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Original

Cardiac autonomic regulation in response to functional power threshold testing in elite cyclists

M. Castillo-Aguilar[a,b], D. Mabe-Castro[a,b], M. Mabe-Castro[b,c], V. Oyarzo[b,d], K. Harris King[a,b], P. Valdés-Badilla[e,f], P. Delgado-Floody[g,h], J.González-Puelma[b,c], C. Núñez-Espinosa[b,c] *

[a] *Departamento de Kinesiología, Universidad de Magallanes, Punta Arenas, Chile.*
[b] *Centro Asistencial de Docencia e Investigación (CADI-UMAG), Punta Arenas Chile.*
[c] *Escuela de Medicina, Universidad de Magallanes, Punta Arenas, Chile.*
[d] *Fonoaudiología, Universidad de Magallanes, Punta Arenas, Chile.*
[e] *Department of Physical Activity Sciences, Faculty of Education Sciences, Universidad Católica del Maule, Talca, Chile.*
[f] *Sports Coach Career, School of Education, Universidad Viña del Mar, Viña del Mar, Chile.*
[g] *Department of Physical Education, Sport and Recreation, Universidad de La Frontera, Temuco, Chile.*
[h] *Strength & Conditioning Laboratory, CTS-642 Research Group, Department Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain.*

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ABSTRACT

Objective: To evaluate the impact of a functional power threshold test (FTP) on cardiac autonomic regulation indicators in high performance cyclists.
Methods: A total of 12 male elite cyclists (mean age 36.1 ± 11.2 years) were recruited. Body composition parameters were measured using bioimpedancemetry and heart rate variability (HRV) before and after the application of the FTP assessment.
Results: We observed that a greater sympathetic nervous system (SNS) index and Stress index on baseline were correlated with a smaller decrease in the parasympathetic nervous system (PNS) activity in response to the FTP test (ρ= 0.69, p = 0.013). Concerning morphological parameters, the skeletal muscle index (SMI) was the only one that was inversely correlated with ΔPNS (ρ= -0.69, p = 0.02) whereas the muscle-bone index (MBI) displayed a positive correlation with ΔSNS (ρ = 0.82, p = 0.001). In fully adjusted models we found that waist-to-hip ratio (β= 7.90, $CI_{95\%}$[4.16, 11.63], $t(8)$ = 4.88, p = 0.001) and SMI significantly influenced ΔPNS (β = -1.38, $CI_{95\%}$[-1.84, -0.92], $t(8)$ = -6.94, p < 0.001), whereas MBI (β= 10.26, $CI_{95\%}$[8.10, 12.42], $t(8)$ = 10.96, p < 0.001) and the interaction between the latter and Power achieved during FTP influenced ΔSNS (β = -0.05, $CI_{95\%}$[-0.09, -4.99e-03], $t(8)$ = -2.56, p = 0.033).
Conclusion: Our findings indicate that the SMI had a negative effect on the ΔPNS, while the MBI was positively correlated with the ΔSNS in cyclists. These findings suggest that a higher SMI and MBI could have a detrimental impact on the cardiac autonomic response to maximal aerobic exercise in high-performance cyclists, such as FTP.
Keywords: Heart Rate; Physical performance; Athletes; Cardiovascular regulation.

* Corresponding author.
E-mail-address: cristian.nunez@umag.cl (C. Núñez-Espinosa).

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Regulación autonómica cardiaca en respuesta a la prueba de umbral de potencia funcional en ciclistas de élite

RESUMEN

Objetivo: Evaluar el impacto de una prueba de umbral de potencia funcional (FTP) sobre los indicadores de regulación autonómica cardiaca en ciclistas de alto rendimiento.

Métodos: Se reclutó a un total de 12 ciclistas de élite masculinos (edad media 36.1 ± 11.2 años). Se midieron los parámetros de composición corporal mediante bioimpedanciometría y la variabilidad de la frecuencia cardiaca (HRV) antes y después de la aplicación de la evaluación del FTP.

Resultados: Observamos que un mayor índice del sistema nervioso simpático (SNS) e índice de estrés basalmente se correlacionaron con una menor disminución de la actividad del sistema nervioso parasimpático (PNS) en respuesta a la prueba FTP (ρ= 0.69, p = 0.013). En cuanto a los parámetros morfológicos, el índice músculo esquelético (SMI) fue el único que se correlacionó inversamente con el ΔPNS (ρ= -0.69, p = 0.02) mientras que el índice músculo-hueso (MBI) mostró una correlación positiva con ΔSNS (ρ = 0.82, p = 0.001). En los modelos totalmente ajustados encontramos que la relación cintura-cadera (β= 7.90, $CI_{95\%}$[4.16, 11.63], $t(8)$ = 4.88, p = 0.001) y el SMI influían significativamente en el ΔPNS (β= -1.38, $CI_{95\%}$[-1.84, -0.92], $t(8)$ = -6.94, p < 0.001), mientras que el MBI (β = 10.26, $CI_{95\%}$[8.10, 12.42], $t(8)$ = 10.96, p < 0.001) y la interacción entre este último y la Potencia alcanzada durante el FTP influían en el ΔSNS (β= -0.05, $CI_{95\%}$[-0.09, -4.99e-03], $t(8)$ = -2.56, p = 0.033).

Conclusión: Nuestros hallazgos indican que el SMI tuvo un efecto negativo sobre el ΔPNS, mientras que el MBI se correlacionó positivamente con el ΔSNS en ciclistas. Estos hallazgos sugieren que un mayor SMI y MBI podrían tener un impacto perjudicial en la respuesta autonómica cardíaca al ejercicio aeróbico máximo en ciclistas de alto rendimiento, como el FTP.

Palabras clave: Frecuencia cardiaca; Rendimiento físico; Atletas; Regulación cardiovascular.

Regulação autonômica cardíaca em resposta ao teste de potência do limiar funcional em ciclistas de elite

RESUMO

Objetivo: Avaliar o impacto de um teste de potência de limiar funcional (FTP) nos indicadores de regulação autonômica cardíaca em ciclistas de alto rendimento.

Métodos: Um total de 12 ciclistas de elite do sexo masculino (idade média de 36.1 ± 11.2 anos) foram recrutados. Parâmetros de composição corporal foram medidos por bioimpedância e variabilidade da frequência cardíaca (VFC) antes e após a aplicação da avaliação FTP.

Resultados: Observamos que um índice basal mais alto do sistema nervoso simpático (SNS) e um índice de estresse correlacionaram-se com uma menor diminuição da atividade do sistema nervoso parassimpático (SNP) em resposta ao teste de FTP (ρ = 0.69, p = 0.013). Com relação aos parâmetros morfológicos, o índice musculoesquelético (SMI) foi o único que se correlacionou inversamente com o ΔPNS (ρ = -0.69, p = 0.02) enquanto o índice músculo-ósseo (MBI) apresentou correlação positiva com o Δ SNS (ρ = 0,82, p = 0,001). Em modelos totalmente ajustados, descobrimos que a relação cintura-quadril (β = 7.90, IC95%[4.16, 11.63], t(8) = 4.88, p = 0.001) e SMI influenciaram significativamente o ΔPNS (β = -1.38, IC95 %[-1.84 , -0.92], t(8) = -6.94, p < 0.001), enquanto o MBI (β = 10.26, IC95%[8.10, 12.42], t(8) = 10.96, p < 0.001) e a interação entre os últimos e a Potência alcançada durante o FTP influenciou o ΔSNS (β = -0.05, IC95%[-0.09, -4.99e-03], t(8) = -2.56, p = 0.033).

Conclusão: Nossos achados indicam que o SMI teve um efeito negativo no ΔPNS, enquanto o MBI se correlacionou positivamente com o ΔSNS em ciclistas. Esses achados sugerem que o SMI e o MBI mais altos podem ter um impacto negativo na resposta autonômica cardíaca ao exercício aeróbico máximo em ciclistas de alto desempenho, como o FTP.

Introduction

The regulation of non-voluntary physiological processes, such as cardiovascular responses, is crucial for optimal athletic performance. The autonomic nervous system plays a pivotal role in this regulation, and heart rate variability (HRV) is considered a viable marker to measure cardiac autonomic modulation.[1,2]

During high-energy-demand sports like cycling, the autonomic system is essential for athletes' response to the competition.[3–5] The modulation of the autonomic nervous system is influenced by various factors, including the volume, intensity, duration, and type of exercise.[6,7] Furthermore, athletes' morphological variables, such as body composition, can influence baseline HRV parameters and, consequently, the athlete's performance.[8–10]

In high-performance cyclists, body composition is relevant and has been correlated with their physical performance during competitions.[11,12] A high muscle index and a low body fat percentage are generally desired by physical trainers and athletes. In this regard, research on amateur cyclists has shown a link between anthropometric measures and training adaptations, showing that training load is associated with a decrease in body weight, body mass index, and body fat percentage.[13] However, it is not clear if this holds true for high-performance athletes when accounting for other key physiological variables.

Although it is well established that physical exercise affects the autonomic response and its immediate recovery,[3–5,14] the impact of morphological variables on this modulation is not fully understood. Therefore, it is crucial to evaluate the immediate post-exercise recovery, as it reflects the athlete's aerobic capacity and performance.[3,15]

In this context, the Functional Threshold Power (FTP) test has been proposed as a reliable method to assess cyclist power for one hour in a "near physiological steady state".[16] It is currently proposed that FTP can be predicted by taking 95% of the power output in a maximum of 20 min all-out effort test.[17] In this way, this test can predict the cyclist's response to this maximum effort in less time and also allows the evaluation of other physiological parameters of interest to the athlete.[18]

Despite the relevance of the FTP test, no evidence has been found on the relationship between body composition parameters, autonomic regulation, and its immediate response after an exercise protocol in high-performance cyclists. The present study aims to fill this gap by evaluating the impact of an FTP test on cardiac autonomic regulation indicators in high-performance cyclists. This study's findings may provide valuable insights into the complex interplay between body composition and autonomic regulation, ultimately informing training strategies to enhance athletic performance.

Methods

Study design

A descriptive, correlational, and cross-sectional study was conducted in two consecutive stages. In the first stage, morphological variables of body composition were measured, and in the second stage, cardiovascular variables of HRV and the physical test of FTP were evaluated. The participants were selected through non-probabilistic sampling among professional cyclists from the Magallanes region. The athletes were informed about the assessments as well as the associated risks and benefits.

Participants

Before undergoing the protocol for this study, all the cyclists signed an informed consent form. The inclusion criteria for the study were as follows: (a) male cyclists between 20 and 40 years of age until the year 2022; (b) permanent residence in the city of Punta Arenas; (c) a minimum of 1 year of participation in competitive cycling; (d) completion of the FTP test; (e) attendance at the two assessment sessions. The exclusion criteria were: (a) use of any supplement or medication that could affect HRV before the physical test; (b) musculoskeletal injuries in the last three months; (c) presence of pain during measurements; (d) cognitive or motor disability. During the registration stage, 35 athletes expressed interest in participating. After determining the participants' eligibility based on the inclusion and exclusion criteria, 12 cyclists were recruited. The study involving human participants was reviewed and approved by The Ethics Committee of the University of Magallanes, Chile (Nº141CEC2018). All participants provided written informed consent to participate in the study.

Procedure

The measurements were conducted in the Movement Analysis laboratory of the Center of Education, Healthcare, and Research (CADI-UMAG) during the early afternoon for all cyclists. In the first session, all morphological parameters, including body weight, height, and anthropometry, were evaluated. In the second session, cardiovascular parameters were assessed before, during, and after the physical performance test.

Functional Threshold Power protocol

The participants wore sportswear appropriate for the test. All participants were asked to: (a) get enough rest the night before, sleeping 8 hours or more; (b) avoid stimulant drinks or drugs before the measurements; (c) drink at least 2 liters of water the day before; and (d) eat regularly without changing their diet. The cyclists arrived 15 minutes before the test. The FTP protocol was carried out in a laboratory designed for the experiment at 22 °C and 30% relative humidity regulated by air conditioning.

Before starting the second stage of assessment, each cyclist remained seated in absolute rest for 10 minutes while pretest HRV was assessed. Five minutes of the recording were considered for the analysis. Then, the cyclist got on the bike to begin the physical test. Throughout the test, the athlete's cardiac activity was monitored, allowing them to monitor their cardiovascular health. Moreover, the athletes could observe their heart rate on the screen in front of them. After completing the test, the athlete recovered for two minutes, and then 10 minutes of HRV assessment, while sitting in absolute rest, were recorded again.

Morphological measures

The multi-frequency bioelectrical impedance analyzer, InBody S10 (Biospace Co, Ltd, Korea/Model JMW140), was used in accordance with the manufacturer's instructions. This device estimates body composition by measuring the differences in conductivity of various tissues, which are determined by their different biological characteristics.[19] The body composition parameters, including fat mass, fat-free mass, body cell mass, appendicular skeletal muscle mass (ASM; kg/m2), whole-body phase angle, and body water status, were measured according to established scientific guidelines.[20]

Functional Threshold Power Test

A Tacx FLUX S Smart Direct Roller (Garmin®) was used for the FTP assessment, as it can be adjusted to fit each athlete's personal bicycle. The roller program calculated the cadence of each athlete, expressed in revolutions per minute (rpm).

The FTP test provides data on functional threshold heart rate (FTHR) or FTP, which is essential for determining intensity levels or zones to follow a training plan. There are two versions of this test; one of long duration (1 hour), and the other of 45 minutes. However, the 1-hour version can be overly demanding, particularly for a group of users taking a high-demand test for the first time. Therefore, we proposed carrying out the shorter-duration test (45 min), which consists of the following phases: (i) Warm-up, consisting of 5 minutes of free pedaling, 20 seconds of resistance rhythm up to 130 W, 20 seconds of resistance rhythm at 165 W, 20 seconds of hard pedaling up to 195 W. After that, 3 minutes of easy pedaling up to 80W, 3 minutes of hard pedaling up to 180 W, 2 minutes of hard pedaling up to 195 W, and 6 minutes of easy pedaling up to 80 W. (ii) The main test involves the cyclist pedaling for 20 minutes with maximum effort. (iii) The cooldown phase is 5 minutes of easy pedaling.

Cardiovascular parameters

Cardiac autonomic modulation was determined by recording RR intervals with a heart rate sensor strap (H10, Polar Electro Oy, Kempele, Finland) using the Polar Team 2 system. The breathing rate of the subjects was spontaneous, and artifacts and ectopic heartbeats, which did not exceed 3% of the recorded data, were excluded.[2] The time-domain parameters analyzed were the square root of the mean squared differences of successive RR intervals (RMSSD, expressed in ms), which reflect parasympathetic influence,[21] and the standard deviation of the RR intervals (SDNN), which reflect total variability, i.e., the sympathetic and parasympathetic contribution of the autonomic nervous system to the heart.[22,23] The frequency domains considered in this study were the high-frequency (HF) power band, which reflects parasympathetic influence and respiratory sinus arrhythmia,[24] and the low-frequency (LF) band, associated with baroreflex activity.[25] The very low-frequency (VLF) band is multifaceted and strongly associated with emotional stress.[26–28]

Additionally, the Parasympathetic Nervous System (PNS) index, Sympathetic Nervous System (SNS) index, and Stress Index (SI) were considered. The PNS index reflects total vagal stimulation and is calculated from the mean RR intervals, RMSSD, and Poincaré plot index SD1 in normalized units (linked to RMSSD). It reflects how many standard deviations above or below the normal population averages the obtained values are. The SNS index reflects total sympathetic stimulation and is calculated from the mean RR intervals, Baevsky's SI (a positively related value to cardiovascular system stress and cardiac sympathetic activity), and Poincaré plot index SD2 in normalized units (related to SDNN). Its interpretation is similar to the PNS index.[22,29] The SI may be used as an indicator that represents the degree of load on the Autonomic Nervous System control.[30] It is normalized by using the square root of Baevsky's SI[31] and calculated from the mode Mo (taken as the median of R-R intervals), AMo (the amplitude of the normalized RR interval histogram), and MxDMn (the distance between the shortest and longest R-R intervals) by the following:

$$SI = \frac{AMO \times 100\,\%}{2 \times MO \times MxDMn}$$

All the data obtained were analyzed using the Kubios HRV software.[32]

Statistical analyses

Descriptive statistics were expressed as median and interquartile range (IQR) for continuous variables, and absolute and relative frequency (n [%]) for categorical outcomes.

To assess the relationship between autonomic indexes, we used Spearman's rank correlation since the data did not follow an approximate Gaussian distribution, which was assessed through graphical and analytical methods. To analyze the change in autonomic parameters in response to FTP measurements, we computed the mean difference with a 95% confidence interval (CI) bias-corrected and accelerated, calculated through the bootstrap resampling technique. Additionally, we reported the bias-corrected standardized mean difference (Hedges' g) with their corresponding 95% CI.

To assess the influence of potential confounders on the autonomic response to FTP, we fitted a robust version of linear regression by iterated reweighted least squares (IRLS). This approach assigns more weight to less extreme values and controls for the influence of outliers when describing the estimated parameters of the model. To this end, the predictors were centered around their mean to interpret the intercept as the estimated response while keeping the predictors constant and thus controlling for their influence.

All analyses were performed using the R programming language[33] within Rstudio.[34] We used complementary R packages for analysis and plotting.[35-39]

Results

Sample characteristics and body composition parameters can be observed in Table1.

Table 1. Body composition and sample characteristics. ECW, Extracellular water; ICW, Intracellular water; TCW, Total cellular water.

Domain	Parameter	Statistics (N = 12)	
		Median	IQR (p25, p75)
Anthropometric	Weight	72.9	(68.6, 75.8)
	Height	170.2	(167.8, 179.1)
	Body mass index	24.9	(22.4, 26.4)
	Waist-Hip ratio	0.8	(0.8, 0.9)
Musculoskeletal	Muscle bone index	2.7	(2.6, 2.8)
	Skeletal muscle index	8.2	(7.9, 8.8)
	Skeletal muscle mass	32.0	(31.0, 35.8)
	Muscle mass	42.3	(41.2, 45.2)
	Bone mass	15.3	(14.9, 16.5)
	Residual mass	28.6	(27.6, 29.4)
Body composition	Visceral fat	61.3	(35.5, 74.6)
	Fat mass	12.3	(11.2, 14.8)
Water composition	ECW/TCW	0.4	(0.4, 0.4)
	ICW	26.4	(25.3, 29.4)
	TCW	42.2	(40.4, 46.8)
	ECW	16.1	(14.7, 17.4)

Autonomic activity and stress

When assessing the relationship between the associated variables within the athletes, we observed that a greater SNS activity and SI on baseline were associated with a smaller decrease in the PNS activity in response to the FTP test (baseline SI, $\rho = 0.67$, $p = 0.017$; baseline SNS, $\rho = 0.69$, $p = 0.013$).

In this sense, a greater baseline PNS activity was associated with larger decreases on the PNS index in response to the FTP test ($\rho = -0.61$, $p = 0.037$), and this decrease in Δ PNS was associated with greater increases in the SNS activity and the SI in response to the FTP test (ΔSNS, $\rho = -0.6$, $p = 0.039$; ΔSI, $\rho = -0.62$, $p = 0.033$).

This is directly linked with PNS activity at post-SFT, whereas greater levels were associated with lower increases in SI and SNS activity levels in response to SFT test (ΔSI, $\rho = -0.69$, $p = 0.014$; ΔSNS, $\rho = -0.77$, $p = 0.003$).

Unadjusted autonomic response

The mean observed difference in the PNS index was -2.03 points ($CI_{95\%}$[-2.53, -1.62]), suggesting a decrease in PNS activity post-SFT test ($t(11) = -8.34$, $p < 0.001$, Hedges $g = 2.24$, $CI_{95\%}$[1.17, 3.29]), while the SNS index experienced an increase of 6.28 points ($CI_{95\%}$[4.47, 8.48], $t(11) = 5.83$, $p < 0.001$, Hedges' $g = -1.56$, $CI_{95\%}$[-2.38, -0.72]) relative to their baseline values. The SI and SNS index tend to exhibit similar behavior between measurements of the FTP (association between ΔSNS and ΔSI, $\rho = 0.98$, $p < 0.001$), so the SI also experienced and increase from baseline relative to the FTP measurements (mean difference = 23.1, $CI_{95\%}$[14.80, 33.27], $t(11) = 4.67$, $p < 0.001$, Hedges' $g = -1.25$, $CI_{95\%}$[-1.96, -0.50]). The autonomic variations within subjects can be seen in Figure 1.

Adjusted PNS response

Rank based correlation analyses suggest that from all body composition parameters, SMI was the only one that was inversely associated with ΔPNS, suggesting that lower levels of SMI were related to a lower decrease in PNS activity in response to FTP test ($\rho = -0.69$, $p = 0.02$).

After fitting a simple linear model based on IRLS, we found that the ΔPNS changed from -2.03 points ($CI_{95\%}$[-2.53, -1.62]) in the first unadjusted comparison to -1.89 points ($CI_{95\%}$[-2.33, -1.45], $t(9) = -9.73$, $p < 0.001$) when controlling for SMI ($\beta = -0.71$, $CI_{95\%}$[-1.53, 0.10], $t(9) = -1.99$, $p = 0.078$).

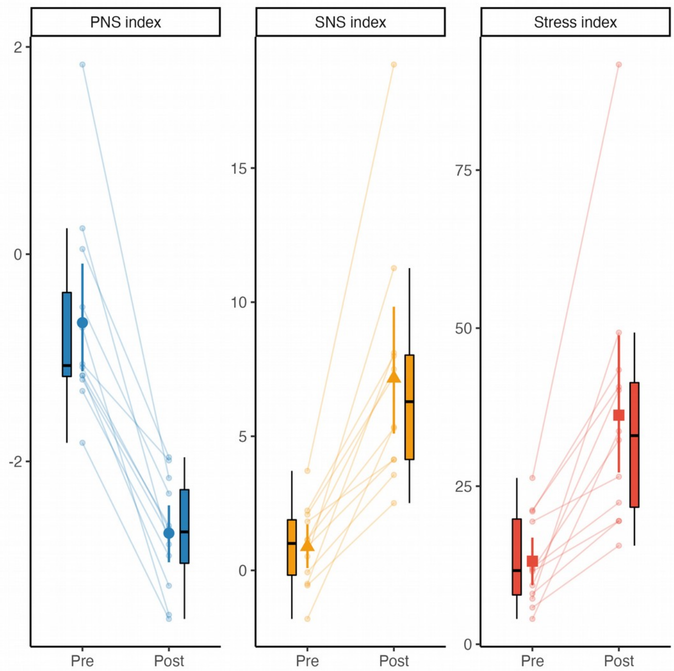

Figure 1. Inter-individual variations of the autonomic regulation indexes. Boxplots and errorbars with 95% CI based on bootstrap resampling around the mean and the within subjects response to the FTP test (represented by conected lines) are shown.

However, and after testing the influence of other predictors in the model while still considering SMI as a predictor, we observed that the inclusion of the waist-to-hip ratio (WH_{ratio}) yielded a significant effect on ΔPNS ($\beta = 7.90$, $CI_{95\%}$[4.16, 11.63], $t(8) = 4.88$, $p = 0.001$), as well as for the effect of SMI on the latter ($\beta = -1.38$, $CI_{95\%}$[-1.84, -0.92], $t(8) = -6.94$, $p < 0.001$). Thus, after adjusting for the effect of SMI and WH_{ratio}, the estimated response of ΔPNS to the FTP test was -1.93 points ($CI_{95\%}$[-2.16, -1.70], $t(8) = -19.15$, $p < 0.001$). The final model explaining the PNS response to the FTP test is best described by the following equation:

$$\Delta PNS = 2.835 - 1.379 \times SMI + 7.898 \times WH_{ratio}$$

Equation 1. Final model using SMI and WH_{ratio} to explain the Δ of PNS in response to the FTP test. The predictors in this equation are not centered, so they can be used for prediction.

Adjusted SNS response

Spearman's rank based correlation suggests a positive association between the muscle-bone index (MBI) and the ΔSNS, suggesting that greater values of MBI could be associated with greater increases in SNS activity in response to the SFT test (ρ = 0.82, p = 0.001).

When fitting a robust linear regression with IRLS, we observed that the response of SNS activity was maintained after adjusting for MBI (Intercept = 6.20, $CI_{95\%}$[5.00, 7.40], $t(10)$ = 11.53, p < 0.001), considering that for every 1 unit increase in MBI, we could expect an increase in 11.72 points in the SNS activity in response to the SFT test (β = 11.72, $CI_{95\%}$[7.39, 16.04], $t(10)$ = 6.04, p < 0.001).

Despite of previous findings in simple models, and after trying different combinations of predictors while keeping MBI in the final model, we could identify an interaction effect between the mean power achieved during the FTP test ($Power^{FTP}$) and MBI (β = -0.05, $CI_{95\%}$[-0.09, -4.99e-03], $t(8)$ = -2.56, p = 0.033), considering that $Power^{FTP}$ itself was not statistically influential on the outcome response (β = -3.23e-03, $CI_{95\%}$[-0.02, 0.01], $t(8)$ = -0.41, p = 0.692) while MBI was still significant, even after including $Power^{FTP}$ in the equation (β = 10.26, $CI_{95\%}$[8.10, 12.42], $t(8)$ = 10.96, p < 0.001). In this sense, and after controlling for the effect of MBI and $Power^{FTP}$, we observed that the estimated response of ΔSNS was 6.06 points ($CI_{95\%}$[5.52, 6.59], $t(8)$ = 26.01, p < 0.001). The linear relationship between variables can be seen in **Figure 2**. The final model that best explains the variations in ΔSNS response was the following:

$$\Delta SNS = -52.007 + 21.180 \times MBI - 0.134 \times Power^{FTP} - 0.050 \times \left(MBI \times Power^{FTP}\right)$$

Equation 2. Final model using MBI, $Power^{FTP}$ and their interaction to explain the Δ of SNS in response to the FTP test. The predictors in this equation are not centered, so they can be used for prediction.

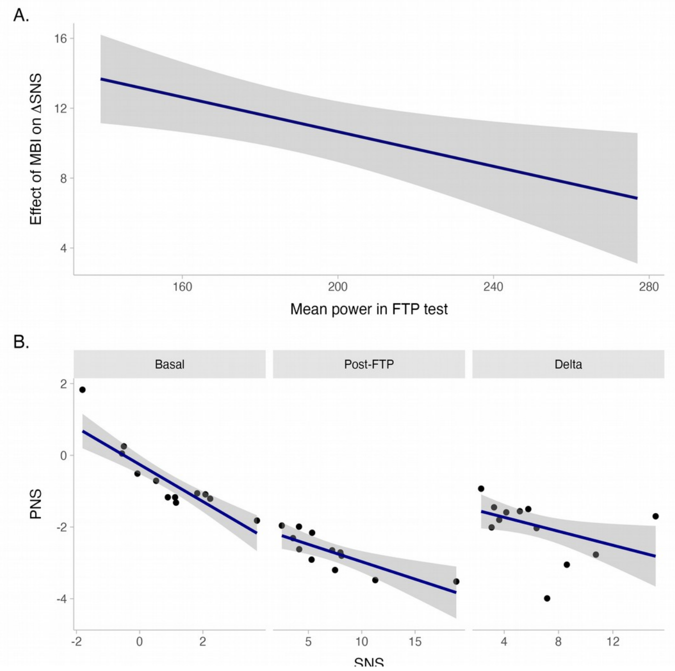

Figure 2. Linear response between autonomic parameters at baseline, post-SFT and the variations between these time periods. A, Interaction effect between PowerFTP and MBI; B, Linear relationship between HRV measurements.

Discussion

In this study, we have identified important associations between autonomic cardiac modulation parameters and body mass composition parameters in response to aerobic maximal exercise, as indicated by Spearman's Rank correlation and IRLS.

Our findings suggest that cardiac autonomic response to the FTP test, an aerobic maximal exercise, could be influenced by muscle indices (SMI and MBI), with higher SMI and MBI negatively affecting cardiac autonomic response, moving SNS and PNS out of balance. Cyclists with lower SMI and MBI maintain a greater cardiac autonomic balance between parasympathetic and sympathetic activity when their response to this type of exercise is observed.

Current evidence seems to support the hypothesis that morphological variables may play a role influencing key performance outcomes that are relevants to high-performance cyclists.[11,12] However, the autonomic effects of this type of variable on cardiac regulation is still not clear. Some important precedents indicate that cycling was the sport with the most sudden deaths during its practice in Spain between 1995 and 2001, which suggests that cycling is very demanding for human systems and there is a need to develop monitoring strategies to assess the neurophysiological regulation of the heart in athletes.[40]

Although the morphological composition of the cyclist partly determines their performance in a competition, we have observed in this study that it may also imply different characteristics of cardiovascular recovery among athletes.[41] Possibly the SMI would reflect a greater autonomic wear and tear compared to a test as demanding as the FTP. This wear could hinder autonomic recovery, especially of the PNS, which we know exerts strong regulation of the autonomic nervous system.[4,42] Due to these characteristics, the autonomic recovery of athletes with a higher muscle index could be influenced by their morphology, which should be considered for a better recovery of cyclists, both in training and after a competition.

HRV, reflecting cardiac autonomic regulation, is known for being a tool for identifying patients at risk of cardiovascular death and a great predictor of prognosis in several neurological disorders. A worse cardiac autonomic response to exercise, found in cyclists with higher muscle indices, could lead to cardiovascular disorders or decrease the effort threshold in longer competitive activities, although these hypotheses have not been explored. Considering this, professionals surrounding high-performance cyclists should consider strategies for minimizing exercise-induced autonomic dysregulation.

Possibly the SMI would reflect a greater autonomic wear and tear compared to a test as demanding as the FTP.

One of the strengths of this study is that it sheds light on the relationship between body composition and cardiac autonomic regulation, which has not been previously investigated in this population. Additionally, we used robust statistical methods such as Spearman's Rank correlation and IRLS to analyze the data, which allowed for a more precise and accurate assessment of the associations between variables.

Despite its strengths, our study has several limitations. First, our sample size was relatively small, which may limit the generalizability of our findings. Second, we only examined the immediate response to the FTP test and did not investigate the long-term effects of body mass composition on cardiac autonomic regulation. Further studies with larger sample sizes and longer follow-up periods are needed to better understand the effects of body mass composition on cardiac autonomic regulation.

In addition, our study only focused on one type of exercise (aerobic maximal exercise), and the effects of body mass composition on cardiac autonomic regulation may differ in other types of exercises or activities. Furthermore, we did not take into account other potentially confounding factors such as age, sex, and medical history. Future studies should consider these factors in their analysis.

In conclusion, our study provides important insights into the effects of body mass composition on cardiac autonomic regulation in high-performance cyclists. We found that muscle indices (SMI and MBI) are associated with changes in cardiac autonomic response to exercise, with higher SMI and MBI leading to an imbalance between parasympathetic and sympathetic activity. Our findings suggest that professionals surrounding high-performance cyclists should consider strategies for minimizing exercise-induced autonomic dysregulation in individuals with higher muscle indices. However, considering our study limitations, further research is needed to confirm and expand upon our findings.

Conclusion

The results of this study highlight the crucial role of muscle indices (SMI and MBI) in modulating the cardiac autonomic response to FTP among elite cyclists. The negative effect of SMI on ΔPNS and the positive correlation of MBI with ΔSNS demonstrate the potential impact of muscle composition on the body's physiological response to intense aerobic exercise. These findings underscore the importance of optimizing muscle indices in high-performance cyclists to improve cardiac autonomic regulation and maximize athletic performance.

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