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ORIGINAL

MODULACIÓN AUTONÓMICA CARDIACA Y RENDIMIENTO FISICO EN EL UMBRAL DE POTENCIA FUNCIONAL

CARDIAC AUTONOMIC MODULATION AND PHYSICAL PERFORMANCE AT THE FUNCTIONAL THRESHOLD POWER

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ABSTRACT

The objective was to establish the relationship between cardiac autonomic modulation and physical performance of the functional threshold power (FTP$_{20.95\%}$W·kg^{-1}). Twenty-nine male cyclists aged 22±3 years participated. The physical performance of the FTP$_{20.95\%}$W·kg^{-1} was 4.3±0.4. A positive relationship of performance with the parasympathetic nervous system index (PNS index) at rest, as well as with parasympathetic reactivity and recovery, R^2 = 0.80, 0.97, 0.96 respectively, p<0.000, was demonstrated. In conclusion, cyclists with higher physical performance had higher parasympathetic activity at rest. As well as greater parasympathetic reactivity and post-P_{20} recovery. Both the PNS index and the SNS index are parameters to identify adaptation/inadaptation to training intensity, presence of fatigue, monitor and predict physical performance according to functional power threshold in competitive level cyclists. Additionally, it raises a scenario for identification of genetic predisposition to long-term endurance sports.

KEY WORDS: Athlete; Autonomic Nervous System; Cardiac System; Exercise; Heart Rate Variability

RESUMEN

El objetivo fue establecer la relación de la modulación autonómica cardiaca con el rendimiento físico del umbral de potencia funcional ($UPF_{20.95\%}W{\cdot}kg^{-1}$). Participaron 29 ciclistas hombres con edad 22±3 años. El rendimiento físico del $UPF_{20.95\%}W{\cdot}kg^{-1}$ fue 4.3±0.4. Se demostró una relación positiva del rendimiento con el índice parasimpático (PNS index) en reposo, así como con la reactividad parasimpática y la recuperación post-P_{20}, R^2 = 0.80, 0.97, 0.96 respectivamente, p<0.000. En conclusión, los ciclistas con mayor rendimiento físico presentaron mayor actividad parasimpática en reposo. Así como mayor reactividad parasimpática y recuperación post-P_{20}. Tanto el índice parasimpático como simpático son parámetros para identificar la adaptación/desadaptación a la intensidad del entrenamiento, presencia de fatiga, monitorear y predecir el rendimiento físico de acuerdo con el umbral de potencia funcional en ciclistas de nivel competitivo. Adicionalmente, plantea un escenario para una identificación de predisposición genética a los deportes de resistencia de larga duración.

PALABRAS CLAVE: Atleta; Ciclismo; Deporte; Fisiología humana; Medicina deportiva; Sistema cardiovascular

INTRODUCTION

Physical performance in road cycling is associated with the ability to maintain intense effort as long as possible, generally with a duration ranging from ~30 minutes to five hours and even in competitions that can last up to 21 days (1). The search for new methods to detect, monitor the body's physiological responses and adaptations to training have been developed with particular intensity. In cycling, the physiological parameters to monitor, predict physical performance and establish training zones have been, on the one hand, the absolute $\dot{V}O_2max$ ($L{\cdot}min^{-1}$) and relative ($ml{\cdot}kg^{-1}.min^{-1}$); the maximum lactatemia ($mmol/L^{-1}$) and the lactate threshold ($mmol/L^{-1}$) (1–3) and on the other hand, the power in watts (W) expressed in maximum, average and relative ($W{\cdot}kg^{-1}$) (4–6). These parameters are mainly determined by tests with progressive increase in intensity until exhaustion, called maximum tests. However, tests with constant intensity called submaximal tests, have become the most used tool to determine physical performance and establish training zones, within this type of tests is the 20-minute test (P_{20}), from which the functional threshold power (FTP) is determined (7). So the FTP expressed in the maximum average power (W) and the relative average power ($W·kg^{-1}$), are the way to establish the power profile, predict physical performance and establish training zones in road cycling (1).

Cardiac autonomic modulation is performed by both intrinsic and extrinsic mechanisms. Extrinsic control is carried out by the autonomic nervous system (ANS) through sympathetic activity (SA), which together with physical exercise increase the mechanisms of cardiac self-regulation, increasing heart rate and parasympathetic activity (PA) through the vagus nerve, which induces a decrease in heart rate. The ANS also controls blood pressure by reflexes that originate in baroreceptors and chemoreceptors. Heart rate variability (HRV) is the variation in time in milliseconds between heartbeat. Therefore, the evaluation of cardiac autonomic modulation through HRV evaluates the sympathetic and parasympathetic activity of the ANS, which reflects the complex interaction between the ANS, arterial baroreflex, central and peripheral chemoreflex, ergo reflex, peripheral afferents such as baroreceptors, mechanoreceptors and metaboreceptors (8).

In parasympathetic reactivation and recovery after exercise, the autonomic and execratory reflex processes involved in increasing heart rate occur essentially in reverse, where the elimination of the "central command" along with the feedback removed from muscle receptors, restores the arterial baroreflex to a lower level and causes an initial decrease in heart rate that is predominantly mediated by an increase in PA. As recovery continues, a gradual "slow phase" occurs, mediated by both progressive parasympathetic reactivation and sympathetic withdrawal (9). Consequently, HRV assessment reflects cardiovascular autonomic modulation at rest, parasympathetic reactivation, and recovery after exercise (10-11).

The present research focused on evaluating the cardiovascular autonomic modulation by HRV in the parameters of PA and SA by the time and non-linear domain method, according to the physical performance obtained at the FTP in cyclists of competitive level. The above, because, predicting physical performance, monitoring adaptation to training intensity and the presence of fatigue in sport, are today the most important aspects, both in the training methodology and to raise the tactics in competition. Thus, new knowledge of the behavior of the cardiovascular autonomic response before and after the realization of a submaximal test, will be of the highest utility for the interpretation of phenomena of adaptation to training in cycling, contributing to a more precise dosage of the intensity of training and additionally, to a possible identification of genetic predisposition to long-term endurance sports.

MATERIAL AND METHODS

PARTICIPANTS. This study involved 29 cyclists, 23 of them from the department of Boyacá and the remaining six from the department of Caldas (Colombia). The power of the study was 0.89 (12). Age (years) 22±3; Weight (kg) 60.0±5.9; Size (m) 1.7±0.5; BMI 21±1.4; Training (years) 6.5±3.7. This research is in accordance with the provisions of article 11 et seq. of resolution 8430 of 1993 of the Ministry of Health of Colombia. The Bioethics Committee of the Faculty of Health Sciences of the University of Caldas (Colombia) approved the study. The cyclists signed a document of consent and full knowledge of the procedures that were conducted before, during and after the tests. They were instructed to refrain from intense physical exercise, as well as from consuming beverages containing caffeine during the 24 hours prior to the experiment or any substance considered doping. The assessments were conducted in October and November 2018 and 2019 before the Covid-2019 pandemic.

INSTRUMENTS AND PROCEDURE. FTP's determination was made by means of a 20-minute time trial (P_{20}), as described by Allen and Coogan (7), using the Tacx Vortex® ergometer and bicycle owned by the cyclist, maintaining a pedaling cadence at 90 rpm. The heating was standardized according to the Tacx software. The data obtained was recorded in Tacx files that were processed in the Power Agent® software. During P_{20} an intense and constant effort was maintained, keeping the watts as high as possible, so the participants were verbally motivated in the last minutes. The FTP was determined as described by Allen and Coggan (7).

Cardiac autonomic modulation was assessed by HRV before and after P_{20}. The resting evaluation was performed fasting between 6:00 a.m. and 8:00 a.m. in the clinical laboratory, simulating, as far as possible, the same environmental conditions for all participants. This measurement was performed at rest for five minutes, after ten minutes in the supine position. Recovery was measured by pedaling on the bike for five minutes (active recovery), all with spontaneous breathing instruction. Data were obtained by recording heartbeat by heartbeat, using the RS800CX Polar monitor (13), whose sensor was placed at the level of the 5-6 rib, around the rib cage. These data were processed in the Kubios software (University of Kuopio, Finland. Standard ver. 3.4.3), which allowed the analysis of the SDNN (ms), RMSSD (ms), PNS index and SNS index time-domain parameters. Likewise, nonlinear parameters of the Poincaré diagram SD1, SD2 and SD1/SD2.

STATISTICAL ANALYSIS. Descriptive data are expressed in mean and standard deviation. Simple linear regression was used to establish the relationship between HRV and FTP. The model without interception ($y = \beta 1\ x + \varepsilon$) of the simple linear regression was the model that best fit the data in each of the study variables, after applying comparison criteria such as: estimation of the most significant coefficient; lower standardized residual; the highest value of the adjusted coefficient of determination R^2 and R^2; minor AIC, lower BIC; lower value, C_p. of Mallows.

RESULTS

Functional Threshold Power. The absolute average power $FTP_{20.95\%}W$ was 267.8±34.6 W and the relative average power was $FTP_{20.95\%}W{\cdot}kg^{-1}$ 4.2±0.5, corresponding to the fifth category of "very good" classification, of the eight categories proposed by Allen and Coggan.

PA and SA at Rest, Parasympathetic Reactivity and Post-P$_{20}$ Recovery. PA y SA was analyzed by HRV by time and nonlinear domain methods (**Table 1**).

Table 1. PA and SA at Rest, Parasympathetic Reactivity and Recovery. Time and Non-Linear Domain PA and SA

PA and SA	Rest	Parasympathetic Reactivity	Recovery Post-P$_{20}$
Mean RR (ms)	1159.33±168.74	406.61±31.41	433.59±33.8
SDNN (ms)	65.96±25.79	4.71±1.51	5.07±1.55
$_L$RMSSD (ms)	80.73±38.32	4.72±2.2	5.04±2.41
SD1 (ms)	59.73±26.06	3.34±1.56	3.56±1.7
PNS index	2.27±1.26	-4±0.33	-3.77±0.37
SA			
Mean HR (beats/min)	52.8±7.57	148.39±11.13	139.18±10.66
Stress index	6.8±2.81	60.45±16.09	52.55±13.29
SD2 (ms)	72.82±26.73	5.65±1.86	6.11±1.79
SNS index	-1.33±0.66	15.96±3.85	13.5±3.29

Note. Mean RR: mean heartbeat intervals; SDNN: standard deviation of all intervals between heartbeats. $_L$RMSSD: square root of the mean value of the differences between successive heartbeats; SD1: standard deviation 1 of the Poincaré plot; PNS index: parasympathetic nervous system index; ms: milliseconds; SA: sympathetic activity; Mean HR (beats/min): mean heart rate in beats per minute; Stress index: stress index; SD2: standard deviation 2 of the Poincaré plot; SNS index: sympathetic nervous system index.

Parasympathetic Activity ratio with FTP$_{20.95\%}$W and FTP$_{20.95\%}$W·kg^{-1}. There was a positive relationship of PA at rest with the physical performance of FTP$_{20.95\%}$W and with FTP$_{20.95\%}$W·kg^{-1}. There was a negative relationship of SA at rest with the physical performance of FTP$_{20.95\%}$W and FTP$_{20.95\%}$W·kg^{-1} (**Table 2**).

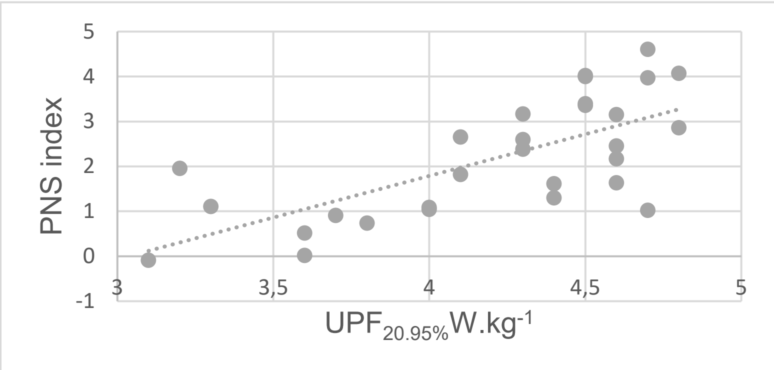
Table 2. PA and SA regression with FTP$_{20.95\%}$W and FTP$_{20.95\%}$W·kg^{-1}

PA and SA	FTP$_{20.95\%}$W		FTP$_{20.95\%}$W·kg^{-1}	
	Sig	R^2	sig	R^2
SDNN (ms)	0.000	0.89	0.000*	0.91
$_L$RMSSD (ms)	0.000	0.85	0.000*	0.87
SD1 (ms)	0.000*	0.87	0.000*	0.86
PNS index	0.000*	0.82	0.000*	0.80
SA				
SNS index:	0.000*	-0.86	0.000*	-0.86

Note. SDNN: standard deviation of all intervals between heartbeats. $_L$RMSSD: square root of the mean value of the differences between successive heartbeats; SD1: standard deviation 1 of the Poincaré plot; PNS index: parasympathetic nervous system index; ms: milliseconds. *: this symbol represents a significant relationship. Sig: significance level; SA: sympathetic activity; SNS index: sympathetic nervous system index; -: this sign signifies a negative relationship.

PNS Index and FTP$_{20.95\%}$W·kg^{-1}. The parasympathetic nervous system index showed a significant relationship with physical performance in the FTP$_{20.95\%}$W·kg^{-1}. This relationship was performed at rest, in a supine position, breathing spontaneously (**Figure 1**).

Figure 1. PNS Index and FTP$_{20.95\%}$W·kg^{-1}



Note. Cyclists with higher PA at rest, in a supine position, breathing spontaneously, presented a higher physical performance in the UPF$_{20.95\%}$W· kg-1, R^2 = 0.80, p = 0.000. Simple linear regression, interceptless model.

Relationship Parasympathetic Reactivity and Recovery with the FTP$_{20.95\%}$W·kg^{-1}. There was a significant positive relationship between the PNS index in both parasympathetic reactivity and recovery with physical performance at FTP$_{20.95\%}$W·kg^{-1}, as in the other parameters of the HRV. Similarly, a significant but negative difference of SA was observed both in parasympathetic reactivity and in recovery (**Table 3**).

Table 3. Parasympathetic Reactivity and PA and SA Recovery with FTP$_{20.95\%}$W.kg^{-1}

PA and SA	**Parasympathetic Reactivity FTP$_{20.95\%}$W·kg^{-1}**		**Recovery FTP$_{20.95\%}$W·kg^{-1}**	
	Sig.	R^2	Sig.	R^2
SDNN (ms)	0.000*	0.89	0.000*	0.91
$_L$RMSSD (ms)	0.000*	0.81	0.000*	0.91
SD1 (ms)	0.000*	0.81	0.000*	0.92
PNS index	0.000*	0.97	0.000*	0.96
SNS index	0.000*	-0.92	0.000*	-0.92

Note. SDNN: standard deviation of all intervals between heartbeats. $_L$RMSSD: square root of the mean value of the differences between successive heartbeats; SD1: standard deviation 1 of the Poincaré plot; PNS index: parasympathetic nervous system index; SNS index: sympathetic nervous system index; ms, milliseconds; *: this symbol represents a significant relationship; -: this sign means a negative relationship.

DISCUSSION

Functional Threshold Power. The FTP expressed absolutely in $FTP_{20.95\%}W$ (4–6) is presented as a parameter to establish seven training zones (7). According to the result of the $FTP_{20.95\%}W$, percentages from 50% to 150% are determined, associated with seven training zones (7). These zones seek to develop and maintain physical capacities, but $\dot{V}O_2max$ and lactate methodology are the classic parameters for establishing training zones (1–3). In this regard, Borszcz et al. (2018) (14) found a correlation of R = 0.81 between $FTP_{20.95\%}W$ and the absolute $\dot{V}O_2max$ ($L\cdot min^{-1}$), 236±38 watts related to 3.5±0.6 $L\cdot min^{-1}$, study conducted on 23 trained cyclists.

According to the lactate measurement methodology, the study by Inglis et al. (2019) found a correlation of R = 0.96 between $FTP_{20.95\%}W$ and maximum lactate steady-state (MLSS) (261±45 compared to 243±45 watts). However, the $FTP_{20.95\%}W$ did not present good sensitivity to the changes induced by 7 months of training. Therefore, it is not recommended to use it as a representation of the MLSS. In contrast, the study by Borszcz et al. (2018) (15) found a ratio of R^2 = 0.81, $FTP_{20.95\%}W$ of 251.7±26.3 associated with 248.3±25 watts, corresponding to a MLSS of 4.1±1 $mmol/L^{-1}$. The authors conclude that $FTP_{20.95\%}W$ is an alternative to MLSS, both in trained and well-trained cyclists. The study by Borszcz et al. (2018) (14) found a correlation of R = 0.61 between the $FTP_{20.95\%}W$ with the individual anaerobic threshold (236±38 watts related to 2.7±0.5 $mmol/L^{-1}$).

Previous studies show that $\dot{V}O_2max$ ($L\cdot min^{-1}$), lactate methodology and $FTP_{20.95\%}W$, are correlated. However, these parameters must be applied individually and are independent measures to evaluate and predict physical performance. In addition, caution should be exercised when predicting lactate concentration only by $FTP_{20.95\%}W$, since it can overestimate the lactate concentration threshold in the different methodologies, because the correlation is corresponding to the level of formation. On the other hand, these studies propose for different levels of training, not to subtract 5% or subtract 8% or 10% of the watts when determining the FTP.

FTP relatively expressed $FTP_{20.95\%}W\cdot kg^{-1}$ (4–6) is presented as an alternative parameter for monitoring and predicting physical performance. However, in cycling are the absolute $\dot{V}O_2max$ ($L\cdot min^{-1}$) and relative ($ml\cdot kg^{-1}\cdot min^{-1}$), MLSS, lactate threshold, individual anaerobic threshold, 4$mmol\cdot L^{-1}$ threshold and lactate threshold (1–3) parameters for monitoring and predicting physical performance. In this regard, the study by Denham et al. (2017) found a correlation of R = 0.93, $UPF_{20.95\%}W\cdot$ kg-1 of 2.62±0.75 compared to the maximum power of 305.5±65.4 watts, associated with a relative $\dot{V}O_2max$ of 46.8±9.1 $ml.kg^{-1}min^{-1}$, R^2 = 0.80, considering the physical performance of the $FTP_{20.95\%}W\cdot kg^{-1}$ predictor of maximum power (16).

The categorization of sports performance in cycling according to the power profile expressed in $FTP_{20.95\%}W\cdot kg^{-1}$, is presented in eight categories. These categories were established by Allen and Coggan (7), according to the results of systematic evaluations of hundreds of cyclists of different levels of training, during more than ten years of cycling training experience (7). In this sense, the physical performance of the cyclists in the study by Denham et al. (2017) corresponded to "Moderate", $FTP_{20.95\%}W \cdot kg^{-1}$ of 2.62±0.75 (16); in the study of Niño and Leguízamo (2019) it was $FTP_{20.95\%}W \cdot kg^{-1}$ 4.5, corresponding to the category "Very good" (17); that of Sanders et al. (2017) was $FTP_{20.95\%}W \cdot kg^{-1}$ of 4.7, corresponding to the category "Very good" (18); that of Borszcz of 2018 was $FTP_{20.95\%}W \cdot kg^{-1}$ of 3.1, corresponding to the "Moderate" category (14) and that of 2019, $FTP_{20.95\%}W \cdot kg^{-1}$ was 3.4±0.3 (15), corresponding to the "Moderate" category; that of Valenzuela et al. (2018) (19) the $FTP_{20.95\%}W \cdot kg^{-1}$ was 3.39±0.62, the classification category corresponded to "Moderate". The results of the previous six studies show that the classification of cyclists evaluated according to the power profile is in two categories, Moderate and Very Good. Despite the few studies conducted in this form of categorization, illustrating the current physical performance of cyclists, the $FTP_{20.95\%}W \cdot kg^{-1}$, is a promising parameter guide for classification and monitoring of physical performance. However, the relationship in these and the range of $W \cdot kg^{-1}$ remains to be demonstrated in each of them, with the standard parameters such as $\dot{V}O_2max$ and lactate, in addition to the relationship with the five categories proposed by De-Pauw, 2013 (3).

Physical performance at $FTP_{20.95\%}W \cdot kg^{-1}$ allows in the methodological part to associate the term, highly trained, well trained, professional, competitive level, recreational level, high performance, world class and highly experienced to a value of $W \cdot kg^{-1}$. In practice, for both cyclists and sports science professionals, it becomes an alternative parameter to $\dot{V}O_2max$ and lactate to monitor physical performance and set short, medium and long-term goals. Additionally, submaximal tests are becoming the most used tool in the preparation of cyclists.

Activity Parasympathetic at Rest.

SDNN (ms). This parameter is associated with or with PA, in the present study was 65.96±25.79 ms, in the following four studies, whose population was SDNN cyclists was: 75.95±15.41 ms (20); 79.6±32.2 ms (21); 57.2±20.9 ms (22) and 59.10±6.52 ms (23). According to the above, the average and standard deviation values for the SDNN index, corresponding to cyclists with different levels of training range from 68.50±0.90 ms. In swimmers values of 75.6 ms (24) are observed, in runners and triathletes values of 80 ms (22.25).

RMSSD (ms). It is an indicator of PA, in the present study it was 80.73±38.32 ms; in the study of Earnest (2004), where eight cyclists who were competing in the 2001 Vuelta España participated, the records were obtained on the first day of competition, the value was 44.89±5.21 (ms) (23); in the study Arslan and Aras (2016) (22) in which six cyclists from Turkey participated (experience 9.7±4.8 years), the records were obtained after two weeks of aerobic training, in the preparatory period, this index corresponded to 42.2±24.2 (ms) (22); in the study of Oliveira-Silva (2018) (20) 12 cyclists from Brazil participated, the records were obtained one day before the competition and was 59.93±18.70 (ms). According to previous studies, the average value for cyclists in RMSSD (ms) is 59.01±22.79 (ms), for swimmers of has observed values of 71.4±46.92

ms (26), for runners and triathletes values of 72.16±39.20 ms (25.27–31) and for skiers 98.15±61.6 ms (32).

SD1 (ms). It is an indicator of PA, SD1 of the Poincaré plot, in the present study it was 59.73±26.06, in the study of Oliveira-Silva (2018) (20) in cyclists it was 52.60±19.38, in triathletes this parameter was 73±48 (25) and in runners 34.34 ± 15.18 (25).

PSN index. In the present study the PSN index was 2.3±1.3, this index is the reference to use to observe the changes according to the period or mesocycle of training and the level of training of cyclists. However, training programs have been reported to influence PA differently, assessed at supine ulna rest (33). All the participants of the studies mentioned above are part of the sport classified as long-term endurance, however, differences are observed in the values of SDNN (ms), RMSSD (ms) and SD1 (ms) between the studies, which affects the PNS Index, because this index is dependent on the values of these parameters. So, this corresponds to each sports discipline and is dependent on the level of training of the athletes. A PNS index value of zero means that the three parameters that reflect parasympathetic activity is, on average, equal to the normal population average. Consequently, a positive value of the PNS index indicates how many standard deviations are above the normal population mean, while a negative value indicates how many standard deviations are below the normal population mean. Therefore, at rest, the PNS index is typically (with 95% of the population) between -2 and +2, that is, within ±2 SD of the normal population distribution (Kubios HRV software). Therefore, this is the parameter to be used in the practical, for a precise dosage of training intensity, assessment of physical performance and adaptation to training loads, in long-term endurance sports such as road cycling, which indicates and reflects the vagal cardiac tone.

SNS index. This SNS index in the present study was -1.3±0.7, a value of the SNS index of zero means that the three parameters that reflect sympathetic activity (Mean HR (beats/min), Stress index, SD2 (ms)). They are, on average, equal to the average of the normal population. On the other hand, a positive value of the SNS index indicates how many standard deviations above the mean of the normal population are the values of the parameters and a negative value indicates how many standard deviations below the mean of the normal population are the values of the parameters. Therefore, SNS index is an alternative indicator to cardiorespiratory capacity and lactate methodology to identify inadaptation to training intensity and the presence of post-training fatigue or competition in road cycling.

Parasympathetic Activity, Parasympathetic Reactivity and Recovery. The cyclists with the highest physical performance in the $FTP_{20.95\%}W{\cdot}kg^{-1}$ presented a greater parasympathetic reactivity and recovery post-P_{20} in the PNS index, R^2 of 0.97 and 0.96 respectively. In the present study, active recovery by pedaling on the bicycle was evaluated, it should be considered that body position affects the measures of PA, with a more upright posture such as sitting or standing, recovery is slower compared to the supine position (34–36). On the other hand, in athletes, post-exercise recovery is walking or pedaling depending on the activity performed, that is, active recovery, and this is commonly evaluated with the person in a passive condition (supine or sitting) (21,37–39).

The evaluation of post-exercise PA, especially the first ten minutes of recovery, is a parameter used to detect adaptations to training intensity (40–43). In addition, the daily monitoring of training and competition, allows on the one hand to structure the training micro cycles with reference to the kinetics of parasympathetic cardiac recovery (11) and on the other in races of one, two or three weeks, provides guidelines to devise the strategy to the gregarious and define the attacks to the team leader. Therefore, PA is an alternative indicator to cardiorespiratory capacity and lactate methodology to monitor physical performance in competitive cyclists.

Parasympathetic activity ratio to $FTP_{20.95\%}W{\cdot}kg^{-1}$. At rest, PA reflects people's cardiac vagal tone. This can be improved with regular physical exercise. Changes are seen in as little as six weeks of training (33), but it is long-term resistance training that causes a significant increase in cardiac vagal tone. Consequently, PA is higher in athletes compared to non-athletes (43).

In the present study, cyclists with higher PA at rest presented higher performance in both $FTP_{20.95\%}W$ and $FTP_{20.95\%}W{\cdot}kg^{-1}$. The R^2 between the PNS index and $FTP_{20.95\%}W{\cdot}kg^{-1}$ was 0.80, which means 80% of the physical performance is explained by PA. According to the above, PA becomes an alternative indicator to cardiorespiratory capacity and lactate methodology to predict physical performance in competitive level cyclists. However, in further studies variables such as ambient temperature, training process (33), level of training of cyclists, specialty within the team, hours of sleep at night and two previous nights, stress level of the previous day and at the time of the test (44) and height where cyclists live (45) should be taken into account (45), which influence the measures of HRV parameters.

The significant relationship between PA at rest with $FTP_{20.95\%}W{\cdot}kg^{-1}$ indicates the participation of the ANS in physical performance. In this sense, Machhada et al. (2017) (46) showed the first evidence that PA generated by a central nervous system circuit determines the ability to exercise, in a study conducted in animals (male mice). In humans, the first evidence of a causal relationship PA and physical performance, was presented by Verweij, Vegte and van de Harst (2018) (47), according to a genetic study (in the complete genome they found 25 single nucleotide polymorphisms of chromosome 23), they found 25 single nucleotide polymorphisms linked to the role of the ANS in heart rate modulation, this modulation related to the SDNN (ms) and RMSSD (ms) indices (R = from 0.42 to 0.60), parameters determined during the exercise and recovery. According to the results of the present and previous studies, it can be inferred that parasympathetic activity is useful to identify a possible genetic predisposition to long-term endurance sports such as road cycling. In addition, the data of the present study support what was proposed by Gourine and Ackland (2019) (48), which indicate that cardiac vagal activity causally determines the ability to exercise, hence a high cardiac vagal tone in elite athletes is critically important to confer greater tolerance to training intensity, essential to achieve superior athletic performance.

CONCLUSIONS

Cyclists with greater parasympathetic activity at rest presented higher physical performance at $FTP_{20.95\%}W{\cdot}kg^{-1}$. Cyclists with greater parasympathetic reactivity and recovery from post-P_{20}. PNS index presented higher physical performance at $FTP_{20.95\%}W{\cdot}kg^{-1}$. Both the PNS and SNS index are parameters to identify adaptation/inadaptation to training intensity, presence of fatigue, monitor and predict physical performance according to the FTP in competitive level cyclists. Additionally, the PNS index poses a scenario for an identification of genetic predisposition to long-term endurance sports.

REFERENCES

1. Faria EW, Parker DL, Faria IE. The science of cycling: Physiology and training - Part 1. Sport Med. 2005;35(4):285–312.
2. Beneke R. Methodological aspects of maximal lactate steady state—implications for performance testing. Eur J Appl Physiol. 2003;89(1):95–9.
3. De Pauw K, Roelands B, Cheung SS, De Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. Vol. 8, International Journal of Sports Physiology and Performance. Human Kinetics Publishers Inc.; 2013. p. 111–22.
4. Ebert T, Martin D, Stephens B. Power output during a professional men's road-cycling tour. Int J Sports Physiol Perform. 2006;1(4):324–35.
5. Passfield L, Hopker J, Jobson S, Friel D, Zabala M. Knowledge is power: Issues of measuring training and performance in cycling. J Sports Sci. 2017 Jul 18;35(14):1426–34.
6. Pinot J, Grappe F. The record power profile to assess performance in elite cyclists. Int J Sport. 2011;32(11):839–44.
7. Allen H, Coggan A. Entrenar y correr con potenciómetro. 4th ed. España; 2018. 443 p.
8. Belli J, Bacal F, Bocchi E. Comportamento do ergorreflexo na insuficiência cardíaca. Arq Bras. 2011.
9. White DW, Raven PB. Autonomic neural control of heart rate during dynamic exercise: Revisited. Vol. 592, Journal of Physiology. Blackwell Publishing Ltd; 2014. p. 2491–500.
10. Dong J. The role of heart rate variability in sports physiology. Exp Ther Med. 2016;11(5):1531–6.
11. Javaloyes A, Sarabia JM, Lamberts RP, Plews D, Moya-Ramon M. Training Prescription Guided by Heart Rate Variability Vs. Block Periodization in Well-Trained Cyclists. J Strength Cond Res. 2020 Jun 1;34(6):1511–8.
12. Kang H. Sample size determination and power analysis using the G*Power software. J Educ Eval Health Prof. 2021;18.
13. Gameli FX, Berthoin S, Bosquet L. Validity of the Polar S810 Heart Rate Monitor to Measure R-R Intervals at Rest. Med Sci Sport Exerc. 2006 May;38(5):887–93.
14. Borszcz F, Tramontin A, Bossi A, Carminatti L, Costa V. Functional Threshold Power in Cyclists: Validity of the Concept and Physiological

Responses. Int J Sports Med. 2018 Oct 25;39(10):737–42.
15. Borszcz FK, Tramontin AF, Costa VP. Is the functional threshold power interchangeable with the maximal lactate steady state in trained cyclists? Int J Sports Physiol Perform. 2019 Sep 1;14(8):1029–35.
16. Denham J, Scott-Hamilton J, Hagstrom AD, Gray AJ. Cycling Power Outputs Predict Functional Threshold Power And Maximum Oxygen Uptake. J Strength Cond Res. 2017 Sep;1.
17. Niño W, Leguízamo J. Correlación entre el Umbral Funcional de Potencia y el Umbral de Lactato en los ciclistas del equipo élite "Boyacá es para vivirla." Tesis maestria en Pedagogia de la cultura Fisica. Universidad Pedagógica y Tecnológica de Colombia; 2019.
18. Sanders D, Taylor RJ, Myers T, Akubat I. A field-based cycling test to assess predictors of endurance performance and establishing training zones. J Strength Cond Res. 2017 Mar;1.
19. Valenzuela P, Morales J, Foster C, Lucia A, de la Villa P. Is the functional threshold power a valid surrogate of the lactate threshold? J Sport. 2018.
20. Oliveira-Silva I, Silva VA, Cunha RM, Foster C. Autonomic changes induced by precompetitive stress in cyclists in relation to physical fitness and anxiety. PLoS One. 2018 Dec 1;13(12).
21. Borges NR, Reaburn PR, Doering TM, Argus CK, Driller MW. Autonomic cardiovascular modulation in masters and young cyclists following high-intensity interval training. Clin Auton Res. 2017 Apr 1;27(2):83–90.
22. Arslan E, Aras D. Comparison of body composition, heart rate variability, aerobic and anaerobic performance between competitive cyclists and triathletes. J Phys Ther Sci. 2016;28(4):1325-1329.
23. Earnest CP, Jurca R, Church TS, Chicharro JL, Hoyos J. Relation between physical exertion and heart rate variability characteristics in professional cyclists during the Tour of Spain. Br J Sport Med. 2004;38:568–75.
24. Scorcine C, Madureira F, Freitas C, Pereira R, Couto A, Kayamori J, et al. Classification of Heart Rate Variability in Swimming. J Exerc Physiol Online. 2019;22(5):157–64.
25. Saboul D, Bernard C, Lyon U, Hautier CA, Pialoux V, Hautier C. The impact of breathing on HRV measurements: Implications for the longitudinal follow-up of athletes. Eur J Sport Sci. 2013 Sep;13(5):534–42.
26. Palak K, Furgała A, Ciesielczyk K, Szyguła Z, Thor PJ. The changes of heart rate variability in response to deep breathing in professional swimmers. Folia Medica Cracoviensia. 2013;LIII:43–52.
27. Abad CCC, Do Nascimento AM, Gil S, Kobal R, Loturco I, Nakamura FY, et al. Cardiac autonomic control in high level brazilian power and endurance track-and-field athletes. Int J Sports Med. 2014;35(9):772–8.
28. Berkoff D, Cairns C, Sanchez L, Moorman III C. Heart rate variability in elite American track-and-field athletes. J strength Cond Res. 2007;21(1):227.
29. Bonaduce D, Petretta M, Cavallaro V, Apicella C, Ianniciello A, Romano M, et al. Intensive training and cardiac autonomic control in high level athletes. Med Sci Sports Exerc. 1998;30(5):691–6.
30. Marocolo M, Nadal J, Benchimol-Barbosa PR. The effect of an aerobic

training program on the electrical remodeling of the heart: high-frequency components of the signal-averaged electrocardiogram are. Brazilian J Med Biol Res. 2007;40(2):199–2008.
31. Molina G, Porto L, Fontana K, Junqueira L. Unaltered R–R interval variability and bradycardia in cyclists as compared with non-athletes. Clin Auton Res. 2013;23(3):141–8.
32. Schäfer D, Gjerdalen GF, Solberg EE, Khokhlova M, Badtieva V, Herzig D, et al. Sex differences in heart rate variability: a longitudinal. Eur J Appl Physiol. 2015;115(10):2107–14.
33. Kingsley JD, Figueroa A. Acute and training effects of resistance exercise. Clin Physiol Funct Imaging. 2016;36(3):179–87.
34. Flatt AA, Globensky L, Bass E, Sapp BL, Riemann BL. Heart Rate Variability, Neuromuscular and Perceptual Recovery Following Resistance Training. Sports. 2019 Oct 18;7(10):225.
35. Buchheit M, Al Haddad H, Laursen PB, Ahmaidi S. Effect of body posture on postexercise parasympathetic reactivation in men. Exp Physiol. 2009;94(7):795–804.
36. Barak O, Jakovljevic D, Gacesa J. Heart rate variability before and after cycle exercise in relation to different body positions. J Sport. 2010.
37. Al Haddad H, Laursen PB, Chollet D, Ahmaidi S, Buchheit M. Reliability of resting and postexercise heart rate measures. Int J Sports Med. 2011;32(8):598–605.
38. Boullosa DA, Barros ES, Del Rosso S, Nakamura FY, Leicht AS. Reliability of heart rate measures during walking before and after running maximal efforts. Int J Sports Med. 2014;35(12):999–1005.
39. Schäfer D, Olstad BH, Wilhelm M. Can Heart Rate Variability Segment Length During Orthostatic Test Be Reduced To 2 Min? Med Sci Sport Exerc. 2015 May;47:48.
40. Ahmadian M, Dabidi Roshan V. Heart rate recovery following arm cranking is positively associated with resting heart rate variability in children. Sport Sci Health. 2015 Dec 5;11(2):153–7.
41. Bellenger CR, Fuller JT, Thomson RL, Davison K, Robertson EY, Buckley JD. Monitoring Athletic Training Status Through Autonomic Heart Rate Regulation: A Systematic Review and Meta-Analysis. Sport Med. 2016 Oct 1;46(10):1461–86.
42. Miranda-Mendoza J, Reynoso-Sánchez LF, Hoyos-Flores JR, Quezada-Chacón JT, Naranjo J, Rangel-Colmenero B, et al. Stress score y LnrRMSSD como parámetros de carga interna durante una competición. revistas.uam.es. 2020;20(77):21–35.
43. Stanley J, Peake JM, Buchheit M. Cardiac parasympathetic reactivation following exercise: Implications for training prescription. Vol. 43, Sports Medicine. 2013. p. 1259–77.
44. Oliveira AB, Bachi ALL, Ribeiro RT, Mello MT, Vaisberg M, Peres MFP. Exercise-Induced Change in Plasma IL-12p70 Is Linked to Migraine Prevention and Anxiolytic Effects in Treatment-Naïve Women: A Randomized Controlled Trial. Neuroimmunomodulation. 2017 May 1;24(6):293–9.
45. Povea C, Schmitt L. Effects of Intermittent Hypoxia on Heart Rate Variability during Rest and Exercise Hypoxic Training View project Heart

Rate varibility In sports and physical Activity View project. Artic High Alt Med Biol. 2005 Sep;6(3):215–25.
46. Machhada A, Trapp S, Marina N, Stephens RC, Whittle J, Lythgoe MF, et al. Vagal determinants of exercise capacity. Nat Commun. 2017;8(1):1–7.
47. Verweij N, Vegte Y, van de Harst P. Genetic study links components of the autonomous nervous system to heart-rate profile during exercise. Nat Commun. 2018;9(1):1–9.
48. Gourine A V., Ackland GL. Cardiac vagus and exercise. Vol. 34, Physiology. American Physiological Society; 2019. p. 71–80.

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