Cardiac autonomic responses of trained cyclists at different training amplitudes

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Summary

Purpose: The aim of this study was to evaluate the effect of different training amplitudes on the autonomic nervous system (ANS) responses and recovery through heart rate (HR), heart rate variability (HRV) and rate of perceived effort (RPE).
Methods: In a counterbalanced design, male trained cyclists (24.8 ± 6.9 years old) performed three training sessions matched by total duration (20 min) and by mean power (55% of maximal power output,), but with different effort:pause ratio and different amplitudes. Continuous training (CT) was composed by efforts of 55% of maximal power (Pmax). The low amplitude training (LAT) was composed by efforts with 80% of Pmax and pauses of 30% of Pmax, and high amplitude training (HAT) with efforts of 110% of Pmax and passive pauses (0% of Pmax). Data were analyzed using a two-way ANOVA with repeated measures or non parametric correspondent.
Results: HAT promoted superior RPE (9.0 ± 1.0 au) in comparison to the LAT (3.8 ±2.8 au), and CT (2.8 ± 1.5 au) with $p <.01$, and higher increments in the maximal HR (172.8 ± 11.8 bpm) in comparison to the CT (140.8 ± 14.2 bpm, $p = .001$). Regarding HRV, the three protocols had similar results, except by the CT, which did not return to baseline levels after 24h of rest.
Conclusions: The HAT showed higher impact on the RPE and in maximum HR at the end of the session and the HRV variables showed similar responses despite the difference in the training protocols.

Key words:
Heart rate. Cycling.
Physical effort. Recovery.
Autonomous nervous system.

Respuesta del sistema cardiaco autónomo en ciclistas entrenados con diferentes amplitudes de entrenamiento

Resumen

Objetivo: El objetivo de este estudio fue evaluar el efecto de diferentes amplitudes de entrenamiento sobre las respuestas y recuperación del sistema nervioso autónomo (SNA) por medio de la frecuencia cardíaca (FC), variabilidad de la frecuencia cardíaca (VFC) y tasa de esfuerzo percibido (RPE).
Métodos: En diseño contrabalanceado, ciclistas masculinos entrenados (24.8± 6.9 años de edad) realizaron tres sesiones de entrenamiento emparejados con duración total (20 min) y promedio de potencia (55% de la potencia máxima), pero con diferentes tasas de esfuerzo-pausa y diferentes amplitudes. El entrenamiento continuo (EC) fue compuesto por esfuerzos de 55% de la máxima potencia (Pmax). El ejercicio con baja amplitud de entrenamiento (EBA) fue compuesto por esfuerzos de 80% de la Pmax con pausas de 30% de la Pmax, y en entrenamiento en alta amplitud (EAA) con esfuerzos de 110% de la Pmax y pausas passivas (0% de la Pmax. Los datos fueron analizados mediante ANOVA de dos vías con medidas repetidas o su correspondiente no paramétrico.
Resultados: EAA promovió RPE superiores (9.0 ± 1.0 u.a) en comparación con EBA (3.8 ± 2.8 au), y EC (2.8 ± 1.5 u.a) con $p<.01$, con elevados incrementos en la FC máxima (172.8 ± 11.8 bpm) en comparación con EC (140.8 ± 14.2 bpm, $p=.001$). Considerándose la VFC, los tres protocolos tuvieron resultados similares, excepto por el EC, pues no volvió a los niveles basales después de 24h de descanso.
Conclusiones: El EAA presentó mayor impacto en la RPE y en la FC máxima al final de la sesión y las variables de VFC mostraron respuestas similares a pesar de la diferencia en los protocolos de entrenamiento.

Palabras clave:
Frecuencia cardíaca. Ciclismo.
Esfuerzo físico. Recuperación.
Sistema nervioso autónomo.

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Introduction

Cycling is characterized as an endurance cyclical modality; in the competition different procedures were used, ranging from time trials, from 4 km to very high durations, lasting days[1,2]. Because of this, the training usually involves continuous efforts applied with moderate to high intensity and long duration, and as well as in other ways, usually using heart rate (HR) to the intensity prescription and control[3].

The HR is a physiological variable intrinsically controlled by the autonomic nervous system (ANS), under the equilibrium between sympathetic and parasympathetic activity[4]. Another parameter observed in the evaluation of cardiac activity and its modulators is the heart rate variability (HRV), which indicates the HR oscillations[5]. In this context, during physical exercise, the sympathovagal balance, and its regulation, are altered as a result of the increased need for blood oxygen distribution[6]. The HRV is also used to control the training load assessment on a daily basis of its parameters after, before, and specifically 24 h hours before training[4,7,8] because of its relations with the ANS stress and recovery patterns of the HR control[4]. Constant loads with high intensity could induce a delay in the HRV recovery but few studies have reported how ANS responds immediately and after 24 hours of exercise using different training amplitudes of the effort: pause ratio[6-9].

With the intention of promoting improvements in these mechanisms, the high intensity interval exercise (HIIE) is a temporally efficient strategy in the development of autonomic regulation and performance determinants in cycling[9,10], which is organized with different protocols[11,12]. In the HIIE, beyond the volume and intensity, one of its variable to training prescription, which have not been common focus of study, is called amplitude between efforts and recoveries[13,14]. Although the intensity seems to be the most important variable that determines, almost alone, the adaptations and their type with training[15], the amplitude that this intensity is involved is guided by the individuality principle, which proposes that the load should be applied considering the functional capacity of each individual, and this response to the training[9]. Trainings with lower or average amplitude can promote similar adaptations on HR, HRV, and performance variables[12,13], different from training sessions with wide amplitude, which promotes higher impact on HR and HRV parameters[8]. In this sense, coaches and trainers can choose trainings with the same mean intensity but different in the amplitude of the effort: recovery ratio, considering the use of wider amplitudes to promote higher impact in their athletes organism[8]. HIIE protocols could be used with high effort intensities, but with same mean intensity of the low continuous trainings, helping the coaches to recognize and to control the training load over the season[8]. The aim of this study was to evaluate the responses and recovery of the ANS through HR and HRV, and the rate of perceived effort (RPE) in trained cyclists after three sessions with different training amplitudes.

Material and method

In this study five highly trained cyclists (between 18 and 33 years old), with weekly training of 4±1 days and weekly total time of training about 11.4 ± 4.4 hours were involved in the study period. They showed, at least, one year of practice in the road cycling, and self-related competitive level of 5.4±0.914 years and were injury free. They were part of a local cycling team selected by a nonprobability sample, considering training status and competitive level, and signed an informed consent (the project has obtained approval from the local ethics committee, protocol 005/2012).

This is an experimental counterbalanced study, with repeated measures. Training amplitude was considered an independent variable and, general and local lower limbs RPE, HR, and HRV parameters as dependent variables.

The study had four separate sessions intercepted by 48 hours. At first, each cyclist filled a questionnaire with medical history and individual habits and realized incremental test to estimate maximal power output (Pmax). In the next three visits, they were submitted to three different training sessions with different amplitudes each, with the execution order determined randomly. All sessions occurred at the same time of day, between 4 and 8 pm, and were previously scheduled with the subjects involvement.

To estimate Pmax in watts (W), the maximal progressive test was applied in lower limb cycle-ergometer (Ergo Cycle 167, Ergo-Fit, Germany), compound by 5-min warm-up with fixed load of 50 W and free cadence. In the sixth minute the power was maintained, but, the cadence was increased to 85 rpm and was controlled until the end of the test, with a possible deviation of ±10 rpm. At each minute 50 W was added until overload of 200 W. Afterwards were the adopted increments of 15 W per minute until the cyclist could not complete the stage due to reported or observed fatigue by the evaluators[16]. In the latter case, the athlete does not support the minimum cadence of 75 rpm for more than five seconds[17].

The athletes were instructed not to perform vigorous exercise in the 24 hours preceding the Pmax test, in addition to not ingesting caffeine to prevent stimulatory effect and HRV modification[12]. These guidelines also were used in training sessions. In addition, they were asked to keep their routines without food, hydration and sleep changes during the data collection period.

The cyclists performed three training sessions with the same total duration (20 minutes), mean power (55% of Pmax) and the same cycle-ergometer used in the Pmax test to avoid ergonomic differences. The characteristic of differentiation in the protocols was the amplitude of the effort: pause relationship, shown in the equation: amplitude = exercise intensity – average intensity / average intensity x 100%[8,13].

The training sessions involved a continuous training (CT) and two interval protocols, with low (LAT) and high (HAT) amplitude. All sessions had the same warm-up procedure from Pmax test day. Table 1 describes and summarizes the training session protocols.

Height and body mass were measured in test session after the anamnesis in a digital scale accurate to 100 g (Filizola™, model ID-1500) with an anthropometer attached, with 0,1 cm precision.

For each subject, heart rate monitoring and recording were performed for five minutes before starting the training sessions, five minutes after the end of the sessions and 24 hours after each one. Previously, it was showed that five minutes of recording is considered valid and sufficient to obtain the desired information about HRV parameters[18]. All the samples were collected with athletes at rest, sitting on the cycle

Table 1. General characteristics of continuous and intermittent training sessions.

	CT	LAT	HAT
Stimulus total duration (min)	20	20	20
Effort: pause relationship	NA	1:1	1:1
Effort intensity (% Pmax)	55	80	110
Recovery intensity (% Pmax)	NA	30	0
Mean training intensity (% Pmax)	55	55	55
Training amplitude (%)	0	45.45	100

CT: Continuous training; LAT: Low amplitude interval training; HAT: High amplitude interval training; %Pmax: Percent value from maximal incremental test; NA: Do not apply.

ergometer and in pedaling position, because it faithfully represents the effort position taken during the cycling competitions[19].

The HRV parameters were registered with portable equipment (Polar™ RS800CX, Polar Electro, Finland) and filtering data procedures[20]. This equipment have its validity tested and aproved against ECG signal, as a gold standard, and other portalbe devices for HRV parameters[21,22]. Also, its HRV data reproducibillity was prooved to be reliable[23]. The HRV parameters were organized in two domains: time and frequency[4]. As to the time domain variables, the following were collected and analyzed: i) the mean of RR intervals (MeanRR); ii) standard deviation normal RR interval (SDNN); iii) root mean square of successive differences squared (RMSSD); and iv) percentage of successive RR intervals with a difference greater than 50 ms (pNN50). In the frequency domain variables, the following was considered of the spectral components: i) very low frequency component (VLF); ii) low frequency component (LF); iii) high frequency component (HF); and iv) LF/HF ratio[4].

The HR and HRV data were collected with heart rate monitor, transferred to Polar ProTrainer 5™ software and analyzed in Kubios HRV 2.0 software (University of Kuopio, Finland). To the HRV frequency domain, the limits were fixed in 0.15 – 0.40 Hz intervals to the HF, 0.05 – 0.14 Hz to the LF and 0.03 – 0.04 Hz to VLF. To the HR, mean and maximum values were considered, in beats per minute (bpm), obtained in each collected moment. To the frequency domain, data from pre- and 24h-post efforts were considered because conventional spectral analysis could not be used during the initial phase of recovery, because the RR intervals are not stationary[11].

With concern to RPE, identified by 0-10 Borg scale[24], in arbitrary units (au), information about general and local lower limb effort perception, 30 min after the training session was collected.

Data analysis was conducted with OriginPro 8.5. For descriptive statistics, mean ± standard deviation (sd) were used. The Mauchly test was employed to check the data sphericity, and the Greenhouse-Geiser correction was used when necessary[25]. Two-way analysis of variance (training protocol and moment), was conducted with repeated measure. When identified significance, Bonferroni post-hoc test was used to identify differences[26]. For the RPE, Kruskal-Wallis non parametric analysis of variance was applied and, when identified differences between moments or conditions a Dunn's post-hoc was conducted to identify differences. Significance level was set in $p \leq .05$.

Results

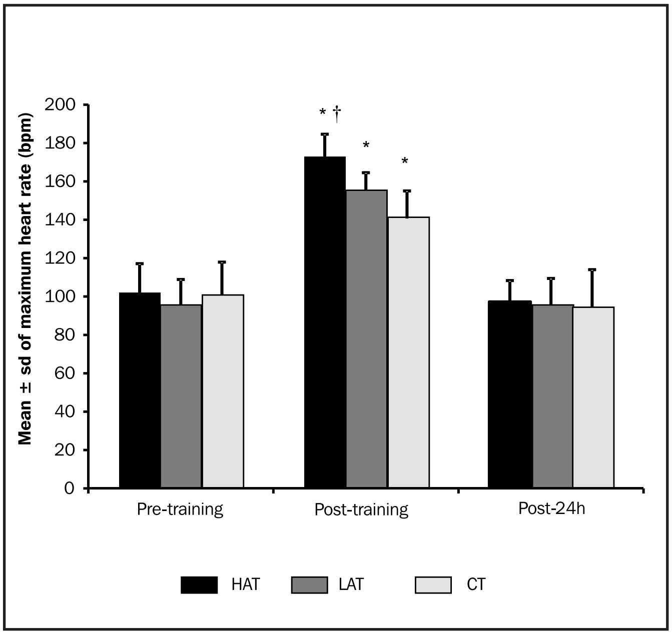
Concerning the descriptive characteristics, the athletes were shown to be 24.8 ± 6.9 years old, with a height of 1.8 ± 0.1 meters, 71.9 ± 5.9 kg of body mass and body mass index of 23 ±1.4. In the Pmax test, they showed a performance of 350 ± 26 W. So, the loads to the training sessions were: i) 192.5 ± 14.3 W in the CT; ii) 280 ± 20.8 : 105 ± 7.8 W in the LAT; and iii) 385 ± 28.6 : 0 W in the HAT.

Regarding the acute changes in cardiac level promoted by training, the mean HR reached higher values with statistical difference in the post-training (HAT: 123.2 ± 15.1 bpm; LAT: 111.2 ± 14.9 bpm; CT: 106.0 ± 15.9 bpm) compared to the pre-training moment (HAT: 81.2 ± 15.8 bpm; LAT: 78.2 ± 14.3 bpm; CT: 79.8 ± 10.8 bpm) and after 24h (HAT: 81.0 ± 12.8 bpm; LAT: 75.8 ± 12.6 bpm; CT: 77.6 ± 17.1 bpm), all $p <.001$. However, no significant differences were observed between training types.

For maximum HR, the three training protocols promoted similar response, with pre-training values (HAT: 102.0 ± 15.1 bpm; LAT: 95.6 ± 13.3 bpm, CT: 100.8 ± 17.1 bpm) significantly lower than the post-training values (HAT: 172.8 ± 11.8 bpm; LAT: 155.4 ± 9.1 bpm; CT: 140.8 ± 14.2 bpm, all $p <.001$) and return to resting levels after 24h (HAT: 96.6 ± 11.7 bpm; LAT: 95.6 ± 13.8 bpm; CT: 94.8 ± 19.2 bpm, all $p <.001$). However, we found a difference between HAT and CT in post-training moment, respectively 172.8 ± 11.8 bpm and 140.8 ± 14.2 bpm, with $p = .001$ (Figure 1).

The HRV results in the time and frequency domains are shown in Table 2. Among all comparisons, just the significant difference is highlighted between moments in LF, with the post-24h values being inferior to pre-training ($F = 6.94$; $p = .02$).

Figure 1. Descriptive measures of maximum HR to the three training types.



*: Statistically different from the pre-training and post 24h, in the same training protocol, with p<.001. †: Statistically different from CT in the same moment, with p:.001. CT: Continuous training. LAT e HAT: Low and high amplitude interval training protocols, respectively.

Table 2. Descriptive values (mean ± sd) of HRV in time and frequency domains, according training protocol.

	HAT	LAT	CT
MeanRR (ms)			
Pretraining	763.9 ± 155.7*	787.58 ± 135.58*	762.4 ± 103.3*
Posttraining	492.5 ± 59.3	546.32 ± 67.83	490.8 ± 256.8
Post-24h	757.1 ± 119.9*	807.50 ± 133.26*	801.3 ± 166.7†
SDNN (ms)			
Pretraining	66.4 ± 16.5	70.86 ± 23.30	76.4 ± 20.9
Posttraining	65.2 ± 23.8	78.84 ± 21.52	54.9 ± 14.1
Post-24h	54.2 ± 12.8	68.66 ± 29.83	60.1 ± 18
RMSSD (ms)			
Pretraining	38.1 ± 16*	44.74 ± 18.96*	50 ± 10.3†
Posttraining	7.2 ± 5.4	12.68 ± 6.49	13 ± 7.3
Post-24h	37.6 ± 15.4*	43.54 ± 24.09*	35.5 ± 16.2
pNN50 (%)			
Pretraining	18.1 ± 15.4†	21.82 ± 17.15†	26 ± 10.3†
Posttraining	0.6 ± 1.2	1.70 ± 1.34	1.4 ± 1.9
Post-24h	18.7 ± 12†	21.12 ± 19.50†	15.3 ± 14.5†
VLF (ms^2)			
Pretraining	1577.2 ± 713	1800.80 ± 808.04	2098.6 ± 886
Post-24h	1353.2 ± 846.2	1830 ± 1470.39	2090.2 ± 2099.9
LF (ms^2)			
Pretraining	1638.6 ± 811.5	2714.4 ± 2038.6	3693.2 ± 3875.8
Post-24h	1055 ± 608.4	1596 ± 1242.2	1270.4 ± 753.5
HF (ms^2)			
Pretraining	554.6 ± 268.2	696 ± 677.7	666.6 ± 305.9
Post-24h	621 ± 420.6	756.2 ± 849.2	431.4 ± 342.5
LF/HF (%)			
Pretraining	3.4 ± 1.7	5 ± 3.3	5.3 ± 4.5
Post-24h	3.2 ± 3.4	3.4 ± 2.6	3.8 ± 1.9

* and †: Statistically different from the post-training moment, in the same protocol, respectively p<.05, p<.01. CT: Continuous training. LAT e HAT: Low and high amplitude interval training protocols, respectively.

The general RPE values presented in HAT (9.0 ± 1.0 au) were statistically superior to LAT (3.8 ± 2.8 au; p = .002). Considering the local RPE, the results resemble those general RPE. In the HAT, differences were observed between moments (H = 9.47; p = .008), with the post-training moment (8.8 ± 1.3 au) being higher than pre- and post-24h (respectively 1.4 ± 1.3 and 1.2 ± 1.6 au; p < .05). Differences between moments were also observed in LAT (H = 8.82; p = .01), with the post-training (4.2 ± 2.2 au) higher than post-24h (1.0 ± 0.2 au; p < .05), but not than pre-training (RPE = 0.8 ± 1.1 au). The continuous training not provided were RPE post-training values (2.8 ± 1.5 points; H = 2.31; p = .31) different from the pre-training (2.4 ± 2.6 au) and post-24h (1.2 ± 1.1 au). Between trainings, the only difference observed was in RPE post-training, with values of the HIIT with higher amplitude greater than the continuous training (H = 9.64; p = .008).

Controlled by type of training and time, significant correlations were between general RPE (local an general) and HR and HRV variables (Table 3).

The comparative between subjects for the variables with statistical significance in HR and HRV parameters are presented in Table 4. Values from variables with no statistical significance are presented in supplementary document.

Discussion

In the present study, which aimed to evaluate the effects of different training programs in HRV, HR and RPE, the amplitude between effort and recovery loads was the variable adopted to differentiate the protocols. The main finding of the study was that the HAT provided greater local and general RPE than the CT protocol, and that this training has generated greater HR at the end of the stimuli when compared to CT. Furthermore, to the knowledge of the authors, this is the first time that three different training protocols, with different training amplitude, but with same mean intensity, were tested and modified the HRV relative to resting levels, and showed similar returns to resting values after 24h.

In another investigation with running, involving three training types with the same distance, but different effort intensity and duration, the authors observed that the protocols with wide variation between effort and pause loads (higher amplitude) produced the greatest impact on ANS, obtaining statistically significant correlations between RPE and HR with studied HRV parameters[11]. These data corroborate with the present study results, since for RPE and maximum HR, the values found at the time of the post-training HAT have greater impact on ANS in relation to the other two protocols.

In concerning to RPE, the training load appears to be a determinant factor of the values obtained immediately after training[11]. Indeed, the increased values after training were confirmed by observing the maximum HR at the same moment; this is information that ensures the relationship between the physiological and psychological impacts of training sessions[27]. Regarding cardiac responses to exercises, it was observed that, although the mean HR have remained similar between the types of training, the maximum HR reached higher values, and with

Table 3. Significant correlations between RPE (local and general), HR, and HRV variables.

	maxHR	meanHR	MeanRR	RMSSD	pNN50
General RPE	r = .47 p = .002	r = .44 p = .003	r = -.44 p = .003	r = -.45 p = .003	r = -.35 p = .02
Local RPE	r = .48 p = .001	r = .45 p = .002	r = -.46 p = .002	r = -.46 p = .002	r = -.36 p = .02

maxHR: maximum heart rate; meanHR: mean heart rate; MeanRR: the mean of RR intervals; RMSSD: root mean square of successive differences squared; pNN50: percentage of successive RR intervals with a difference greater than 50 ms.

Table 4. Individual values between moments, for variables with statistical significance in the three training protocols.

					HAT					
Subjects	**maxHR**		**meanHR**		**MeanRR**		**RMSSD**		**pNN50**	
	pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	86	169	69	104	874.9	576.2	51.3	10.6	29.7	0.2
Subject 2	120	192	99	146	608.4	410	25.7	2.6	6.1	0
Subject 3	112	173	92	125	653.5	479.6	30.4	4.4	8.3	0
Subject 4	87	170	61	121	976.2	495.5	59	3.5	39.4	0
Subject 5	105	160	85	120	706.7	501.2	24	15.1	7	2.8
					LAT					
	maxHR		**meanHR**		**MeanRR**		**RMSSD**		**pNN50**	
	pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	88	153	66	96	905	624.6	48.3	16.9	24.6	2.5
Subject 2	113	169	99	135	608.6	445.1	22.5	3	3.6	0
Subject 3	105	153	84	107	714.9	560.4	46.5	19.5	19.3	2.6
Subject 4	80	158	64	115	936.6	520.8	73	9.8	49.1	0.5
Subject 5	92	144	78	103	772.8	580.7	33.4	14.2	12.5	2.9
					CT					
	maxHR		**meanHR**		**MeanRR**		**RMSSD**		**pNN50**	
	pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
Subject 1	84	131	68	89	881.4	673.3	48.2	22.3	23.5	4.7
Subject 2	112	158	91	125	659.5	48.9	34	3.3	12.9	0
Subject 3	125	147	91	111	657	540.6	50.2	11.7	25.1	1.1
Subject 4	93	146	71	115	844.5	522.5	57.6	10.1	27	0.5
Subject 5	90	122	78	90	769.7	668.9	60.2	17.6	41.6	0.9

maxHR: maximum heart rate; meanHR: mean heart rate; MeanRR: the mean of RR intervals; RMSSD: root mean square of successive differences squared; pNN50: percentage of successive RR intervals with a difference greater than 50 ms.

statistical differences, in the HAT. This fact demonstrates the increased demand for blood supply in short duration and with intensity activities[28], like that applied in HAT.

For HRV, three variables representing the parasympathetic way showed similar patterns of change (MeanRR, RMSSD and pNN50), with a significant decrease in the post-training compared to the two rest moments. This represents predominant influence of the sympathetic component during exercise, characterized by the lower values found in the resting moments in all training protocols for these three variables[4]. A recent study showed that only intense continuous running (95% versus 75% of VO_2max) change HRV variables in post-exercise assessment, and that 24h can be sufficient to HRV recovery[29]. The present study showed that the same behavior is observed in HIIE protocols with different amplitudes. Here, the three training protocols similarly stimulate the ANS activation, and the HRV responding so close between them, showing that 24 hours of rest can be sufficient to organic recovery, at least, from the autonomic control (HRV) viewpoint. However, additional studies need to be conducted to analyze its impact on cardiovascular and neuromuscular variables[28,30,31].

As a study limitation, the authors pointed to the cycle ergometer used, because it has different dimensions than cyclists' equipment, allowing a few adjustments in order to find the better position of the athlete on it. Additionally, there was no record of the total distance fulfilled in each training session. It is indicated then that further studies consider these two points and, when possible, to test higher number of competitive cyclists with different fitness level.

From the results of this case series, it can be concluded that in the HAT, the training session with large amplitude, the impact promoted in RPE, and maximum HR was superior to continuous training protocol. Regarding the time-domain variables of HRV, a statistically significant difference of immediately post-training in relation to at least one of the rest values (pre-training and post-24h) in all protocols was found, but no observed differences were found in all HRV variables between the rest values. Therefore, it is considered that these training protocols have similar impact on the cardiac control by ANS and recovery pattern for the present study group and with these training conditions applied.

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