Rev Andal Med Deporte. 2020; **13**(**2**): *71-75*

JUNTA DE ANDALUCIA
CONSEJERÍA DE EDUCACIÓN Y DEPORTE

Revista Andaluza de
Medicina del Deporte

https://ws072.juntadeandalucia.es/ojs

Original

Basal and post-exercise heart rate variability correlates with training load in endurance athletes

C.Nieto-Jiménez[a], J. F. Ruso-Álvarez[b], E. Pardos-Mainer[c], M. Schnettler-Ramírez[d], J. Naranjo Orellana[b]

[a] *Universidad del Desarrollo. Santiago. Chile.*
[b] *Pablo de Olavide University. Department of Sport and Computing. Seville. Spain.*
[c] *San Jorge University. Villanueva de Gállego. Zaragoza. Spain.*
[d] *Universidad Católica de Chile. Escuela de Medicina. Santiago. Chile.*

ARTICLE INFORMATION: Received 9 September 2019, accepted 4 February 2020, online 13 March 2020

ABSTRACT

Objective: Heart rate variability has been proposed as a valid method to examine the individual response to training load in endurance athletes. Thanks to this tool, the relationship between basal and post-exercise Heart rate variability measurements can be analyzed during a microcycle (one week) using straight values or their coefficients of variation.
Method: Ten amateur endurance athletes (n = 5 men, n = 5 women) were monitored during a 7-day microcycle that included three road-cycling sessions, two running sessions and two trail-running sessions. The RR series were measured for 5 minutes upon wake up and after training, in a seating position, using a chest strap.
Results: Basal and post-exercise Heart rate variability measurements showed high correlation when weekly mean values were used, very similar to when coefficients of variation values were used. In women, the root mean square of successive differences (RMSSD) was: r= 0.73; RMSSD coefficients of variation (RMSSDcv) was: r= 0.66; natural logarithm (Ln) RMSSD: r= 0.68; LnRMSSDcv: r= 0.79; and in men it was root mean square of successive differences: r= 0.78; RMSSDcv: r= -0.62; LnRMSSD: r= 0.75; LnRMSSDcv: r= -0.73).
Conclusion: the relationship between these two measurements could be useful to program the training loads of the following microcycle.
Keywords: RMSSD, Endurance training, Training load, HRV.

La variabilidad de la frecuencia cardíaca basal y posterior al ejercicio correlaciona con la carga de entrenamiento en atletas de resistencia.

RESUMEN

Objetivo: La variabilidad de la frecuencia cardíaca se ha propuesto como un método válido para examinar la respuesta individual a la carga de entrenamiento en atletas de resistencia. El objetivo de este estudio fue analizar la relación entre las mediciones basales y post ejercicio durante un microciclo (una semana) utilizando valores directos o sus coeficientes de variación.
Método: Se monitorizó a diez atletas aficionados de resistencia durante un microciclo de 7 días, que incluyó tres sesiones de ciclismo de ruta, dos sesiones de carrera y dos sesiones de trail running. Las series RR se midieron durante 5 minutos al despertar y después del entrenamiento, en posición sentado, utilizando una banda torácica.
Resultados: Las mediciones de variabilidad de la frecuencia cardíaca basales y post ejercicio mostraron una alta correlación cuando se usaron valores medios semanales, como cuando se usaron valores de los coeficientes de variación. En mujeres la raíz cuadrada de la media de las diferencias de la suma de los cuadrados entre intervalos RR adyacentes (RMSSD) fue: r = 0.73; el coeficiente de variación (cv) de la RMSSD fue RMSSDcv: r = 0.66; el logaritmo natural (Ln) de la RMSSD (LnRMSSD) fue: r = 0.68; LnRMSSDcv: r = 0.79; y en los hombres fueron RMSSD: r = 0.78; RMSSDcv: r = -0.62; LnRMSSD: r = 0.75; LnRMSSDcv: r = -0.73.
Conclusiones: La relación entre estas dos mediciones podría ser útil para el programa de entrenamiento del microciclo posterior.
Palabras Clave: RMSSD, Entrenamiento resistencia, Carga entrenamiento, VFC.

∗ Corresponding author.
E-mail-address: . c.nieto@udd.cl (C.Nieto-Jiménez).

https://doi.org/10.33155/j.ramd.2020.02.011

A variabilidade da frequência cardíaca basai e pós-exercício está correlacionada com a carga de treinamento em atletas de resistência

RESUMO

Objetivo: A variação da frequência cardíaca tem sido utilizada como método de análise de respostas individuais a carga de treino em atletas de endurance. Graças a esta ferramenta, a relação entre a variação da frequência cardíaca basal e pós-exercício pode ser analisada durante um microciclo (uma semana) usando valores diretos ou seus coeficientes de variação.

Método: Dez atletas de endurance amadores (n = 5 homens, n = 5 mulheres) foram monitorados durante microciclos de 7 dias que incluíram 3 sessões de ciclismo em estrada, duas sessões de corrida e duas sessões de corrida em trilha. As series de RR foram medidas durante 5 minutos depois de acordar e depois do exercício, em posição sentada, com recurso a cardiofrenquencímetros toráxicos.

Resultados: Os resultados mostram uma correlação alta entre as medidas de variação de frequência cardíaca basal e pós-exercício quando utilizados valores médios semanais, muito semelhantes aos resultados quando utilizados coeficientes de variação. Nas mulheres, a raiz quadrada media das diferenças sucessivas (RMSSD) foi: r= 0.73; coeficientes de variação RMSSD, (RMSSDcv) foi: r= 0.66; logaritmo natural (Ln) RMSSD: r = 0.68; LnRMSSDcv: r= 0.79; e nos homens, raiz quadrada media das diferenças sucessivas r= 0.78; RMSSDcv: r= -0.62; LnRMSSD: r= 0.75; LnRMSSDcv: r= -0.73).

Conclusão: a relação entre estas duas medidas poderia ser útil para prescrição de cargas de treino dos microciclos seguintes.

Palavras-chave: RMSSD, Treino resistido, Carga treino, VFC.

Introduction

Heart rate variability (HRV) is a non-invasive tool that allows for parasympathetic modulation assessment[1,2] and it has been proposed as a valid method to examine the individual response to training load.[3-6]

According to the literature, one way of assessing this individual response within the time domain[7] is the root mean square of the squares of the differences between adjacent RR intervals (RMSSD), which has become the most widely used statistic to assess parasympathetic activity.[8,9] It is common to find this variable expressed as its natural logarithm or LnRMSSD[10], what allows for parametrical data analysis[11] and yields lower day-to-day variability than other HRV indexes, such as those related with the frequency domain.[10]

Some authors use RMSSD (or its Ln) for daily monitoring of athletes, while others suggest using the coefficient of variation (CV) of this variable along several days.

Within the first group, there are various authors who analyzed LnRMSSD response in daily measurements in football players. Thorpe et al.[12] studied professional players during two weeks of training and found slight fluctuations the days prior to a game. Flatt et al.[13] reported changes in female football players during five high-load weeks, while they observed no clear changes during low-load weeks. Besides, Ravé and Fortrat[14] found no fluctuations in LnRMSSD during a 4-week training period including one tapering week. With regard to individual sports, Nieto-Jiménez et al.[15] reported the usefulness of daily LnRMSSD measurements upon wake up in order to monitor the parasympathetic tone during a 16-week competitive period in an ultra-trail and Ironman female athlete.

Within the second group, some studies stated that high CV values would be associated with poorer physical fitness and higher perceived fatigue,[16] while low CV values could mean progressive adaptation to training.[16,17] In line with this, the CV of LnRMSSD in professional athletes showed fluctuations ranging between 4 and 9% during training periods in elite rowers[18] and elite triathletes.[19,20]

Nonetheless, all these studies used daily basal measurements (generally in the morning), but did not provide measurements conducted on the same day after the training session, which would be a good indicator of internal load.[4]

So, there is a double problem to highlight: 1) Is the information of daily RMSSD better than its CV along several days? 2) Is the basal measure related to the response to the training load?

Consequently, the aim of the present study was to analyze the relationship between daily basal and post-exercise RMSSD measurements during a microcycle, using both straight measurements and CV values.

Methods

Sample

Ten amateur endurance athletes, 5 women (age 30.62 ± 2.81 years, height 164.44 ± 4.12 cm and body mass 56.20 ± 4.65 kg) and 5 men (age 39.20 ± 6.80 years, height 174.40 ± 2.90 cm and body mass 67.20 ± 5.20 kg), were monitored during a 7-day microcycle that included three road-cycling sessions, two running sessions and two trail-running sessions. This sample is a Trail running team because it is a pilot study, whereas it had been prioritized having a group under the same coach; therefore, under the same work system.

Experimental Design

The external training load (ETL), as the product of intensity and volume,[9] was programmed and administered according to the microcycle training plan and quantified through the weekly total load. The ETL was divided into three modalities. Cycling training was conducted on days 1 (70 km), 3 (80 km) and 7 (100 km), reaching a total of 250 km. There was running training on days 2 (21 km) and 5 (21 km), covering a total of 42 km. And trail-running training was performed on days 4 (15 km at 6% mean slope) and 6 (28 km at 5% mean slope), covering a total of 43 km with similar mean slope.

The participants were informed about the procedure to be followed before they provided written informed consent to participate in the study, which followed the guidelines stated in the Declaration of Helsinki.

HRV measurements were obtained every day upon wake up and after the training session, using RMSSD as the variable for analysis. It adds the values of each subject along the microcycle. In other words, the individual evolution of each participant before the training session and how they respond to it. For the upon-wake-up recordings, and in accordance with the general guidelines of the Task Force,[7] the participants were requested not to drink alcoholic and/or caffeinated beverages during the whole duration of the study. Following Naranjo Orellana et al.[4], the post-training recordings were conducted within the first 30 minutes after the training session and the first 5 minutes were discarded due to the loss of time series stability derived from the sudden change between the end of exercise and the start of recovery.[21]

The RR series were measured for 5 minutes upon wake up and after training, in seating position, using an H10 HR Sensor chest strap (Polar Inc., Kempele, Finland) and the data were exported in txt format for analysis with Kubios HRV software (version 2.1, University of Eastern Finland, Kuopio, Finland). Each record was previously inspected in order to detect potential artefacts and/or anomalous beats.[7] The corresponding filters were then applied if needed.

Statistical analysis

Firstly, a descriptive analysis was conducted. All data are presented as mean and standard deviation. The paired Student's t test was applied to determine whether there were significant differences between men and women. The confidence level was set at 95% and the significance level at $p < 0.05$ in all cases. Pearson's correlation coefficient was used to analyze the relationships of LnRMSSD and its CV between basal and post-exercise measurements. Likewise, the graphic relationship between both variables was examined for every microcycle day.

Results

Since significant differences ($p < 0.001$) were observed between men and women in the variables under study, both basal and post-exercise, the results were presented divided by gender.

Table 1 contains the mean values (as well as SD and CV) of every participant for the seven days of training. Basal and post-exercise results are shown, divided by gender. Pearson's correlation coefficients between basal and post-exercise data are shown in every case.

Table 1. Basal and post-exercise root mean square of the successive differences and coefficient of variation root mean square of the successive differences (as well as their respective Natural Logarithm) values. Results are expressed as mean and standard deviation.

Basal			**Women**			
Subject	RMSSD	SD	RMSSDcv	LnRMSSD	SD	LnRMSSDcv
1	75.86	18.85	0.25	4.30	0.28	0.07
2	69.29	13.19	0.19	4.22	0.20	0.05
3	103.71	23.50	0.23	4.62	0.22	0.05
4	66.14	24.92	0.38	4.11	0.47	0.11
5	57.14	13.56	0.24	4.02	0.26	0.06
Mean	74.43	18.80	0.26	4.25	0.28	0.07
Recovery						
1	37.14	15.15	0.41	3.55	0.37	0.11
2	36.77	10.53	0.29	3.57	0.31	0.09
3	45.14	9.79	0.22	3.79	0.22	0.06
4	20.71	9.38	0.45	2.94	0.45	0.15
5	32.00	4.82	0.15	3.46	0.15	0.04
Mean	34.35	9.93	0.30	3.46	0.30	0.09
r	**0.73**		**0.66**	**0.68**		**0.79**
Basal			**Men**			
Subject	RMSSD	SD	RMSSDcv	LnRMSSD	SD	LnRMSSDcv
6	71.43	25.84	0.36	4.22	0.34	0.08
7	54.43	21.03	0.39	3.94	0.37	0.09
8	29.29	6.55	0.22	3.35	0.27	0.08
9	37.71	19.52	0.52	3.53	0.47	0.13
10	64.71	15.85	0.24	4.15	0.23	0.06
Mean	51.51	17.76	0.35	3.84	0.34	0.09
Recovery						
6	23.86	11.28	0.47	3.08	0.48	0.16
7	25.94	6.72	0.26	3.22	0.30	0.09
8	13.71	5.99	0.44	2.53	0.46	0.18
9	22.57	7.55	0.33	3.07	0.32	0.10
10	28.14	13.48	0.48	3.22	0.54	0.17
Mean	22.85	9.00	0.40	3.02	0.42	0.14
r	**0.78**		**-0.62**	**0.75**		**-0.73**

RMSSD: root mean square of the successive differences; SD: standard deviation; RMSSDcv: coefficient of variation of RMSSD; LnRMSSD: Natural Logarithm of RMSSD, LnRMSSDcv: Coefficient of variation of LnRMSSD. r: Pearson's correlation coefficient.

The analysis of the daily individual values yielded a Pearson's correlation coefficient between basal and post-exercise RMSSD of 0.46 for women and 0.42 for men, while it was 0.39 and 0.45, respectively, when comparing LnRMSSD values. Figure 1 shows the relationship between individual basal (daily measurement) and post-exercise LnRMSSD measurements for women (A) and men (B).

Figure 2 shows the relationship between mean weekly values of LnRMSSD and CV basal and post-exercise for both women and men.

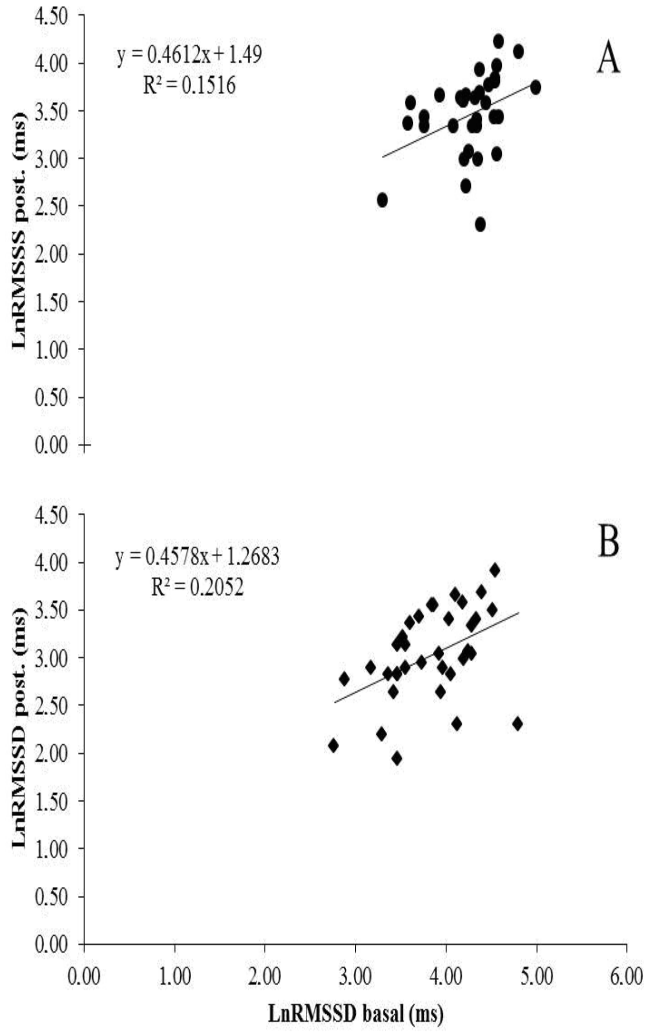

Figure 1. Graphic association between daily basal and post-exercise (Post) LnRMSSD values for women (A) and men (B). LnRMSSD: natural logarithm of the root mean square of the squares of the differences between adjacent RR intervals; Post: post-exercise; A: women; B: men.

Discussion

The main finding of this study was the high correlation between basal HRV measurements and those conducted on the same day after the training session, being higher for mean weekly values than for daily values and the same for LnRMSSD as for its CV.

The daily monitoring of athletes using the CV or RMSSD (or their respective logarithms) and their relationship with ETL have been studied by several authors. Some of them recommended taking measurements several days a week to then analyze the mean[19,20,22], while others suggested using daily values not calculating the mean[23-25]. Furthermore, there are authors who believe that RMSSD or its Ln do not provide sufficient information and recommend using the CV of the recorded values as assessment tool[16,19].

Nevertheless, all these studies included values obtained in resting conditions before the training, but none of them reported post-training data that can be compared with basal recordings of the same day. Therefore, it is not possible to know whether those basal recordings can be used to somehow predict the response to the load applied afterwards. In the present study, the upon-wake-up and post-exercise measurements showed high correlation (r between 0.6 and 0.8) in all variables for both men and women (Table 1). It seems obvious that there is a relationship between the parasympathetic response to the applied loads and the values

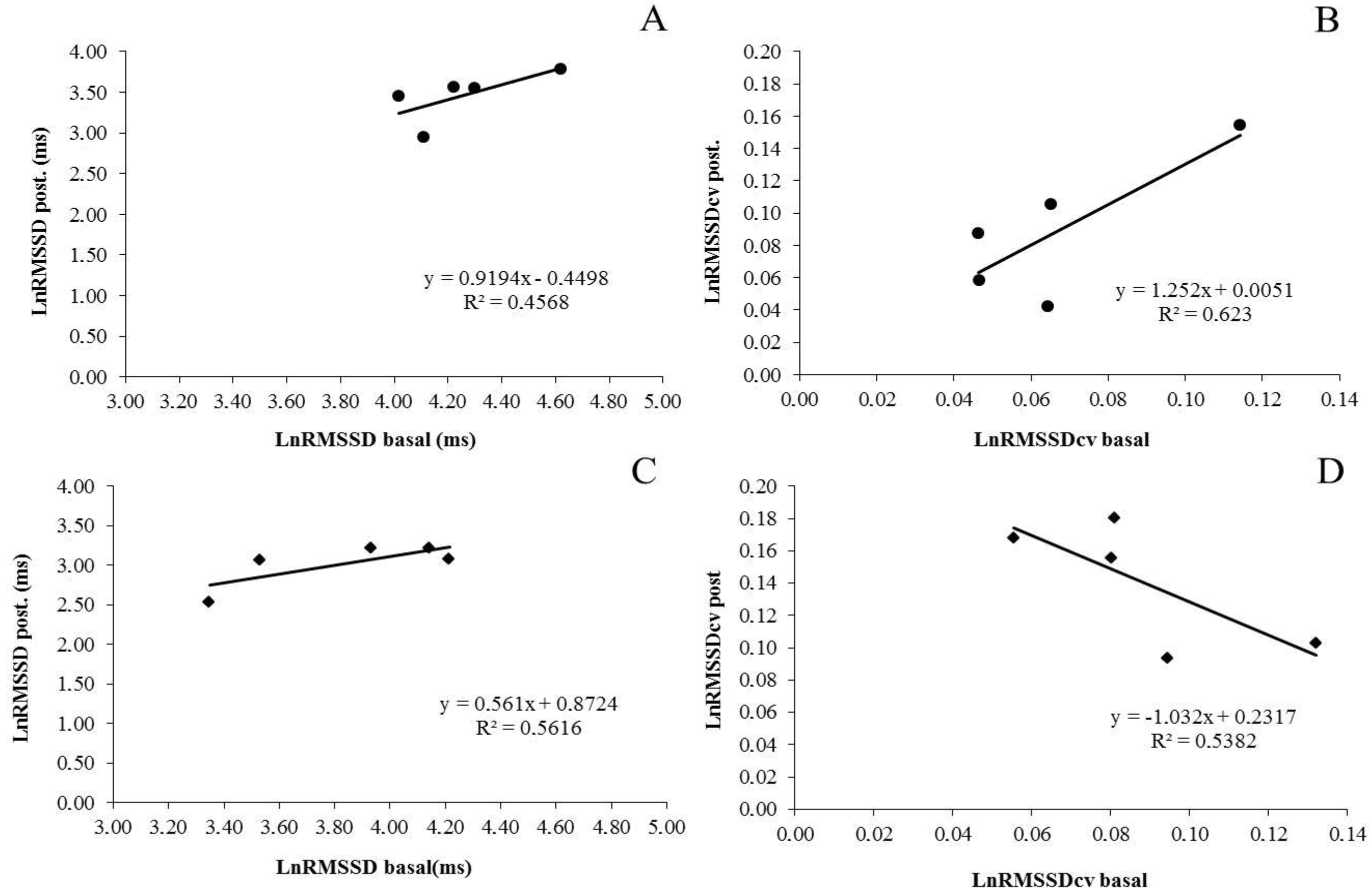

Figure 2. Graphic association between weekly basal and post-exercise (Post) LnRMSSD and their CV. Values for women (A and B) and men (C and D). LnRMSSD: natural logarithm of the root mean square of the squares of the differences between adjacent RR intervals; Post: post-exercise

obtained upon wake up on that same day, so it could be useful to incorporate this double measurement into the athlete monitoring routine.

The correlation coefficients (r) as well as the graphic analysis revealed that the relationships between basal and post-exercise LnRMSSD values are much lower when calculated with daily data (Figure 1) than with weekly mean values. This means that these relationships could be useful when applied during time periods (microcycles) in which mean values can be obtained. By contrast, we believe that this analysis strategy would not be useful to make any kind of daily prediction.

When analyzing whether the LnRMSSD provides better information than its CV or vice versa, our data indicate that the relationship between basal and post-exercise values is very similar for both variables (Table 1 and Figure 2). Consequently, from our point of view, the debate about using LnRMSSD or its CV is no longer fruitful, since both of them provide the same information.

We believe that the methodology consisting in taking basal and post-exercise measurements every day during a microcycle would allow us to obtain information on the athlete's readiness towards the subsequent training load. Besides, the measurement after a specific training load would allow us to assess the individual response to the ETL applied and, therefore, to gather information about the internal load. The analysis of the relationship between these two variables could be useful to program the loads of the following microcycle.

The utility of the obtained values of each subject along the microcycle allows the identification of the individual evolution of the participants to each training load. The correlation between the basal measurement and the ones obtained just after the physical exercise demonstrates that the changed observed in each one (increase or decrease) are in the same proportion. The drop of HRV after the training session could be express in different values, depending on each subject if the load impact would vary, allowing the coach to have a monitoring tool for the training program design.

The main limitation of this study was the reduced sample size (10 athletes). This number was not previously determined, but it was the number of athletes of this modality who were training together using the same methodology. Therefore, this is more a descriptive study in which a methodology that can be useful for training is proposed. Nevertheless, since two measurements were taken from every participant every day for seven consecutive days, the total number of recordings analyzed was 140.

In conclusion, basal and post-exercise RMSSD measurements show high correlation when weekly mean values are handled. This correlation is the same if its coefficients of variation are used.

Authotship. All the authors have intellectually contributed to the development of the study, assume responsibility for its content and also agree with the definitive version of the article. **Conflicts of interest.** The authors declare no conflicts of interest. **Provenance and peer review.** Not commissioned; externally peer reviewed. **Ethical Responsabilities.** *Protection of individuals and animals:* The authors declare that the conducted procedures met the ethical standards of the responsible committee on human experimentation of the World Medical Association and the Declaration of Helsinki . *Confidentiality:* The authors are responsible for following the protocols established by their respective healthcare centers for accessing data from medical records for performing this type of publication in order to conduct research/dissemination for the community. *Privacy:* The authors declare no patient data appear in this article.

References

1. Sandercock GRH, Bromley PD, Brodie DA. Effects of exercise on heart rate variability: Inferences from meta-analysis. Med Sci Sports Exerc. 2005;37(3):433–9.
2. Stanley J, Peake JM, Buchheit M. Cardiac parasympathetic reactivation following exercise: Implications for training prescription. Sport Med. 2013;43(12):1259–77.
3. Kiviniemi AM, Hautala AJ, Kinnunen H, Tulppo MP. Endurance training guided individually by daily heart rate variability measurements. Eur J Appl Physiol. 2007;101:743–51.
4. Naranjo Orellana J, Nieto-Jiménez C, Ruso-Álvarez JF. Recovery Slope of Heart Rate Variability as an Indicator of Internal Training Load. Health. 2019;11:211–21.
5. Choo HC, Nosaka K, Peiffer JJ, Ihsan M, Yeo CC, Abbiss CR. Effect of water immersion temperature on heart rate variability following exercise in the heat. Kinesiol Int J Fundam Appl Kinesiol. 2018;50(Supplement 1):67–74.
6. Pichot V, Roche F, Gaspoz JM, Enjolras F, Antoniadis A, Minini P, et al. Relation between heart rate variability and training load in middle-distance runners. Med Sci Sports Exerc. 2000;32(10):1729–36.
7. Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Eur Heart J. 1996;17:354–81.
8. Buchheit M, Papelier Y, Laursen PB, Ahmaidi S. Noninvasive assessment of cardiac parasympathetic function: postexercise heart rate recovery or heart rate variability? Am J Physiol Heart Circ Physiol. 2007;293(1):8–10.
9. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. Sport Med. 2014;44:139–47.
10. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome? Front Physiol. 2014;5(73):1–19.
11. Michael S, Graham KS, Davis GM. Cardiac Autonomic Responses during Exercise and Post-exercise Recovery Using Heart Rate Variability and Systolic Time Intervals — A Review. Front Physiol. 2017;8:1–19.
12. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players. Int J Sport Perform. 2015;10:958–64.
13. Flatt AA, Esco MR, Nakamura FY, Plews DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. J Sports Med Phys Fitness. 2017;57(6):907–15.
14. Ravé G, Fortrat JO. Heart rate variability in the standing position reflects training adaptation in professional soccer players. Eur J Appl Physiol. 2016;116(8):1575–82.
15. Nieto-Jiménez C, Pardos-Mainer E, Ruso-Álvarez JF, Naranjo-Orellana J. Training Load and HRV in a Female Athlete: A Case Study. Rev Int Med y Ciencias la Act Física y el Deport (In press).
16. Flatt AA, Esco MR, Nakamura FY. Individual heart rate variability responses to preseason training in high level female soccer players. J Strength Cond Res. 2017;31(2):531–8.
17. Nakamura FY, Pereira LA, Rabelo FN, Flatt AA, Esco MR, Bertollo M, et al. Monitoring weekly heart rate variability in futsal players during the preseason: the importance of maintaining high vagal activity. J Sports Sci. 2016;34(24):2262–8.
18. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. Sport Med. 2013;43(9):773–81.
19. Plews DJ, Laursen PB, Kilding AE, Buchheit M. Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. Eur J Appl Physiol. 2012;112(11):3729–41.
20. Le Meur Y, Pichon A, Schaal K, Schmitt L, Louis J, Gueneron J, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. Med Sci Sports Exerc. 2013;45(11):2061–71.
21. Javorka M, Žila I, Balhárek T, Javorka K. Heart rate recovery after exercise: Relations to heart rate variability and coplexity. Brazilian J Med Biol Res. 2002;35(8):991–1000.
22. Buchheit M, Racinais S, Bilsborough JC, Bourdon PC, Voss SC, Hocking J, et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. J Sci Med Sport. 2013;16(6):550–5.
23. Hedelin R, Kentta G, Wiklund U, Bjerle P, Henriksson-Larsen K. Short-term overtraining: effects on performance, circulatory responses, and heart-rate variability. Med Sci Sport Exerc. 2000;32(8):1480–4.
24. Hedelin R, Bjerle P, Henriksson-Larsen K. Heart rate variability in athletes: relationship with central and peripheral performance. Med Sci Sport Exerc. 2001;33(8):1394–8.
25. Hynynen E, Uusitalo A, Konttinen N, Rusko H. Cardiac autonomic responses to standing up and cognitive task in overtrained athletes. Int J Sports Med. 2008;29(7):552–8.