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Original article

Heart rate variability to assess ventilatory thresholds in professional basketball players

Domingo Jesús Ramos-Campo [a,*], Jacobo A. Rubio-Arias [a], Vicente Ávila-Gandía [b], Cristian Marín-Pagán [c], Antonio Luque [b], Pedro E. Alcaraz [a,c]

[a] *Department of Physical Activity and Sport Science, Faculty of Sports, Catholic University of Murcia, Murcia 30107, Spain*

[b] *Department of Physiology, Catholic University of Murcia, Murcia 30107, Spain*

[c] *UCAM Research Center for High Performance Sport, Murcia 30107, Spain*

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Abstract

Purpose: The aim of this study was to determine if heart rate variability (HRV) during incremental test could be used to estimate ventilatory threshold (VT) in professional basketball players, with sufficient precision to be used in their training. Furthermore, the second aim was to analyse the association between HRV and three methods of VT determination by gas analysis.

Methods: Twenty-four professional basketball players (age: 23.4 ± 4.9 years; height: 195.4 ± 9.8 cm; body mass: 92.2 ± 11.9 kg) performed an incremental running test to exhaustion. First ventilatory threshold (VT1) was determined by ventilatory equivalent (VE) and HRV and second ventilatory threshold (VT2) was determined by three methods of gases analysis (V-slope, VE and gas exchange ratio (R), and HRV). Pearson's coefficient (r) was used to detect differences between data and the strength of each relationship. The mean of absolute differences and Bland–Altman analysis were used to evaluate whether there was agreement.

Results: The results showed no significant differences in HR and oxygen consumption (VO_2) at VT1 between the two methods. Furthermore, no significant differences among the methods of gases analysis and HRV were observed in speed, HR, and VO_2 at VT2. Moreover, VTs estimated using HRV and gas methods were significantly correlated. Correlation was higher between R and HRV ($r = 0.96$) and VE and HRV ($r = 0.96$) than V-slope and HRV ($r = 0.90$).

Conclusion: These findings provide a practical, inexpensive approach for evaluating specific training loads when determining VT2 in basketball players. Therefore, HRV is an alternative method to determine VT2 without the application of expensive technology that limits its use to laboratories.

Keywords: Anaerobic threshold; Basketball; Oxygen uptake; Performance; Training; Ventilatory threshold

1. Introduction

Competitive basketball is an intermittent, high-intensity physical activity that requires a well-developed aerobic and anaerobic fitness.[1] The main actions are related to anaerobic ability; however, aerobic capacity plays a determinant role for recovery.[2] Specifically, a higher maximum oxygen uptake (VO_{2max}) improves the ability to recover from anaerobic actions,[3] where the anaerobic threshold (AT) is used as an indicator of endurance performance and stress.[4] Thus, determining the ventilatory thresholds (VTs) is essential for coaches and physical trainers because they can use these physiological points as a reference to establish individual training zones and to evaluate training interventions.[2,5]

AT is the work rate above which the oxidative metabolism does not provide for all the required energy, and the greater anaerobic contribution to energy production results in lactate accumulation in the blood.[6] Several methods have been proposed to determine AT, such as the onset of blood lactate accumulation, maximal lactate steady state, or second ventilatory threshold (VT2).[7] Respiratory compensation point is linked with VT2, as hyperpnoea is not sufficient to eliminate carbon dioxide (CO_2) metabolic production; thus, ventilation increases more markedly and is strongly related to AT.[6] Moreover, during a graded maximal exercise, there is a significant inflection point in ventilation known as the first ventilatory threshold (VT1),

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* Corresponding author.

E-mail address: domingojesusramos@gmail.com (D.J. Ramos-Campo)

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which is elicited by the increase in CO_2 metabolic production during hyperpnoea. The VT1 is related to the increased contribution of anaerobic metabolism and has been shown to be strongly related to AT.[6,7]

Although the ventilatory method is useful in determining VTs, the technology (i.e., gas analyser) is expensive and its use is limited to laboratories and specialized centres. For this reason, we decided to use the gold standard method (ventilatory equivalent, VE) to determine the VT2[8] in addition to gas exchange or V-slope that has been used in other studies. However, some studies suggest that heart rate variability (HRV) could be an alternative method for determining VTs.[8–10]

HRV is measured by the beat-to-beat variation in HR and time between each heartbeat.[11] This variance reflects the status of the neurocardiac function, which is regulated by the autonomic nervous system. Previous research suggests that VTs may also be under the same type of nervous system control.[9] The synchronization between the cardiac and respiratory rhythms modulates the respiratory sinus arrhythmia (RSA).

During exercise, the increase in exercise intensity produces a higher HR and lower HRV,[12] which may be due to an increment in sympathetic nervous activity and a decrease of vagal modulation to the heart.[13] The onset of intensity-induced blood lactate accumulation produces an increase in ventilation. Furthermore, the amplitude of RSA is proportional to ventilation at moderate-intensity exercise (60%–65% VO_{2max}).[14] Some researchers have found that the relationship between HRV and VT enables the detection of a similar threshold by examining changes in HRV during progressive exercise.[7,9,15–18] In fact, there appears a dominant frequency (dfHF) in the high-frequency range (HF) of the HRV spectrum, which corresponds to breathing rate. Therefore, HRV could be a reliable, non-invasive, and low-cost method of assessing VT. This HRV technique has been developed and validated using specific populations, primarily, endurance sports,[5,10,14–16,19] healthy people,[9] older people,[20] children,[7,21] and people with illness.[18] However, further research is needed to elucidate if HRV is a reliable and valid approach to measure VTs in professional athletes from sport teams. Thus, the purpose of this study was to determine if changes in HRV, during incremental VO_{2max} tests, could be used to reliably estimate VTs (VT1, VT2) in professional basketball players. This could lead to accurate determination of suitable workloads when designing a training program. The second aim of this study was to examine the relationship between HRV and the three methods used to determine VT, using gas analysis.

2. Methods

2.1. Participants

Twenty-four professional basketball players from the Association of Basketball Clubs (ACB) league participated in this study. All participants provided signed informed consent, which was approved by the Institutional Review Board of Catholic University of Murcia and in accordance with the Declaration of Helsinki, prior to their participation. Table 1 shows the descriptive data of the players.

Table 1
Descriptive data of the participants (mean ± SD).

Parameter	Value
Age (year)	23.4 ± 4.9
Height (cm)	195.4 ± 9.8
BM (kg)	92.2 ± 11.9
BMI (kg/m^2)	24.2 ± 1.9
VO_{2max} (mL/kg/min)	51.6 ± 6.2
HR_{max} (bpm)	187.3 ± 10.9

Abbreviations: BM = body mass; BMI = body mass index; VO_{2max} = maximal oxygen uptake; HR_{max} = maximal heart rate.

2.2. Protocol

The participants had trained and competed regularly in professional basketball teams, for at least 4 years, prior to the study. The participants refrained from ingesting caffeine and alcohol for a minimum of 12 h before testing. Furthermore, the participants performed their last exhaustive bout of training 48 h before the evaluation. The basketball players completed an incremental test to exhaustion on a treadmill (Run Med Technogym, Cessena, Italy) in standard environmental conditions, with the grade set at 1%.[22] The tests were performed between 10:00 a.m. and 12:00 p.m. in the laboratory with the room temperature set between 20°C and 22°C. During testing, gas exchange was measured using a breath-by-breath gas analyser (Metalyzer 3B; Cortex-medical, Leipzig, Germany), where oxygen consumption (VO_2), carbon dioxide production (VCO_2), and expired minute volume (VE) were continuously recorded and averaged every minute. The respiratory exchange ratio ($R = VCO_2/VO_2$), the oxygen ventilatory equivalent (VE/VO_2) and the carbon dioxide ventilator equivalent (VE/VCO_2) were calculated. The gas analyser system was calibrated before each test using the manufacturer's recommendations. Additionally, a Polar RS800CX HR monitor (Polar Electro, Kempele, Finland) was fitted around the chest and used to measure HR and record the R-R intervals (beat-to-beat fluctuation of HR) at a sampling frequency of 1 kHz.[7] After a 5-min warm-up at 7 km/h, the velocity was increased by 1 km/h every minute for optimal determination of the VTs.[23] The test was terminated when participants reached volitional fatigue. The end criteria was in accordance with the traditional physiological standards:[24] (1) occurrence of a plateau despite an increase in speed; (2) elevated blood lactate concentration (≥8 mmol/L); (3) elevated respiratory exchange ratio ($r \geq 1.0$); (4) elevated HR (≥90% of (220–age)); and (5) maximal perceived exertion. Verbal encouragement was given to ensure maximum physical effort.

2.3. Data collection and reduction

The VT1 was determined by VE and HRV, and VT2 was determined by three methods of gas analysis: VE, V-slope and gas exchange ratio (R), and HRV.

Inflection points over time were used to determine thresholds of the VE/VCO_2, VE/VO_2 and the VE. The second increase in VE with a concomitant rapid increase in VE/VO_2 and VE/VCO_2 was defined as VT2.[8] The VT1 was defined as the

first increase of VE/VO_2 *vs.* workload, without a simultaneous increase in VE/VCO_2 *vs.* workload.[8]

The VT2 was defined as the exercise intensity that brought about a disproportionate increase in excess CO_2 from steady state.[25] VT2 determination was assessed by gas exchange and defined when R (VCO_2/VO_2) was greater than 1.

Furthermore, the VT2 was defined as the exercise intensity in which the slope represented the increase in the minute production of CO_2 over the minute utilization of oxygen (VO_2) from less than 1 to greater than 1.[26] VT2 identification was determined using the V-slope method. This method was applied to the sampling frequency, used in breath-by-breath gas analysis, which was modified to display the 20-s gas collection averages.

All measurements of VT were made by visual inspection of graphs by two experienced exercise physiologists independently and in a blinded fashion. If the determinations of VT were not within a 3% agreement between investigators, a third trained researcher independently analyzed the same data to adjudicate the determination of VT. The adjudicated VT value was then compared with those of the initial determinations and averaged using the value within 3% of the initial measurement.

To determine VTs by HRV, all R-R interval data were exported from Polar Pro-Training v5 software (Polar Electro) and analysed using Kubios HRV analysis software (version 2.0 beta 4; University of Kuopio, Kuopio, Finland). All tachograms were examined to detect and correct artefacts (<2% of the analysed beats in the present study) before HRV analysis. The R-R intervals of each stage of 60-s were used to measure HRV. For determination of the first VT1 by HRV (HRVT1), the values of the instantaneous variability in the R-R intervals (SD1), from the Poincaré plot, were used. The HRVT1 was assessed in the first stage of exercise, in which the difference between the instantaneous variability in the R-R intervals (SD1), of two consecutive stages, was less than 1 ms and no longer changed significantly. Furthermore, the instantaneous HF power (HFp) trend, as a function of time and frequency over the entire exercise period, was calculated from R-R interval series using a time-varying short-term Fourier transform with 64-s moving window. VT2 was determined from HFp at the final abrupt increase in the HF band (HRVT2). HFp range was extended from resting recordings (>0.15–0.5 Hz to >0.15–2 Hz).[15] Workload speed in HRVT1 and HRVT2 was obtained for further analysis and to attain HR and VO_2 in these physiological points.

Two independent researchers determined the thresholds using HRV analysis. When there was a greater disagreement of 3%, a third experienced investigator was involved in the process. The methodology used was similar to those made with VTs, assessed by gas exchange.

2.4. Statistical analysis

Statistical analysis was carried out using the statistical package SPSS version 21.0 (IBM SPSS Inc., Chicago, IL, USA) and XLstat for Windows (Addinsoft, New York, NY, USA). The Gaussian distribution for the data was verified by the Kolmogorov–Smirnov goodness-of-fit test (Z value < 1.0). HR, VO_2, and speed were the variables analysed in each technique. The relationships were initially assessed by Pearson's coefficient correlation (r). The magnitude of the correlations was assessed according to Hopkins et al.[27] Agreement between the methods was then determined by calculating the difference between the HRV method and the gas analysis methods tested. Furthermore, the means of absolute differences were compared to zero. Finally, Bland–Altman pairwise comparisons[28] were used to evaluate whether there was an agreement or bias between the VT2 and VT1. This was determined from respiratory measurements (reference technique) and HRV spectral analyses. Differences between the HRV and gas analysis methods were also tested with a paired t test. All data were reported as mean ± SD and statistical significance was set at $p < 0.05$.

3. Results

All the tests performed in the study were considered maximum tests because the physiological criteria, explained in the methodology section, were met. The basketball players obtained 51.6 ± 6.2 mL/kg/min of VO_{2max} and 187.3 ± 10.9 bpm of maximum HR. The time of the test was 12 min 19 s ± 2 min 4 s and the R value at VO_{2max} was 1.13 ± 0.20.

3.1. VT1

There were no significant differences between the VO_2 (mL/kg/min) and HR (beats/min), corresponding to VT1 calculated by gas analysis and HRV methods (Tables 2 and 3). However, speed (km/h) was significantly higher with inflection when compared to the HRV method.

Significant correlations between HRV technique and gas analysis method ($r = 0.54$ in VO_2; $r = 0.57$ in HR; $r = 0.47$ in speed) were observed (Table 3). Fig. 1 illustrates the Bland–Altman analysis of the HRVT1 method and the VT1 gas analysis method. There was minimal bias, with the majority of differences remaining in the 95% confidence interval (95% CI).

3.2. VT2

There were no significant differences between the VO_2, HR and speed, corresponding to VT2, calculated by gas analysis

Table 2
Comparison in VO_2, heart rate and speed between HRV and gas analysis methods (mean ± SD).

	VO_2 (mL/kg/min)	Heart rate (bpm)	Speed (km/h)
$Th1_{inflection}$	30.6 ± 4.5	142.5 ± 9.4	9.6 ± 1.2
HRVT1	29.2 ± 3.5	140.1 ± 10.5	8.7 ± 0.7*
$Th2_{V\text{-}slope}$	45.4 ± 7.6	173.5 ± 10.9	14.4 ± 2.4
$Th2_{VE}$	45.4 ± 6.7	173.8 ± 10.1	14.3 ± 1.8
$Th2_{R}$	45.3 ± 6.1	173.9 ± 9.7	14.3 ± 1.8
HRVT2	45.7 ± 6.3	175.1 ± 11.5	14.3 ± 1.6

* $p < 0.005$, HRV *vs.* $VO_{2inflection}$.
Abbreviations: Th = threshold; V-slope = slope trends; VE = ventilatory equivalent; R = gas exchange ratio; HRVT = threshold determined by heart rate variability; Th1 = aerobic threshold; Th2 = anaerobic threshold; VO_2 = oxygen consumption.

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Table 3
Correlations and mean of absolute differences at Th1 and Th2 between HRV technique and gas analysis methods of VO_2, heart rate and speed (mean ± SD).

	VO_2 (mL/kg/min)				Heart rate (bpm)				Speed (km/h)			
	Agreement	*r*	*p*	MH	Agreement	*r*	*p*	MH	Agreement	*r*	*p*	MH
$Th1_{VE}$ *vs.* HRVT1	1.4 ± 3.9	0.54	0.016	L	2.4 ± 4.3	0.57	0.011	L	0.9 ± 1.0*	0.47	0.039	M
$Th2_{V\text{-}slope}$ *vs.* HRVT2	−0.3 ± 3.2	0.91	0.0001	NP	−1.5 ± 4.9	0.90	0.0001	NP	0.1 ± 1.0	0.93	0.0001	NP
$Th2_{VE}$ *vs.* HRVT2	−0.3 ± 2.3	0.94	0.0001	NP	−1.2 ± 3.5	0.96	0.0001	NP	−0.1 ± 0.6	0.92	0.0001	NP
$Th2_{R}$ *vs.* HRVT2	−0.5 ± 2.0	0.95	0.0001	NP	−1.2 ± 3.6	0.96	0.0001	NP	0.0 ± 0.7	0.91	0.0001	NP

* $p < 0.005$.
Abbreviations: Th = threshold; HRVT = threshold determined by heart rate variability; V-slope = slope trends; VE = ventilatory equivalent; R = gas exchange ratio; *r* = correlation coefficient; MH = magnitude Hopkins; L = large; NP = nearly perfect; M = moderate.

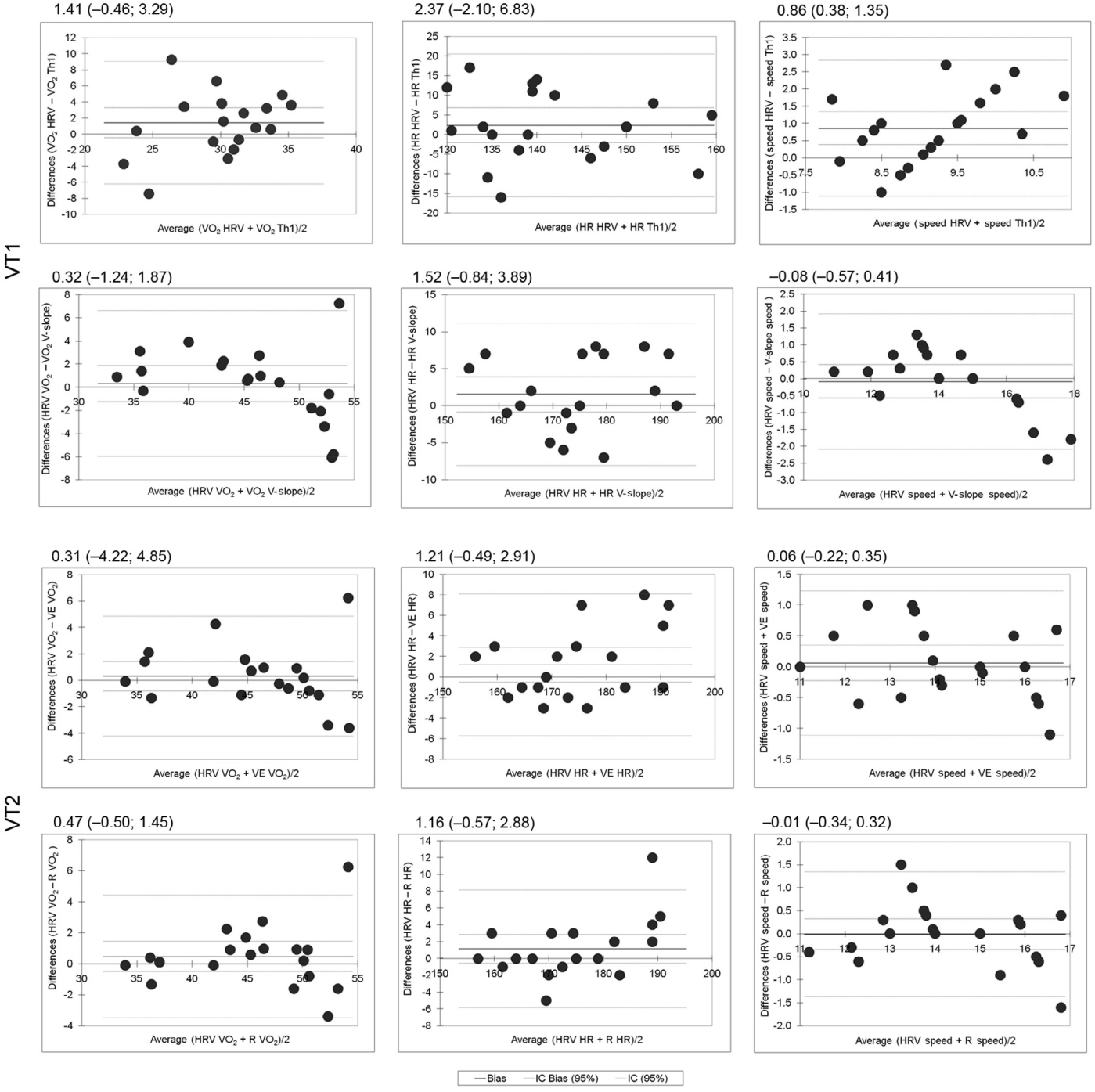

Fig. 1. Bland–Altman plots representing the central line and 95% limits of agreement between the ventilator threshold (VT) parameters, as assessed from heart rate variability (HRV) and from the gas analysis. Th = threshold; V-slope = slope trends; VE = ventilatory equivalent; R = gas exchange ratio; HR = heart rate; IC = interval of confidence.

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and HRVT2 (Table 2). However, significant correlations between the HRVT2 method and variables obtained from the gas analyser VT2 were observed (Table 3). Correlations between methods in VO_2, HR, and speed were: a) VO_2: $r = 0.91$ between HRV and V-slope, $r = 0.94$ between HRV and VE, and $r = 0.95$ between HRV and R; b) HR: $r = 0.90$ between HRV and V-slope, $r = 0.96$ between HRV and VE, and $r = 0.96$ between HRV and R; c) speed: $r = 0.93$ between HRV and V-slope, $r = 0.92$ between HRV and VE, and $r = 0.91$ between HRV and R. Bland–Altman analysis of the HRVT2 method and gas analysis VT2 procedures showed minimal bias and the majority of differences remained in the 95%CI.

4. Discussion

The present study shows that HRV methods may be an alternative for analysing the autonomic modulation during an incremental test to exhaustion on a treadmill in basketball players. Specifically, HFp analysis may be useful for determining VT2, and the quantitative Poincaré plot may be appropriate for analysingVT1. Although previous studies have shown the determination of VTs using HRV in swimmers,[5] cyclists,[15,29] skiers,[19] and runners,[7,16] to our knowledge, this is the first study that has correlated HRV responses with different gas analyser procedure techniques in professional basketball players.

In this study, HR and VO_2, determined by the HRV method, could be used for measuring VT1. However, a significant difference was observed in the speed of HRVT1. Furthermore, a moderate correlation (Table 3) was seen (r values ranging from 0.47 to 0.57) between HRVT1 and ergospirometric techniques in VT1. Cottin et al.'s[16] results showed a larger correlation between VT1 determined by gas analysis and the HRV method ($r = 0.97$) compared to our study ($r = 0.54$). This difference may be explained by the different methodology used to determine HRVT1. Dourado and Guerra[20] suggested the use of non-linear methods to obtain data, such as the quantitative Poincaré plot methodology (SD1), rather than the HFp method. However, the R-R interval during incremental physical efforts (results of the spectral analysis) is inconsistent when determining VT1.[30] Using SD1, Dourado and Guerra[20] found a higher correlation ($r = 0.84$) between the speed of HRVT1 and the speed of VT1 determined by respiratory equivalent compared with our study ($r = 0.47$). This difference may be explained by the differences in subject characteristics (older adults *vs.* professional athletes) and the type of testing protocol (walking *vs.* running). Although we have not found significant differences in VO_2 and HR, we found significant differences in speed. These findings have led us to reconsider the validity of HRV for determining the VT1.

We observed an overall significant correlation (r values ranging from 0.90 to 0.96) between the VT2 measured by gas analysis methods and the HRV technique, supporting the hypothesis that VT1 and VT2 can be estimated using the HRV in an incremental running test in basketball players. Specifically, the results obtained in this research showed significant correlations between HRV and the gas analyser methods used, with a nearly perfect Hopkins magnitude. Although there were no significant differences between gases analysis methods, the correlation in HR values was higher between R and HRV ($r = 0.96$) and VE and HRV ($r = 0.96$) than V-slope and HRV ($r = 0.90$). These correlations could be explained by the marked alternation exercise causes in autonomic function, where there is a gradual vagal withdrawal followed by sympathetic activation,[17] and are commonly observed during the transition between moderate- and high-intensity exercises.[31]

Intensities at VT2 are quite demanding, requiring great autonomic responses which may lead to a better recognition of inflection points, as well as less discrepancy between respiratory exchange methods and HRV analysis.[19] In fact, high intensity exercise at VT2 causes higher concentration of catecholamines, mediated by the increase in sympathetic activity, and increased muscle glycogenolysis, which in turn increases ventilation.[32] In the present study, HRVT2 was determined using the time-varying method that is based on HFp and changes in breathing frequency and tidal volume.[15,16] In all of the basketball players, an abrupt increase in both indices was observed and associated with VT2. Therefore, when using HFp for determining HRVT2, the limit of agreement between the HR at VT2 from HRV (175.05 ± 11.46 bpm) and ventilatory measurements (V-slope: 173.53 ± 10.90 bpm; VE: 173.84 ± 10.05 bpm; R: 173.89 ± 9.71 bpm) was low (~2 bpm). These findings are consistent with others studies with regard to HR,[7,19] intensity such as power output, speed,[5,15] and VO_2.[9] Cassirame et al.'s[19] study showed a strong correlation with HR and speed between VT2 and HRVT2 during a field test in skiers. Cottin et al.[15] found no significant difference in workload at HRVT2 and VT2 during cycloergometry in healthy adults. Karapetian et al.[9] showed results similar to those found in this study and a strong significant correlation ($r = 0.89$) between oxygen uptake at VT2 and HRVT2 during a cyclergometer test in healthy adults. These findings suggest that HRV is an effective method to determine VT2, particularly when designing exercise intensity training for professional basketball. Additionally, HRV was found to be a reliable indicator of aerobic capacity improvements post-training.

One of the limitations of the present study was the small number of subjects ($n = 24$) who participated in this study. Furthermore, this study was conducted on a homogenous group of basketball players during a specific time of the season; thus, this may limit the applicability of the results. Further studies are necessary to examine the efficacy of HRV technique at different points of the season, with different groups of players. Moreover, further research is needed to confirm whether or not this approach provides similar results with repeated testing.

5. Conclusion

Based on the limitations and the level of the participants of this study, we concluded that the ability of the HRV time varying spectral analysis to estimate VT2 during incremental running test, in professional basketball players, was demonstrated to provide sufficient reliability and validity and thus may be implemented into a training session without the use of a gas analyser to determine HR, speed, or VO_2. However, the speed at VT, in these basketball players, could not be determined with

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the HRV method, although no differences were observed in HR and VO_2. In conclusion, the HRV method is able to identify the exercise intensity that represents the transition from a lower to a higher sympathetic activity. This method is particularly practical for coaches and basketball players to determine and adjust exercise intensities throughout the season without using expensive, ergospirometric and invasive techniques.

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Authors' contributions

DJR conceived of the study, participated in its design and coordination, helped to determine ventilatory thresholds and drafted the manuscript; JAR: participated in the design and coordination and performed the statistical analysis; VAG: carried out the performance test and participated in the threshold analysis. CMP: carried out the performance test and participated in the threshold analysis; AL: carried out the performance test and participated in the threshold analysis; PEA: participated in the design of the study and helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

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