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RELATIONSHIP BETWEEN POST-EXERCISE HRV AND INTERNAL TRAINING LOAD IN TRIATHLETES

RELACIÓN ENTRE VFC POST-EJERCICIO Y LA CARGA INTERNA DE ENTRENAMIENTO EN TRIATLETAS

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ABSTRACT

The aim of the study was to relate post-exercise HRV values to internal training load components measured by three Training Impulse (TRIMP) methods in youth triathletes. The TRIMP methods were related to each other (r = 0,970 to 0,983, R^2 = 0,940 to 0,967), nevertheless, they showed significant differences in mean values ($p < 0,01$). Training significantly reduced HRV ($p < 0,01$) and there is a significant time effect on HRV recovery ($p < 0,01$). Post5 HRV reduction was negatively related to exercise intensity, volume at >90% HRres, and TRIMP values (r = -0,302 to -0,495, $p < 0,01$) and positively related with volume at <50% HRres (r = 0.488, $p < 0,01$). Immediate post-exercise HRV reduction can provide valuable information for assessment of physiological effects at intervallic or continuous training in youth triathletes.

KEY WORDS: Autonomic nervous system, TRIMP, exercise, autonomic responses, autonomic recovery.

RESUMEN

El objetivo del estudio fue relacionar valores de VFC post-ejercicio con componentes de carga interna de entrenamiento medida por tres métodos de Estímulo de Entrenamiento (*Training Impulse,* TRIMP) en triatletas juveniles. Los métodos de TRIMP estuvieron relacionados entre ellos (r = 0,970 a 0,983, R^2 = 0.940 a 0.967), sin embargo, mostraron diferencias significativas en sus valores promedio ($p < 0.01$). El entrenamiento redujo significativamente la VFC ($p < 0.01$) y existe un efecto significativo del tiempo en la recuperación de la VFC ($p < 0.01$). La reducción de la VFC en Post5 está negativamente relacionada con la intensidad del ejercicio, volumen en >90% FCres y valores de TRIMP (r = -0.302 a -0.495, $p < 0.01$) y positivamente relacionada con el volumen en <50% FCres (r = 0.488, $p < 0.01$). La reducción post-ejercicio de la VFC puede proporcionar información valiosa para evaluar efectos fisiológicos del entrenamiento interválico o continuo en triatletas juveniles.

PALABRAS CLAVE: Sistema nervioso autónomo, TRIMP, ejercicio, respuestas autónomas, recuperación autónoma.

INTRODUCTION

Internal training load quantification is an important part of the training process. The trainer must verify that the physical stimulus is sufficiently large to activate compensation mechanisms and it should not exceed the athlete´s ability to recover (1). The assessment methods of internal load based on heart rate (HR), known as training impulse (TRIMP) are frequently used in field scenarios because of their objective and practical nature. Banister introduced this concept in 1991 (2) calculating in TRIMP the duration of exercise in minutes multiplied by the average HR reserve (HRres) obtained during the training session and analyzed according to the intensity of exercise using the exponential relationship between fractional elevation of the HR and the blood lactate concentration (BL) (3,4). Although it has been reported that this method is useful for continuous activity, it has been stated that it cannot discriminate between continuous and intermittent training sessions that have the same duration and average HR, and that it is not valid for high intensity interval training with a high anaerobic contribution (5).

To solve this problem, several methods have been referenced in the literature. Edwards´ TRIMP uses five arbitrary training zones based on the percentage of maximum HR (HRmax), multiplying the elapsed time in each zone by arbitrary weighting factors (6). Lucia´s TRIMP uses three training zones based on the ventilatory thresholds with arbitrary weighting factors (7). There are references of another method similar to that of Lucia, but instead of using ventilatory thresholds, the authors evaluated lactate thresholds (8,9). Stagno´s TRIMP defined five training zones using physiological parameters and assigned arbitrary weighting factors according to the regression equation of the lactate curve using average team data (10). Manzi´s TRIMP, considered the most advanced, assigns individualized weighting factors to each HR value observed during exercise (11).

Akubat, Patel and Abt reviewed these methods (12) and noticed some limitations: a) The use of training zones can either underestimate or overestimate the internal load when exercise HR values approach the boundaries of the zones; b) Edwards' TRIMP training zones do not have a physiological basis; c) The TRIMP of Lucia and Edwards does not provide a physiological basis to establish the weighting factors; d) The weighting factor of Stagno's TRIMP does not reflect individual responses. The only method that apparently overcomes these limitations is Manzi´s TRIMP. However, so trainers and athletes can use this method, they must consider the time needed, the high-cost, access to laboratory installations, equipment, and qualified personnel.

HR variability (HRV) is a physiological marker that evaluates both the sympathetic and parasympathetic autonomic nervous system (ANS) and it is commonly used in clinical studies and research because of its apparent ease of calculation (13). Three methods have been used to analyze HRV: the time, frequency and non-lineal domains (13). It is thought that the frequency domain methods are not reliable in the context of very trained athletes since these indexes are affected by breathing frequency (BF)nand they can lead to a false classification of fatigue (14). Therefore, most recent studies prefer to use time domain methods, particularly, the square root of the mean of the sum of squared differences between adjacent R-R intervals (RMSSD) since these represent the short-term variability of HRV and parasympathetic modulation, which seem not to be affected by the BF and because of their reliability and sensitivity to detect physiological adaptations (5). One study proposes a new HRV index, the stress score (SS), which is thought to represent sympathetic activity (15). Before this study, we could not find any index that could be proposed as a unique indicator of sympathetic activity. The SS is based on a non-lineal model, the Poincare plot. The cross-sectional axis of the plot (SD1) reflects short-term changes of the R-R intervals and it is believed to be directly proportional to parasympathetic activity (15). The significance of the longitudinal axis (SD2) is not clearly defined but it seems inversely proportional to parasympathetic activity (15). The SS can be calculated with the inverse of SD2 and establish a sympathetic/parasympathetic relationship (15).

In sports scenarios, the HRV at rest is used to monitor the status of the ANS. It is believed that fluctuations of the HRV are related to training load adaptation (16). Although most studies use morning values at rest, interest in monitoring the acute effects of the training load on post-exercise HRV have increased. It has been stated that physical training changes the sympathetic impulse of the ANS to a parasympathetic withdrawal (17,18) and although the HRV values during exercise tend to zero regardless of volume or intensity (19), several studies agree that an immediate reduction of post-exercise HRV (in the first 2 to 5 minutes of recovery) is affected more by the intensity of the exercise than by the volume or duration (5,20,21).

The rate of post-exercise HRV recovery has also been studied since it can be explained by a reduction in sympathetic activity with a simultaneous increase in vagus nerve activation (5). Several studies state that the main factor that affects the delay in HRV recovery is the intensity of exercise (20,22–24) , and this is not affected by the training volume (22,23). When subjects train at low intensities (below the ventilatory threshold), a rapid recovery of the post-exercise HRV indexes can be seen (24). In high intensity training (above the ventilatory threshold), a delay in the recovery of the HRV indexes is observed, which can be attributed to the anaerobic nature of the activity, probably explained by metabolic reflex responses (20,24). The notion that intensity and not volume of training affects the delay in the recovery of HRV indexes can be misleading, since reviewed studies compare treatments of different duration in the same low intensity range. It would be interesting to see if HRV recovery is affected by changing the duration of high-intensity exercises. On the other hand, several studies maintain that post-exercise HRV recovery is also affected by training status (21,22). Furthermore, it has been stated that the exercise modality (intermittent vs. continuous) affects HRV recovery, but these results are ambiguous, since comparisons were made between treatments carried out at the same exercise intensity (25).

Although most studies that have measured immediate post-exercise HRV have considered volume and intensity, we found that the literature comparing these values with TRIMP values is incipient. Most studies compare TRIMP to HRV at rest to assess autonomic activity responses and adaptation to exercise (18,26). However, one study established a negative relationship between the TRIMPs of Manzi and Banister with post-exercise HRV values at 60, 120, and 180 seconds (23). Another study proposed a novel TRIMP method based on the HRV for continuous exercise, observing a reduction of HRV and recovery at 30 minutes as a function of training intensity multiplied by duration in minutes (5). This method showed a significant correlation and agreement with Banister´s TRIMP using treatments in controlled conditions of intensity and duration. Therefore, the objective of this study was to analyze the relationship between the estimation of internal load with different TRIMP methods and several post-exercise HRV indexes in young triathletes who participate in a true training regimen.

MATERIALS AND METHODS

SUBJECTS

Six young national level triathletes, four men (age 15 ± 0,8 years, height 167,6 ± 2,6 cm, body mass 54,9 ± 1,9 kg; % fat 12,7 ± 1,7) and three women (age 15 ± 2,7 years; height 165,3 ± 6,7 cm; body mass 51,5 ± 3,9 kg; % fat 20,5 ± 2,5), were invited to participate in the study. Data were collected during the preparation phase of macrocycle training for the national championship. Subjects who had any condition that could alter the results were excluded. Since all the subjects were minors, both the participants and their legal guardians voluntarily signed an informed consent that expressed their agreement to participate. The study was approved by the Bioethics Committee in Health Science Research of the Center for Research and Development in Health Sciences of the Universidad Autonoma de Nuevo Leon with registration number COBICIS-58/12/2017/02-FOD-BRRC. All procedures were performed in agreement with the guidelines established in the Helsinki declaration.

DESIGN

The total duration of the study was two weeks. The subjects performed two running training sessions per day, one in the morning and one in the afternoon. During this period be abstained from training cycling and swimming. HR was monitored during all training sessions. HRV measurements were carried out in each subject in a sitting position before and after each training session. This was an observational study.

METHODOLOGY

The HRmax was determined using an incremental effort field test (Leger test) by running until exhausted (27). HR was registered during the test and the maximum value observed was considered the HRmax. The HR minimum (HRmin) was considered as the lowest value observed during a five-minute at rest monitoring period before the test (3).

HRV measures consisted of recording R-R intervals in a sitting position (23). Subjects were instructed to not move or speak during the measure. Data were collected and recorded using a HR monitor that is capable of recording R-R intervals (Polar Team2, Finland). All the R-R series recorded by the HR monitor were extracted to a personal computer using a processing program (Polar Team2, Polar Electro) and to an Excel spreadsheet. Occasional ectopic beats were identified visually and these were replaced by interpolated adjacent R-R intervals. Kubios software (The University of Eastern Finland, Kuopio, Finland) was used to calculate HRV parameters (15).

HRV measures during each training session were performed at two different times, five minutes before warm-up (Pre5) and for 20 minutes after the training session. For a subsequent analysis, this second measure was divided into four five-minute periods (0-5 minutes, Post5; 5-10 minutes, Post10; 10-15 minutes, Post15; y 15-20 minutes, Post20). The measurement of HRV in a short period of five minutes, especially RMSSD, is a parameter that can be used to assess post-exercise recovery as an index of parasympathetic reactivation (28). A five-minute follow up after exercise seems to be sufficient to differentiate exercises with different internal loads (23).

For the analysis of HRV data, the time domains were restricted to Ln RMSSD (5). We abstained from using frequency markers of HRV because of their low reliability in the context of highly trained athletes (5).

In the non-lineal methods, we obtained the SD1 and SD2 indexes of the Poincare plot. Two additional indexes were obtained, the SS and the sympathetic/parasympathetic (S:PS) ratio (15) calculated in the following way:

$$SS = 1000 * 1/SD2$$

$$S:PS = SS/SD1$$

Three TRIMP methods based on HR were used to estimate the internal training load. Edwards´ TRIMP, Banister´s TRIMP and a new adjusted TRIMP proposed by the authors. Edwards´ TRIMP sums the time in minutes elapsed in each of the five discrete training zones relative to the %HRmax; a multiplier is associated to each HR zone providing greater weight to the highest HR values (6).

Banister´s TRIMP is based on the average HRres and the duration of exercise. The product of these factors is weighted by the blood lactate (BL) concentration predicted by the equation, which is different according to gender:

$$Banister\acute{}s\ TRIMP\ man = T * \frac{HRaxis - HRmin}{HRmax - HRmin} * 0.64 * e^{1.92 * \frac{HRaxis - HRmin}{HRmax - HRmin}}$$

$$Banister\acute{}s\ TRIMP\ woman = T * \frac{HRaxis - HRmin}{HRmax - HRmin} * 0.86 * e^{1.67 * \frac{HRaxis - HRmin}{HRmax - HRmin}}$$

Where:
T = The duration of the training session in minutes.

HRaxis = average HR of the training session in beats per minute.HRmin = HR at rest in beats per minute.
HRmax = maximum HR in beats per minute.
e = Napierian logarithm of 2,712.

With practical purposes, performance was evaluated with a new method called adjusted TRIMP. To calculate this, we used Banister's equation adjusted to sex to weigh each HR value observed during exercise at a sampling rate of one second, in the same way as with the Manzi method (11), overcoming the limitation of Banister´s TRIMP which uses average HRres.

For the ecological validity of the data, training sessions were designed and conducted by the athletes' trainer (21). The researchers abstained from participating in the training process. Two daily training sessions were conducted, at 8:00 am and at 5:00 pm. The morning sessions consisted of high intensity interval training and the afternoon sessions consisted of continuous low and moderate intensity training.

STATISTICAL ANALYSIS

All descriptive data are shown as mean ± SD. The normality of the data was verified with the Shapiro-Wilk test. Post-exercise HRV data were transformed by logarithm and normalized to a percentage of the individual pre-exercise values. The time duration of HRV recovery as a function of training modality was analyzed using an ANOVA of repeated measures of 2 training modalities for 4 recovery times. To compare the HRV values between the morning and afternoon sessions, a *t* test of related samples was used. Pearson´s correlation coefficient was used to study the relationship between post-exercise HRV and volume, intensity, and TRIMP values. Statistical significance was established as $p < 0,05$. SPSS statistical software version 22 (IBM Inc., Armonk, NY) was used to perform all the statistical analyses.

RESULTS

TRIMP methods were highly correlated with each other (Figure 1). Significant differences were found between the three methods regardless if the training session was intervallic or continuous (Table 1).

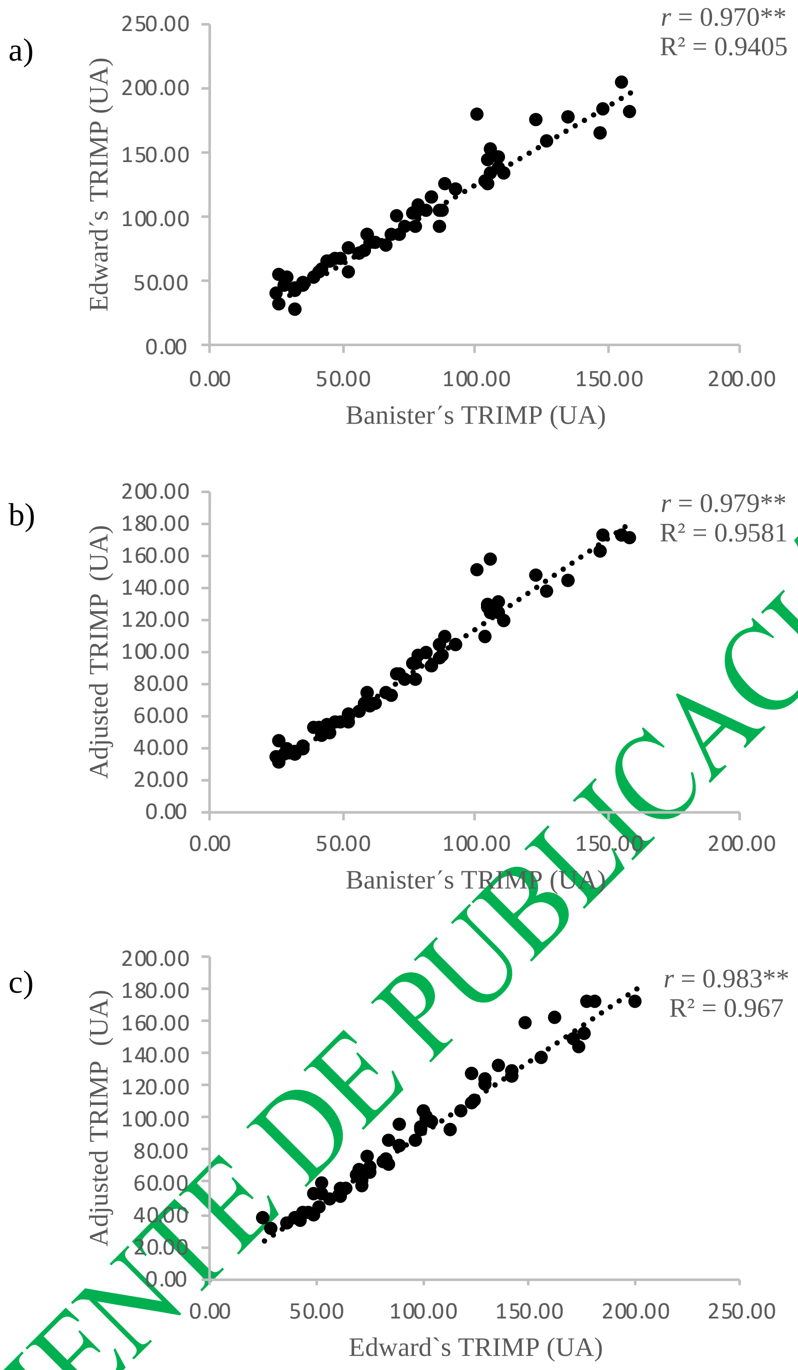

Figure 1. Correlations between TRIMP methods a) Edwards and Banister, b) Banister and Adjusted, c) Edwards and Adjusted; AU = arbitrary units; ** = $p < 0.001$.

Table 1. Difference in means of TRIMP methods.

Training mode	TRIMP method		
	Banister	Adjusted	Edwards
General	75.64 ± 35.65**	86.33 ± 40.87**	96.16 ± 44.58**
Continuous	75.01 ± 37.97**	83.74 ± 42.38**	94.71 ± 47.28**
Intervallic	77.83 ± 27.29**	95.29 ± 35.16**	101.15 ± 34.76**

** = Differences between the methods, $p < 0.01$.

The behavior of the HRV indexes in Pre5, Post5, Post10, Post15 and Post20 is shown in Figure 2. The training sessions significantly reduced HRV. Differences were found in the RMSSD, the SS and the S:PS between Pre5 and Post5 (p <o,01). The analysis showed a significant effect on HRV recovery time in parasympathetic markers and in the S:PS balance since all repeated measurements were different between them (p < 0,01). Ln SS, which is considered a marker of sympathetic activity, did not show a significant reduction until Post20.

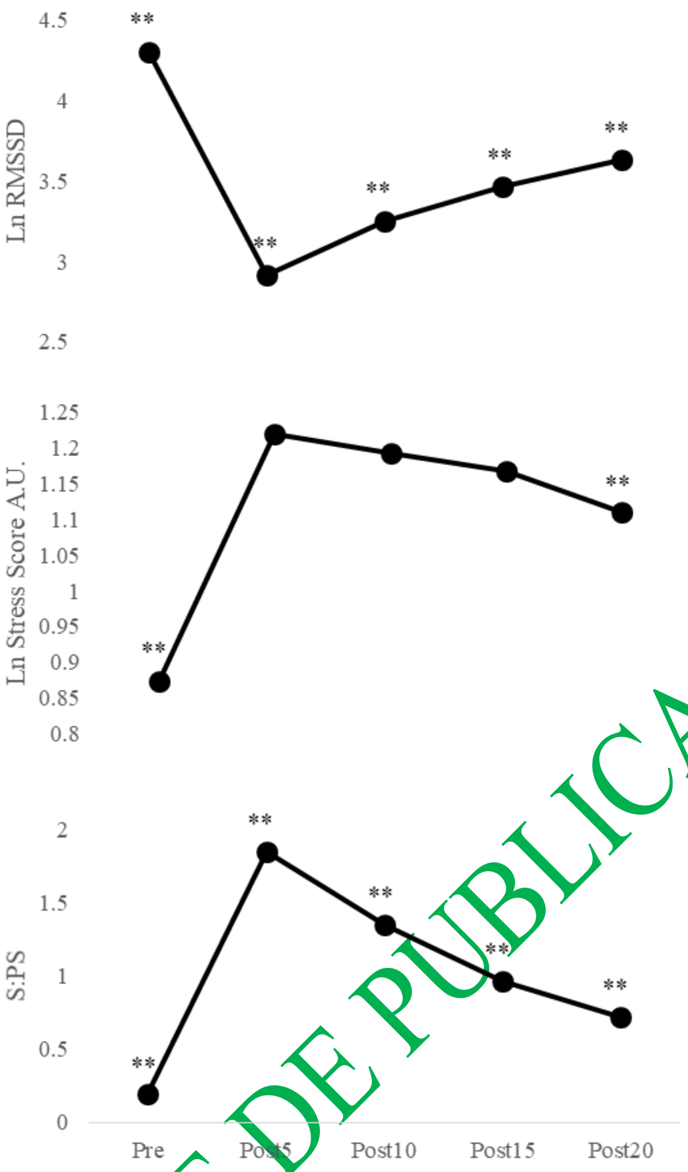

Figure 2. Differences in HRV values at the time of sampling. Ln RMSSD = Natural logarithm of RMSSD; Ln stress score = Natural logarithm of the Stress Score, S:PS = sympathetic/parasympathetic ratio (Stress score/SD1); ** = p <0.01.

The correlation coefficients between the HRV reduction relative to Pre5, Post5, Post10, Post15, and Post20 and the intensity of exercise, volume, and TRIMP are shown in Table 2. The reduction in the normalized Ln RMSSD in Post5 had no relationship with total minutes but showed a relationship with volume in time elapsed < 50% HRres and >92% HRres. None of the Post5 values of SS and S:PS had a relationship with any exercise or internal training load variable.

Table 2. Correlation coefficients of HRV indexes and training variables (intensity, volume and training stimulus).

	Intensity		Volume			TRIMP		
Normalized values relative to Pre5	mean HR	mean % HRres	Total minutes	< 50% HRres	> 90% HRres	Banister	Edwards	Adjusted
RMSSD Post5	-0.47**	-0.49**	0.03	.488**	-.030*	-0.32*	-0.37**	-0.34**
RMSSD Post10	-0.34**	-0.35**	-0.02	.302*	-0.33*	-0.19	-0.26	-0.23
RMSSD Post15	-0.21	-0.23	-0.02	.177	-0.29*	-0.14	-0.18	-0.19
RMSSD Post20	-0.15	-0.16	0.02	.132	-0.25	-0.07	-0.10	-0.11
SS Post5	-0.07	-0.05	0.16	.079	0.25	0.01	0.07	0.09
SS Post10	0.01	0.02	0.22	.076	0.14	0.02	0.09	0.07
SS Post15	0.07	0.10	0.17	.020	0.25	0.08	0.13	0.14
SS Post20	0.11	0.14	0.20	-.003	0.12	0.12	0.14	0.16
S:PS Post5	0.01	-0.02	-0.18	-.066	0.05	-0.11	-0.09	-0.09
S:PS Post10	0.07	0.04	-0.04	-.020	0.02	-0.06	-0.03	-0.05
S:PS Post15	0.06	0.04	-0.11	-0.03	0.04	-0.07	-0.07	-0.05
S:PS Post20	0.09	0.08	-0.20	-0.15	-0.06	-0.07	-0.09	-0.08

Note. HRV data of RMSSD and SS HRV in this table were logarithm transformed.
* = $p < 0.05$, ** = $p < 0.01$.

No relationship was found with any exercise or internal training load variable and HRV recovery parameters.

DISCUSSION

The objective of this study was to analyze the relationship between the estimation of internal training load with different TRIMP methods and several post-exercise HRV indexes in young triathletes who participate in a true training regimen. Also, a new methodology of internal training load quantification adjusted to the Banister TRIMP method is proposed.

The publications reviewed argue that the intensity of exercise is the main factor for HRV reduction post-exercise (5,20,25) and that it is not related to volume (29). Our results seem to confirm this since the general intensity measured as the mean HR of the training session and as the %HRres, are significantly related to the immediate parasympathetic reduction of HRV post-exercise and no relationship was found between post-exercise HRV and volume, considered as total minutes. However, we think that this approach is incomplete, since the studies reviewed only compare treatments of different volumes at low intensities and, as far as we know, none of these have compared different volumes and high intensities.

It has been said that parasympathetic heart suppression is mediated by the metabolic muscle reflex, with this being a key factor in parasympathetic index measurements of reduced HRV (30). It is also believed that the duration of exercise at very low intensities (below the first ventilatory threshold) seems to have little effect on the reduction of parasympathetic heart activity while the elapsed time at high intensity (above the second ventilatory threshold) is associated with reduced parasympathetic values (21). One possible explanation is that below the first ventilatory threshold, a preponderant aerobic energy system is used and the BL concentrations do not surpass the values at rest. In contrast, above the second ventilatory threshold, an anaerobic glycolytic energy system is mainly used. This causes BL concentrations to increase exponentially triggering metabolic reflexes that suppress parasympathetic activity. Although we did not measure BL in this study, we can say that the aforementioned agrees with our results, given that we found a positive correlation with post-exercise HRV indexes and the time elapsed at intensities <50% HRres, which are known to be predominantly aerobic; and we found a negative relationship with the elapsed time >90% HRres, which has been found to provoke higher BL concentrations.

It is thought that the time elapsed between the first and second lactate threshold does not seem to have an effect on HRV reduction (21). Although the BL concentration exceeds the values at rest at these intensities, by the combination of the energy supply between aerobic and anaerobic systems, the body is capable of metabolizing lactate at the same rate that it is produced, maintaining a stable state. This agrees with our results, since HRV reduction and the time elapsed between the 50% and the 90% HRres did not have any relationship. This contradicts the report that establishes the first lactate threshold as a binary value for autonomic heart alterations (22).

HRV recovery is explained by a reduction of sympathetic activity and an increase in parasympathetic activity (5). Apparently, all the studies that analyze post-exercise recovery of HRV only use parasympathetic indexes. This study explores the use of SS as a sympathetic index and the S:PS ratio as an indicator of autonomic balance (15). A significant effect of time on the recovery of Ln RMSSD was found in Post5, Post10, Post15 and Post20. It is believed that sympathetic withdrawal contributes more to early HRV recovery (23). But this does not seem to be the case in this study, since the results do not show a reduction of SS until Post20. Apparently, the sympathetic and parasympathetic activities do not follow the same trends causing the S:PS ratio to show a non-lineal response to the effect of time on HRV recovery. It has been reported that post-exercise HRV recovery reaches baseline values between 15 and 30 minutes, approximately (22). None of the HRV parameters in our study, Ln RMSSD, Ln SS and S:PS, reached baseline value levels at Post20.

As with HRV reduction, it is said that HRV recovery is affected mainly by exercise intensity and not by volume (20,23). Several studies maintain that the duration of exercise performed below the first ventilatory threshold is related to a rapid post-exercise reactivation, but this is significantly delayed with higher intensities (20,22,23,30). Others mention that post-exercise parasympathetic reactivation is a response to training individualized to the specificities and content of exercise (5). Our results agree with the statement that HRV recovery is a multifactorial process that does not depend only on volume, intensity or even internal training load (31). We did not find a relationship between HRV recovery and any training load variable. The results suggest that for the analysis of HRV recovery, it is important to consider the subject´s condition, state of fatigue, and training level (22).

It is stated that the Banister TRIMP method does not discriminate between continuous, intermittent or interval training since it uses the mean HRres of the session (5). We have adjusted this method adopting the Manzi process of considering all and each of the HR values observed during the training session and weighing each of these values individually with a factor instead of averaging them. We examined if this modification presented a better relationship with interval training and HRV values. We found greater differences in interval training in comparison with continuous training between the Banister and adjusted method, although these use the same weight factor. This suggests that the adjusted method is more sensitive for quantifying changes in intensity during training than mean HRres values. The Banister method shows a lower correlation coefficient with Post5 Ln RMSSD, while the Edwards and adjusted methods correlate better. It seems that the method takes into account the changes in exercise intensity during training, whether in training zones or considering each individual HR value; this offers better interpretation of the physiological effect of exercise on the body.

The use of post-exercise HRV has been explored as a marker of internal training load (5,20), establishing relationships between the HRV and rate of perceived exertion (RPE) as measures of training intensity; however, no relationship has been found between the Banister TRIMP and HRV, thus, the previous results do not recommend the use of post-exercise HRV as an indicator of internal training load(20). Our results contradict this position, since a significant relationship between Post5 Ln RMSSD and the Banister, Edwards and adjusted TRIMP methods was found. This suggests that the reduction in HRV can be an indicator of internal training load. This relationship weakens from Post10 until Post20, confirming that HRV recovery is not related to internal training load parameters. The Post5 Ln SS and S:PS indexes are not related with the TRIMP methods. This suggests that Ln RMSSD is a more viable option for assessing internal training load than the sympathetic and sympathetic/parasympathetic indexes. Triathlon trainers can consider the use of this method in combination with HRV values at rest and TRIMP calculations to assess the fitness-fatigue status of youth triathletes.

CONCLUSION

The aim of this study was to analyze the relationship between internal load, quantified by several TRIMP methods, and the decrease and recovery of several post-exercise HRV indices in youth triathletes using measurements made in the field. The reduction of sympathetic, parasympathetic and sympathetic/parasympathetic balance rates of the HRV not only provides objective and rational information on the intensity of the training session, but also the volume and total internal load, evidenced by the relationship shown with TRIMP methods accepted as a measure of internal training load. HRV recovery after triathlon training is a complex phenomenon that does not seem to be related with the volume or intensity of exercise but with the training and fitness status of the subject. For this reason, it seems inappropriate to use this parameter to assess the internal training load in youth triathlon training.

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