Parasympathetic recovery following exercise as a measure of training load

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Summary

In the Heart Rate Variability (HRV), the RMSSD (root mean square of the successive differences between adjacent RR intervals in ms) is the most used indicator of parasympathetic activity in sport. Its recovery after an effort can be a good indicator of workload but there is some controversy about how to use it and its relationship with intensity or volume.
After a maximum stress test to determine ventilatory thresholds (VT1 and VT2), 14 physically active men performed two separate tests for 48-72 hours. In the first one, subjets ran for 20 minutes to VT1 speed. In the second one, subjets ran to VT2 speed a time in which the product of intensity per duration was the same as VT1 (5 minutes warming-up). In both sessions, we measured the HRV during 10 minutes at rest and up to 10 minutes after the exercise, in a sitting position, with a Polar V-800 device. The subjective perception of effort on the Borg scale was recorded.
The RMSSD was calculated obtaining the slope formed by the values of the 10 minutes of recovery (Slope-10).
During the exercise, there was an identical and very significant fall ($p < 0.001$) of RMSSD in both tests. All recovery values remained significantly below those at rest, being higher in VT1 compared to VT2. Slope-10 values were 1.51 at VT1 and 0.34 at VT2, inversely correlating with the Borg scale ($r = -0.63$).
The parasympathetic reduction produced by any workload is independent of the type of work performed. The recovery of the parasympathetic system is inverse to the intensity of the work done. The recovery slope of the RMSSD is a good indicator of internal load.

Key words:
Heart rate Variability.
Workload. RMSSD.

La recuperación parasimpática tras el esfuerzo como medida de carga de trabajo

Resumen

En la variabilidad de la frecuencia cardiaca (VFC), la RMSSD (raíz cuadrada de la media de las diferencias de la suma de los cuadrados entre intervalos RR adyacentes) es el indicador de actividad parasimpática más utilizado en el deporte. Su recuperación tras un esfuerzo puede ser un buen indicador de carga de trabajo, pero existe cierta controversia sobre cómo utilizarla y sobre su relación con la intensidad o el volumen.
Tras una prueba de esfuerzo máxima para determinar umbrales ventilatorios (VT1 y VT2), 14 hombres físicamente activos realizaron dos pruebas separadas por 48-72 horas. En la primera, corrieron durante 20 minutos a velocidad de VT1. En la segunda, corrieron a velocidad de VT2 un tiempo en el que el producto de intensidad por duración fuese el mismo que el VT1 (calentamiento 5 minutos). En las 2 sesiones, medimos la VFC durante 10 minutos en reposo y hasta 10 minutos posterior al ejercicio, en posición sentado, con un dispositivo Polar V-800. Se registró la percepción subjetiva del esfuerzo en escala de Borg.
Se calculó la RMSSD obteniendo la pendiente formada por los valores de los 10 minutos de recuperación (Slope-10).
Durante el ejercicio, se produjo una caída muy significativa ($p<0{,}001$) de la RMSSD idéntica en ambas pruebas. Todos los valores de recuperación se mantuvieron significativamente por debajo de los de reposo, siendo superiores en VT1 respecto a VT2. Los valores de Slope-10 fueron de 1,51 en VT1 y 0,34 en VT2, correlacionando inversamente con la escala de Borg ($r = -0.63$).
La reducción parasimpática producida por una carga de trabajo es independiente del tipo trabajo realizado. La recuperación del sistema parasimpático es inversa a la intensidad. La pendiente de recuperación de la RMSSD es un buen indicador de carga interna.

Palabras clave:
Variabilidad de la frecuencia cardíaca.
Carga de trabajo. RMSSD.

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Introduction

The use of heart rate variability (HRV) in the field of sports and physical activity has grown in recent years as it provides a non-invasive tool to assess sympathetic and parasympathetic modulation[1,2].

The control of the training load (TL) in athletes[3] is currently one of the main challenges in training research and several authors advance HRV as a valid method for assessing individual responses to such loads[4,5]. However, there are still too many methodological discrepancies and conflicting results to draw any clear conclusions which can easily be applied to control training.

The method most commonly used is the measurement of HRV immediately after exercise to assess the way in which the values are recovered. But there is no work methodology, there only existing laboratory studies[6-9] and studies which evaluate complete training sessions[4,5,10,11] or sessions designed specifically in the field[12].

Nor is there uniformity in the variables measured: some authors use time-domain variables[6,10,13], others use frequency-domain variables[14] and others use both[15-17].

When analysing the HRV response after an exercise load, most studies focus on the effects of intensity[14,16-18], although some studies show changes related to the duration of the exercise[19] and others centre on both aspects[7].

In summary, although agreement is not absolute and no uniform methodology exists, the predominant idea in the literature would seem to be that: a) time-domain variables generate fewer discrepancies than frequency-domain variables[20]; b) exploring various exercise intensities is more useful[7,16,17]; c) immediate recovery of the parasympathetic variables (especially RMSSD or its natural logarithm) depends primarily on the intensity of the exercise[1].

In the literature reviewed, however, these variables (intensity and volume) are not adjusted to make the load obtained the same, so there is no information on the behaviour of HRV against TL as a whole.

Moreover, no useful indexes which can easily be applied to control responses to training loads on a daily basis have been extracted from the behaviours observed following exercise. Although some indexes have been described[6,8], their application does not throw up consistent data and they have not been used on an everyday basis.

This study, therefore, centres on analysing the RMSSD response in two tests of different intensity and duration, but with the same TL, in order to design a recovery index based on RMSSD which may prove useful when assessing athletes.

Materials and methods

14 physically active, healthy, male non-smokers (age: 20.93 ±1.38 years old; weight: 75.34 ± 10.07 kg; height 178.04 ± 5.83 cm; VO_2max 49.33 ± 3.93 ml · kg^{-1} · min^{-1}) took part in the study.

Following the general Task Force recommendations[2], all the subjects were told not to drink alcohol or caffeine-based drinks and to refrain from physical activity during the 24 hours prior to each test.

Each participant was subjected to an anamnesis to ensure that they were not under treatment or had any cardiovascular or other type of disorder which might affect or alter the state of the autonomic nervous system. All the subjects were informed about the procedure and gave their written consent to participate in the experiment. The Ethics Committee approved the study, which respected all the principles expressed in the Declaration of Helsinki.

The experiment lasted a total of 2 weeks and consisted of three sessions separated by 48-72h at about the same time of day 10 a.m. (± 2 h), maintaining stable environmental conditions (temperature and humidity).

In the first session, each subject filled in a background questionnaire and his height and weight were recorded. An incremental and maximum cardiopulmonary exercise test was conducted on an Ergo Run Medical 8 treadmill (Daum Electronic; Fürth, Germany), following a staged protocol with an initial load of 7 km/h at an inclination of 1% for 3 minutes with 1 km/h increases every minute until exhaustion. The test was performed with a BreezeSuite CPX ergospirometer (Medical Graphics, St. Paul, Minnesota, USA) calibrated before each measurement. The breath data were obtained breath by breath using a differential pressure flowmeter and the inspired and expired fractions of O_2 and CO_2 were obtained using a galvanic cell sensor and an infrared sensor, respectively.

For the purposes of this study, the positions of the ventilatory thresholds (VT1 and VT2) were determined following each test using the ventilatory technique proposed by Skinner and McLellan[21], and the speed corresponding to each threshold was recorded. VO_2max and maximum aerobic speed (MAS) were also determined for reference purposes.

In the second session, each subject ran constantly for 20 minutes at the VT1 speed and, given the low intensity, without warming up.

In the third session, each subject ran constantly at the VT2 speed for a time set so that the product of intensity by duration was the same as at VT1. This test was preceded by a 5 minute warm-up at 60% of each subject's VAS.

This ensured that both tests involved the same TL, which was calculated in each session as the product of intensity (speed) by volume (time)[20]. By expressing speed in km/h and time in hours, the TL was expressed as the distance travelled in kilometres.

In sessions 2 and 3, a Polar V800 pulse watch with H10 HR sensor chest strap (Polar Inc., Kempele, Finland) was worn from 10 minutes before the test until 10 minutes after completion of the test to measure HRV. All pre- and post-exercise measurements were taken seated in a calm and quiet environment. In all the sessions, the subject had to sit down immediately on completing the test (without active recovery) to measure recovery.

The RR interval time series were exported via the Polar FlowSync application (version 2.6.2) for analysis with Kubios HRV software (Version 2.1, University of Eastern Finland, Kuopio, Finland).

In each session, the last 5 minutes of the recording at rest (rest) and during exercise (exer.) were taken. In the case of the 10 minutes of recovery, the measurements were divided into two 5-minute periods (rec. 5 and rec. 10).

In order to develop a simple method which would be easy to use in real situations in which athletes are assessed, we chose to use a single variable of parasympathetic state for analysis. In accordance with the literature, RMSSD was calculated in the time domain[2], this being the tool most used to assess parasympathetic activity[20,22].

Each recording analysed was previously examined to detect the possible presence of artifacts and abnormal heartbeats, proceeding, when necessary, to apply the appropriate filters.

In each exercise session, the Borg scale 1-10 was used to subjectively rate perceived effort[23].

To compare with these algorithms, and in order to advance a recovery index based on HRV, we calculated the recovery slope of the RMSSD values over the 10 minutes based on the final value of the exercise for each of the intensities used in the experiment (VT1 and VT2). In this way, we devised an index called Slope-10 which could be applied without difficulty in real assessment situations.

Statistical analysis

First, descriptive statistics were calculated to present all the data through mean and standard deviation. Then hypothesis tests were conducted. First of all, the Kolmogorov-Smirnov test was used to test the normality of the distributions. Then Levene's test was used to assess the equality of variances and, there being more than two independent distributions, an ANOVA test was applied with a Games-Howell post-hoc test. To rule out the null hypothesis, a significance level of $p < 0.05$ was used for a confidence level of 95%.

To analyse the relationship between the slopes proposed and other load variables, a Pearson correlation analysis was run.

Statistical analysis was conducted using SPSS version 15.0 for Windows (SPSS Inc, Chicago, IL).

Results

Table 1 shows the data for intensity (speed), duration and TL, and the Borg scale values for the two tests.

Table 2 shows the RMSSD values measured at rest in the last 5 minutes of exercise and throughout recovery. The p-values are shown comparing each datum with the at rest value and those of recovery with exercise.

There were no significant differences in baseline HRV between tests. Significant differences were observed in RMSSD in every minute of recovery at the 2 intensities compared to at rest.

Figure 1 shows a comparison of the RMSSD data and their evolution during the two tests conducted. In this figure, the p-values show the differences between the two exercise intensities. No differences between the two tests can be observed in the RMSSD values during either rest or exercise. However, there were significant differences ($p < 0.05$) between the two tests throughout recovery.

Table 3 shows the mean, minimum and maximum Slope-19 values for both exercise loads.

Table 1. Characteristics of the tests.

	VT1	VT2
Speed (km/h)	10.24 ± 1.44	13.71 ± 0.89
Time (h)	0.33 ± 0	0.22 ± 0.05
TL (km)	3.43 ± 0.48	3.43 ± 0.88
Borg (1-10)	3.93 ± 0.92	7.57 ± 1.74

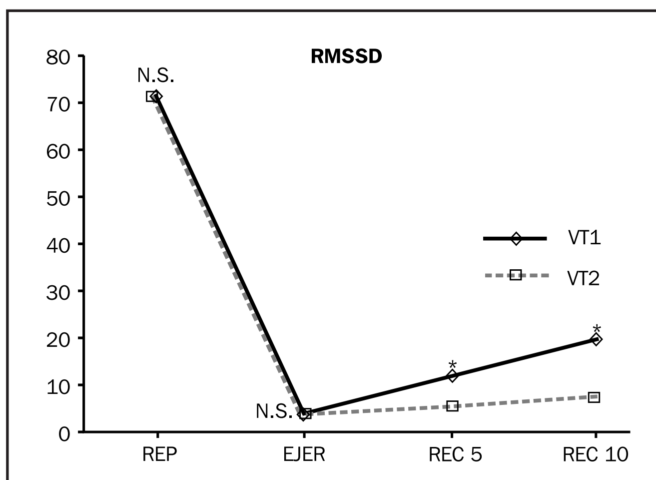
VT1: first ventilatory threshold; VT2: second ventilatory threshold; TL: training load.

Table 2. RMSSD values in the tests.

		RMSSD	
		VT1	VT2
REST	Mean	71.24	71.15
	SD	31.22	21.69
EXER.	Mean	3.92	4.26
	SD	1.11	0.83
	p (rest)	0.000	0.000
REC. 5	Mean	12.21	5.15
	SD	7.77	2.02
	p (rest)	0.000	0.000
	p (exer.)	0.025	0.782
REC. 10	Mean	19.56	7.69
	SD	10.33	4.58
	p (rest)	0.001	0.000
	p (exer.)	0.001	0.184

RMSSD: root mean square of the successive differences in ms; VT1: first ventilatory threshold; VT2: second ventilatory threshold; Rest: at rest; Exer: exercise; Rec: recovery; SD: standard deviation.

Figure 1. Evolution of the RMSSD values in the tests.



RMSSD: root mean square of the successive differences in ms; VT1: first ventilatory threshold; VT2: second ventilatory threshold; Rest: at rest; Exer: exercise; Rec: recovery. NS: not significant.

The Slope-10 index has a Pearson correlation coefficient (r) of 0.37 with TL, -0.63 with the Borg scale, -0.16 with VO_{2max} at VT1 and -0.11 with VO_{2max} at VT2.

Table 3. Values of the RMSSD recovery slope.

	Slope-10 Min	Mean	Max
VT1	0.64	1.51	2.49
VT2	0.10	0.34	0.72

RMSSD: root mean square of the successive differences in ms; VT1: first ventilatory threshold; VT2: second ventilatory threshold; MIN: minimum; MEAN: mean; MAX: maximum.

Discussion

The main finding of this study is that the reduction in parasympathetic stimulation produced by the same training load is independent of the type of exercise performed, while recovery of the autonomic nervous system depends on exercise intensity.

RMSSD suffers a significant drop in its values regardless of the intensity and duration of the exercise (Figure 1). Therefore, we can say that the suppression of parasympathetic stimulation during physical exertion is total regardless of the intensity, provided that the TL is the same. However, once recovery starts, a progressive increase in RMSSD values can be seen which is significantly faster when the intensity is lower (VT1). Other studies also find that RMSSD recovery is much quicker at lower intensities[1,6,14,16,17].

Nevertheless, these studies do not measure intensities according to thresholds but as percentages of HR_{max}; nor is intensity adjusted to duration[7,19] as we have done with the VT1 and VT2 loads to obtain the same TL.

Since RMSSD recovers faster, the lower the intensity and this results in a different slope for each situation, we understand that the numerical value of that slope could be a good indicator of the ease of recovery and, therefore, the internal load that the exercise supposes. That is to say, the steeper the recovery slope, the less the internal load. For our purpose, we assessed the slope in the first 10 min of recovery (SLOPE-10) trying to find an indicator easy to measure in real situations after training.

When these slopes were compared with the Borg scale, which is another common internal load indicator, they were found to correlate well and inversely (r = -0.63). Table 3 shows the Slope-10 values to be expected as a reference for each of the intensities studied.

In conclusion, reduction in parasympathetic stimulation is independent of the type of exercise performed and its recovery depends on the intensity of the exercise. The RMSSD recovery slope would seem to be a good indicator of the internal training load.

Conflict of interest

The authors declare that they are not subject to any type of conflict of interest.

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