
45. Lukonaitienė, I.; Kamandulis, S.; Paulauskas, H.; Domeika, A.; Pliauga, V.; Kreivytė, R.; Stanislovaitienė, J.; Conte, D. Investigating the workload, readiness and physical performance changes during intensified 3-week preparation periods in female national Under18 and Under20 bas-ketball teams. *J. Sports Sci.* **2020**, *38*, 1018–1025. [CrossRef]
46. Khan, Z.; Ahmad, I.; Hussain, M.E. Intermittent pneumatic compression changes heart rate recovery and heart rate variability after short term submaximal exercise in collegiate basketball players: A cross-over study. *Sport Sci. Health* **2021**, *17*, 317–326. [CrossRef]
47. Schwartz, M.S.; Andrasik, F. (Eds.) *Biofeedback: A Practitioner's Guide*, 3rd ed.; The Guilford Press: New York, NY, USA, 2003. Available online: https://psycnet.apa.org/record/2004-00006-000 (accessed on 7 March 2023).
48. Edwards, T.; Spiteri, T.; Piggott, B.; Bonhotal, J.; Haff, G.G.; Joyce, C. Monitoring and Managing Fatigue in Basketball. *Sports* **2018**, *6*, 19. [CrossRef]
49. Phillips, R.O. A Review of Definitions of Fatigue—And a Step Towards a Whole Definition. *Transp. Res. Part F Traffic Psychol. Behav.* **2015**, *29*, 48–56. [CrossRef]
50. Noakes, T.D.; Gibson, A.S.C.; Lambert, E.V. From Catastrophe to Complexity: A Novel Model of Integrative Central Neural Regulation of Effort and Fatigue during Exercise in Humans: Summary and Conclusions. *Br. J. Sports Med.* **2005**, *39*, 120–124. [CrossRef]
51. Gibson, C.; Noakes, T.D. Evidence for Complex System Integration and Dynamic Neural Regulation of Skeletal Muscle Recruitment During Exercise in Humans. *Br. J. Sports Med.* **2004**, *38*, 797–806. [CrossRef]
52. Green, H.J. Mechanisms of muscle fatigue in intense exercise. *J. Sports Sci.* **1997**, *15*, 247–256. [CrossRef] [PubMed]
53. Tornero-Aguilera, J.F.; Jimenez-Morcillo, J.; Rubio-Zarapuz, A.; Clemente-Suárez, V.J. Central and Peripheral Fatigue in Physical Exercise Explained: A Narrative Review. *Int. J. Environ. Res. Public Health* **2022**, *19*, 3909. [CrossRef] [PubMed]
54. Billman, G.E.; Huikuri, H.V.; Sacha, J.; Trimmel, K. An introduction to heart rate variability: Methodological considerations and clinical applications. *Front. Physiol.* **2015**, *6*, 55. [CrossRef] [PubMed]
55. Sagarra-Romero, L.; Ruidiaz Peña, M.; Monroy Antón, A.; Calero Morales, S. Athlete Heart Rate Variability app: Knowing when to train. *Br. J. Sports Med.* **2017**, *51*, 1373–1374. [CrossRef]
56. Lucini, D.; Marchetti, I.; Spataro, A.; Malacarne, M.; Benzi, M.; Tamorri, S.; Sala, R.; Pagani, M. Heart rate variability to monitor performance in elite athletes: Criticalities and avoidable pitfalls. *Int. J. Cardiol.* **2017**, *240*, 307–312. [CrossRef]
57. McInnes, S.E.; Carlson, J.S.; Jones, C.J.; McKenna, M.J. The physiological load imposed on basketball players during competition. *J. Sports Sci.* **1995**, *13*, 387–397. [CrossRef]
58. Calleja-González, J.; Terrados, N.; Mielgo-Ayuso, J.; Delextrat, A.; Jukic, I.; Vaquera, A.; Torres, L.; Schelling, X.; Stojanovic, M.; Ostojic, S.M. Evidence-Based Post-Exercise Recovery Strategies in Basketball. *Physician Sportsmed.* **2016**, *44*, 74–78. [CrossRef]
59. Mercer, R.A.J.; Russell, J.L.; McGuigan, L.C.; Coutts, A.J.; Strack, D.S.; McLean, B.D. Understanding 'monitoring' data–the association between measured stressors and athlete responses within a holistic basketball performance framework. *PLoS ONE* **2022**, *17*, e0270409. [CrossRef]
60. Huyghe, T.; Alcaraz, P.E.; Calleja-González, J.; Bird, S.P. The underpinning factors of NBA game-play performance: A systematic review (2001–2020). *Physician Sportsmed.* **2021**, *50*, 94–122. [CrossRef]

61. Paul, M.; Garg, K.; Sandhu, J.S. Role of Biofeedback in Optimizing Psychomotor Performance in Sports. *Asian J. Sports Med.* **2012**, *3*, 29–40. [CrossRef]
62. Maxwell, J.; Masters, R.; Eves, F. From novice to no know-how: A longitudinal study of implicit motor learning. *J. Sports Sci.* **2000**, *18*, 111–120. [CrossRef] [PubMed]
63. Vanderlei, L.; Silva, R.; Pastre, C.; Azevedo, F.; Godoy, M. Comparison of the Polar S810i monitor and the ECG for the analysis of heart rate variability in the time and frequency domains. *Braz. J. Med. Biol. Res.* **2008**, *41*, 854–859. [CrossRef] [PubMed]
64. Espasa-Labrador, J.; Fort-Vanmeerhaeghe, A.; Montalvo, A.M.; Carrasco-Marginet, M.; Irurtia, A.; Calleja-González, J. Monitoring Internal Load in Women's Basketball via Subjective and Device-Based Methods: A Systematic Review. *Sensors* **2023**, *23*, 4447. [CrossRef] [PubMed]
65. Davis, J.K.; Oikawa, S.Y.; Halson, S.; Stephens, J.; O'riordan, S.; Luhrs, K.; Sopena, B.; Baker, L.B. In-Season Nutrition Strategies and Recovery Modalities to Enhance Recovery for Basketball Players: A Narrative Review. *Sports Med.* **2021**, *52*, 971–993. [CrossRef]
66. Hautala, A.; Tulppo, M.P.; Mäkikallio, T.H.; Laukkanen, R.; Nissilä, S.; Huikuri, H.V. Changes in cardiac autonomic regulation after prolonged maximal exercise. *Clin. Physiol. Funct. Imaging* **2001**, *21*, 238–245. [CrossRef]
67. Nakamura, F.Y.; Pereira, L.A.; Cal Abad, C.C.; Cruz, I.F.; Flatt, A.A.; Esco, M.R.; Loturco, I. Adequacy of the Ultra-Short-Term HRV to Assess Adaptive Processes in Youth Female Basketball Players. *J. Hum. Kinet.* **2017**, *56*, 73–80. [CrossRef]
68. Heishman, A.D.; Curtis, M.A.; Saliba, E.; Hornett, R.J.; Malin, S.K.; Weltman, A.L. Noninvasive assessment of internal and external player load: Implications for optimizing athletic performance. *J. Strength Cond. Res.* **2018**, *32*, 1280–1287. [CrossRef]
69. Jin, Y.; He, J. Effects of visual search task on attentional bias and stress response under pressure. *Work* **2021**, *69*, 687–696. [CrossRef]
70. Schneider, C.; Hanakam, F.; Wiewelhove, T.; Döweling, A.; Kellmann, M.; Meyer, T.; Pfeiffer, M.; Ferrauti, A. heart rate monitoring in team sports—A conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Front. Physiol.* **2018**, *9*, 639. [CrossRef]
71. Garrido, J.; López-Laval, I.; Hernando, D.; Garatachea, N.; Bailón, R. Relación entre la variabilidad del ritmo cardiaco y la fatiga en jugadores de baloncesto profesionales. In Proceedings of the Libro de Actas del XXXVI Congreso Anual de la Sociedad Española de Ingeniería Biomédica, Ciudad Real, Spain, 21–23 November 2018; pp. 97–100.
72. Huyghe, T.; Scanlan, A.T.; Dalbo, V.J.; Calleja-González, J. The Negative Influence of Air Travel on Health and Performance in the National Basketball Association: A Narrative Review. *Sports* **2018**, *6*, 89. [CrossRef]
73. Calleja-Gonzalez, J.; Marques-Jimenez, D.; Jones, M.; Huyghe, T.; Navarro, F.; Delextrat, A.; Jukic, I.; Ostojic, S.M.; Sampaio, J.E.; Schelling, X.; et al. What Are We Doing Wrong When Athletes Report Higher Levels of Fatigue from Traveling Than from Training or Competition? *Front. Psychol.* **2020**, *11*, 194. [CrossRef] [PubMed]
74. Fox, J.L.; Scanlan, A.T.; Stanton, R.; Sargent, C. Insufficient Sleep in Young Athletes? Causes, Consequences, and Potential Treatments. *Sports Med.* **2019**, *50*, 461–470. [CrossRef] [PubMed]
75. Díaz-Castro, F.; Astudillo, S.; Calleja-González, J.; Zbinden-Foncea, H.; Ramirez-Campillo, R.; Castro-Sepúlveda, M. Change in Marker of Hydration Correspond to Decrement in Lower Body Power Following Basketball Match. *Sci. Sports* **2018**, *33*, e123–e128. [CrossRef]
76. Escribano-Ott, I.; Calleja-González, J.; Mielgo-Ayuso, J. Ergo-Nutritional Intervention in Basketball: A Systematic Review. *Nutrients* **2022**, *14*, 638. [CrossRef]
77. Young, H.A.; Benton, D. Heart-rate variability: A biomarker to study the influence of nutrition on physiological and psychological health? *Behav. Pharmacol.* **2018**, *29*, 140–151. [CrossRef]
78. Cheatham, S.W.; Kolber, M.J.; Cain, M.; Lee, M. The Effects of Self Myofascial Release using Foam Roller massager on Joint Range of Motion, Muscle Recovery and Performance: A systematic review. *Int. J. Sports Phys. Ther.* **2015**, *10*, 827–838.
79. Wiewelhove, T.; Döweling, A.; Schneider, C.; Hottenrott, L.; Meyer, T.; Kellmann, M.; Pfeiffer, M.; Ferrauti, A. A Meta-Analysis of the Effects of Foam Rolling on Performance and Recovery. *Front. Physiol.* **2019**, *10*, 376. [CrossRef]
80. Kanojia, S.; Kumar Sharma, V.; Gandhi, A.; Kapoor, R.; Kukreja, A.; Kumar Subramanian, S. Effect of yoga on autonomic functions and psychological status during both phases of menstrual cycle in young healthy females. *J. Clin. Diagn. Res.* **2013**, *7*, 2133–2139.
81. Poppendieck, W.; Wegmann, M.; Ferrauti, A.; Kellmann, M.; Pfeiffer, M.; Meyer, T. Massage and Performance Recovery: A Me-ta-Analytical Review. *Sports Med.* **2016**, *46*, 183–204. [CrossRef]
82. Zainuddin, Z.; Newton, M.; Sacco, P.; Nosaka, K. Effects of massage on delayed-onset muscle soreness, swelling, and recovery of muscle function. *J. Athl. Train.* **2005**, *40*, 174–180.
83. Sánchez-Ureña, B.; Martínez-Guardado, I.; Crespo, C.; Timón, R.; Calleja-González, J.; Ibañez, S.J.; Olcina, G. The use of continuous vs. intermittent cold water immersion as a recovery method in basketball players after training: A randomized controlled trial. *Physician Sportsmed.* **2017**, *45*, 134–139. [CrossRef] [PubMed]
84. Calleja-González, J.; Mielgo-Ayuso, J.; Sampaio, J.; Delextrat, A.; Ostojic, S.M.; Marques-Jiménez, D.; Arratibel, I.; Sánchez-Ureña, B.; Dupont, G.; Schelling, X.; et al. Brief ideas about evi-dence-based recovery in team sports. *J. Exerc. Rehabil.* **2018**, *14*, 545–550. [CrossRef] [PubMed]

85. Caparrós, T.; Alentorn-Geli, E.; Myer, G.D.; Capdevila, L.; Samuelsson, K.; Hamilton, B.; Rodas, G. The Relationship of Practice Exposure and Injury Rate on Game Performance and Season Success in Professional Male Basketball. *J. Sports Sci. Med.* **2016**, *15*, 397. [PubMed]
86. Pérez-Chao, E.A.; Gómez, M.; Lisboa, P.; Trapero, J.; Jiménez, S.L.; Lorenzo, A. Fluctuations in External Peak Demands Across Quarters During Basketball Games. *Front. Physiol.* **2022**, *13*, 868009. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.