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Original Article

ARE THERE RELATIONSHIP BETWEEN INTERNAL AND EXTERNAL LOAD OF AEROBIC TRAINING WITH HEART RATE VARIABILITY IN WOMEN?

HÁ RELAÇÃO DA CARGA INTERNA E EXTERNA DO TREINAMENTO AERÓBIO COM VARIABILIDADE DA FREQUÊNCIA CARDÍACA EM MULHERES?

Tiago Volpi Braz[1], **Fábio Yuzo Nakamura**[3,4], **Michael Esco**[2], **Felipe Ornelas**[1], **Marlene Aparecida Moreno**[1], **Marcio Antônio Gonsalves Sindorf**[1], **Moisés Diego Germano**[1] and **Charles Ricardo Lopes**[1]

[1]Piracicaba Methodist University, Piracicaba-SP, Brazil.
[2]Alabama University, Tuscaloosa-AL, United State of America.
[3]Chieti University, Chieti-PE, Itália.
[4]Paraíba Federal University, João Pessoa-PA, Brazil.

RESUMO

O objetivo foi investigar a relação da carga interna de treinamento (CIT), carga externa de treinamento (CET) e variabilidade da frequência cardíaca (VFC) em mulheres. 16 mulheres (48,2 ± 6,4 anos) realizaram medidas de VFC em repouso (variável lnRMSSD – modulação cardiovagal) e o teste incremental de caminhada (TIC) antes e depois de 12 semanas de treinamento aeróbio. O limiar da VFC (LVFC) foi utilizado para prescrição da CET. A percepção subjetiva de esforço (PSE) foi utilizada para cálculo da CIT. O valor de CIT encontrado nas 12 sessões foi de 2878 ± 380 unidades arbitrárias e para CET de 36822 ± 5852 m. Foi observada diferença significativa para lnRMSSD (3,14 ± 0,30 vs. 3,43 ± 0,38 ms^{-1}; $P = 0.001$). Verificou-se uma correlação grande entre lnRMSSD basal e TIC ($r = 0.73$, $P = 0.001$), LVFC ($r = 0.67$, $P = 0.004$) e CIT ($r = 0.62$, $P = 0.011$). Foi encontrada uma correlação muito grande entre a mínima diferença detectável individual do lnRMSSD após treinamento e CIT. Conclui-se que há uma forte relação entre VFC e performance aeróbia (LVFC e $TIC_{distância}$), VFC e acúmulo de CIT, porém, sem relação com a CET acumulada nas 12 semanas nas mulheres estudadas.
Palavras-chave: Modulação autonômica cardiovascular. RMSSD. Exercício. Treinamento aeróbio.

ABSTRACT

The purpose was to investigate the relationship between internal training load (ITL), external training load (ETL) and heart rate variability (HRV) in women. 16 women (48.2 ± 6.4 yrs) performed HRV recordings (i.e. lnRMSSD – cardiovagal modulation) and Incremental Shuttle Walk Test (ISWT) before and after 12 aerobic training sessions. HRV threshold (HRVT) were used to prescribe aerobic ETL. The session rating of perceived exertion (s-RPE) was analyzed and served as the measure of ITL. The score found for ITL in the 12 sessions was 2878 ± 380 arbitrary units and ETL were 36822 ± 5852 m. A significant difference was observed in the lnRMSSD (3.14 ± 0.30 vs. 3.43 ± 0.38 ms^{-1}; $P = 0.001$). There were observed large correlation between lnRMSSD at baseline vs ISWT ($r = 0.73$, $P = 0.001$), HRVT ($r = 0.67$, $P = 0.004$) and ITL ($r = 0.62$, $P = 0.011$). Very large correlation between individual smallest worthwhile change lnRMSSD after training and ITL ($r = 0.81$, $P = 0.0001$) was observed. There is a strong association between the HRV and aerobic performance (HRVT and $ISWT_{distance}$) and strong relationship between HRV and the potential to accumulate ITL, but not aerobic ETL in women.
Keywords: Cardiovascular autonomic control. RMSSD. Exercise. Aerobic training.

Introduction

Session rating of perceived exertion (s-RPE) has often been used as a subjective method to estimate internal training load (ITL)[1] in various training contexts[2,3]. Indeed, it emerges as a valid and simple tool with low implementation cost[4]. The method proposed by Foster et al.[5] represents the magnitude ITL by multiplying the s-RPE score by the volume of the entire training session in minutes. This method has been used and validated in athletes[6–8] and non-athletes[1,9]. An insufficient ITL might not provide an appropriate stimulus to induce positive adaptations and a detraining state might emerge [7].

The appropriate prescription of volume and intensity of exercise to induce a meaningful ITL for improving health and fitness have not been accurately described among sedentary individuals. The individual responses to training are related to fitness level and proportional to the magnitude of the provided ITL[7]. For example, post myocardial infarction patients showed a similar improvement in functional capacity, ventilatory efficiency and metabolic adaptation between continuous versus interval aerobic trainings with ETL prescribed in order to result in similar individually tailored doses of ITL[9]. On the other hand, an insufficient ITL might not provide an appropriate stimulus to induce positive adaptations and a detraining state might emerge[7].

As a result, the quantification of individual ITL response to a given external training load (ETL) is a vital component of training-related adaptive processes[10]. In this case, heart rate variability (HRV) has been used to monitor and guide individual aerobic training[11,12]. Resting vagally-mediated HRV is positively associated to individual cardiorespiratory fitness[13,14] and health-related quality of life for asymptomatic adults[15]. Subjects who display high cardiovagal modulation at baseline have been shown to display a greater propensity to improve aerobic peak capacity after a 16-week aerobic training program[16]. A dose-dependent curvilinear relationship exists between HRV indicators of ITL and fitness improvement in cardiac patients [9] and athletes[2,10,17,18].

However, up to now, no previous study has analyzed the longitudinal dose-response relationship between ITL and HRV cardiovagal modulation in women. An important limiting factor in the establishment of the relationship between training load and physiological adaptation is the unique individual response to each training stimulus[4,14]. The individual change can be assessed through a standard difference score and magnitude-based inferences which allows the comparison of a response to the smallest worthwhile difference (SWC) [19]. SWC definition is the smallest difference that researchers and subjects would care about in the dependent variable analyzed[19]. It needs to be recognized that the contributions documented at the group level may not fully apply individually, even when all members of the exercising group are exposed to the same standardized training program.

In this case, the issue of individual responses to a given treatment is one of the most important considerations in experimental research, yet attempts to quantify such responses are rare[19]. Furthermore, an important limiting factor in the establishment of the relationship between training load and physiological adaptation is the unique individual response to each training stimulus[4,14]. Nevertheless, to date, there is no study that has analyzed the individual change in HRV and individual response in ITL from aerobic training. Thus, the aim of this study was to investigate a relation between ITL, aerobic ETL and physiological adaptation in heart rate variability in women. Additionally, the individual responses will be analysed and reported. The hypothesis of the study is that there will be a relationship between the accumulation of ITL and chronic adaptations in HRV.

Methods

Subjects

The sample size was calculated using Gpower software version 3.1.9.2 (Universite¨t Kiel, Kiel, Germany. For this study design, 11 participants were required to result in a statistical power of 0.99, a moderate correlation (r = 0.50), and an overall level of significance of p = 0.05. Thus, a convenience sample of 16 healthy adult women normotensive (48.2 ± 6.4 years, 164 ± 10.8 cm, 72.5 ±12.6 kg, BMI = 25.8 ± 5.1 $kg \cdot m^{-2}$, heart rate variability threshold = 6.1 ± 1 $km \cdot h^{-1}$and VO_2peak = 32 ± 9 $ml \cdot kg^{-1} \cdot min^{-1}$) were selected to participate in the study. The participants were classified as sedentary according to the International Physical Activity Questionnaire (IPAQ - short version). All subjects were healthy, nonsmokers, and had a body mass index (BMI) under 35 $kg \cdot m^{-2}$. None of the subjects regularly consumed any substance that influenced autonomic control or currently undergoing hormone replacement therapy.

Procedures

An introductory session was held to familiarize the volunteers with the procedures before the commencement of data collection. Body composition (body weight, height, and fat) and blood pressure were measured on the same day between 8:00 to 10:00 AM. Pre-training HRV evaluations were conducted 48 hrs after the familiarization session. Forty-eight hrs later, the first training session began. The study lasted 5 weeks with a total of 12 sessions with 48 to 72 hrs recovery between the training sessions. Post-training HRV evaluation was performed 48 hrs after the end of session 12, in the morning between 7:30 to 8:30 AM. The room temperature of the experiment was kept between 22 and 25°C with relative humidity between 40 and 60%. In both experimental conditions days (pre- and post-training), the subjects had been previously instructed to: (a) not drink stimulating caffeinated or alcoholic beverages 48 hrs before testing; (b) not perform strenuous physical exercise; and (c) eat a light meal 2 hrs prior to the testing and sessions trainings. All research was conducted ethically according to international standards[20]. The current study was approved by the Research Ethics Committee of the Local Institution, as recommended by Resolution 466/12 of the National Health Council (950.277/2015).

HRV Analysis

The subjects were kept in supine position for 10 min with no talking or moving. Heart rate data was recorded while spontaneous breathing was monitored[11]. Heart rate data was obtained with a Polar RS800CX® heart rate monitor, which was previously validated to record HRV both at rest and during exercise[21]. Then, heart rate signals were processed to calculate HRV using the Kubios HRV® version 3.0.1 (Biomedical Signal Analysis Group, University of Kuopio, Finland). All R-R intervals with differences greater than 20% of the previous adjacent interval were automatically filtered and inappropriate heart beats were eliminated (low filter). The root mean square of the successive differences between the normal adjacent RR intervals (RMSSD) were used in the study. This metric was chosen as it is more reliable than other HRV indexes[22] and can be obtained during spontaneous breathing[23]. RMSSD is more robust for changes in breathing frequency than high-frequency power[23]. Due to the skewed nature of HRV recordings, the RMSSD data were transformed into their natural logarithm (lnRMSSD)[18].

Incremental Shuttle Walk Test

The Incremental Shuttle Walk Test (ISWT) was performed in a 10-meter-long covered and airy hallway marked by cones. The initial cadence of 0.5 $m \cdot s^{-1}$ was increased by 0.17 $m \cdot s^{1}$ every minute until the subjects showed exhaustion. The heart rate variability threshold (HRVT) was obtained by the SD1 index calculated by *Poincaré* plot during the ISWT[24]. Next, the ISWT phase speed was matched with the SD1 values. The HRVT in ISWT corresponded to the first phase of the incremental exercise test in which the difference between the SD1 of two consecutive phases was less than 1 millisecond[24]. The HRVT was identified by visual inspection performed by 3 independent examiners, and it was defined when at least 2 concordant assessments occurred.

Aerobic training sessions

Three different intensity zones were used to prescribe aerobic external training load (ETL), as follows: Zone 1 occurred at an intensity level below the heart rate variability threshold (HRVT); Zone 2 occurred at an intensity level at the HRVT; and Zone 3 occurred at an intensity level above the HRVT. HRVT was used for the prescription of the 12 training sessions with 3 variations (session 1 [S1], 2 [S2] and 3 [S3]). In S1, the subjects jogged or walked for 30 min at intensity 20% below HRVT in Zone 1. In S2, they performed 3 sets of 8 min in HRVT with 2 min of active recovery at intensity 20% below HRVT, totalling 30 min. In S3, they performed 3 sets of 6 x 1-min repetitions at 20% above HRVT, with 1 min of active recovery at 20% below

HRVT, totalling 36 min. All the 16 subjects participated in 5 S1, 4 S2, and 3 S3 (398 minutes). The total ETL corresponded to the sum of the distance in meters in Zone 1, 2 and 3 during the 12 sessions The sessions were separated by 48 hours and took place on Mondays, Wednesdays and Fridays at the same time (8:00 to 10:00 AM).

Monitoring the Internal Training Load using s-RPE (ITL)

The ITL was monitored according to Foster method[5]. The s-RPE score was obtained 30 min after the end of each session, in all 12 sessions. The subjects individually indicated the degree of perceived exertion according to the Borg CR10 s-RPE. The perceived score reported by the subjects was multiplied by the total session time in minutes in order to calculate the ITL[5]. The total ITL corresponded to the sum of the load calculated in the 12 sessions. The data were expressed in arbitrary units (AU).

Statistical Analysis

The normality were verified using the Shapiro-Wilk. Data are shown as means ± standard deviations (DP) or 95% confidence intervals. The paired *t*-test was used to check the lnRMSSD difference from baseline ($lnRMSSD_{baseline}$) to post-training. The magnitude of the differences was examined using the standardized differences based on Cohen's d units by means of effect sizes (ES)[19]. The ES results were qualitatively interpreted using the following thresholds: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; 2.0-4.0, very large and; >4.0, extremely large. The smallest worthwhile change (SWC) was set as 0.2 x between subject DP. According to Buchheit[25] the thresholds for trivial, small, moderate, large, and very large standardized changes (Cohen d) being <0.2, 0.2, 0.6, 1.2, and 2, respectively, means that any change of <1x, 1x, 3x, 6x, and 10x SWC can be considered trivial, small, moderate, large, and very large. Data analysis was performed using a modified statistical Excel spreadsheet[19]. The relation between $lnRMSSD_{baseline}$ and ITL, $lnRMSSD_{baseline}$ and HRVT, $lnRMSSD_{baseline}$ and ISWT distance ($ISWT_{distance}$), $lnRMSSD_{baseline}$ and ETL, individual change in SWC lnRMSSD after training vs ITL and ETL was determined through the Pearson's correlation using the SPSS software (version 22.0; IBM Corp., Armonk, NY, USA). The confidence interval (95% CI) of the association between variables was calculated in Bioestat software (version 5.3; Instituto Mamirauá, Tefé, AM, Brazil). The following criteria were adopted in order to interpret the correlation magnitude: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, extremely large[19]. The adopted significance was $P \leq 0.05$.

Results

The total ITL in the 12 sessions were 2878 ± 380 AU (IC95%= 2692 to 3065 AU; average per session 240 ± 32 AU) and ETL were 36822 ± 5852 m (Zone 1 = 20041 ± 3140 m, Zone 2 = 10586 ± 1729 m; Zone 3 = 5956 ± 973 m). Table 1 displays the HRV results at baseline and after 12 sessions of aerobic training. A significant difference was observed between baseline and after aerobic training in the log-transformed root mean square of successive R-R intervals (lnRMSSD).

Table 1. Heart rate variability results in baseline and after 12 sessions of aerobic training in women

Variable	Baseline (mean ± SD)	After (mean ± SD)	*P*	ES (±90% CL) *classification*
lnRMSSD (ms)	3.14 ± 0.30	3.43 ± 0.38	0.001	0.85 (0.57 to 1.13) *Moderate*

Notes: lnRMSSD = log-transformed root mean square of successive R-R intervals; ES= Effect Size; CL= Confidence Limits; Chances = rate of having better/similar/poorer chances
Source: The authors

Figure 1 shows individual comparison between subjects ITL (1A) and change in lnRMSSD (1B) after aerobic training. Of the 16 subjects, 14 presented a substantial difference effect after aerobic training in lnRMSSD (small improvement = 2 subjects [1 and 14]; moderate improvement = 7 subjects [2, 5, 7, 10, 12, 13 and 16]; large improvement = 5 subjects [3, 4, 8, 9 and 11]). Only subjects 6 and 15 presented trivial difference. The subject 15 presented lower ITL (2350 AU) and changes in lnRMSSD (0.7 xSWC) compared to all subjects (1A).

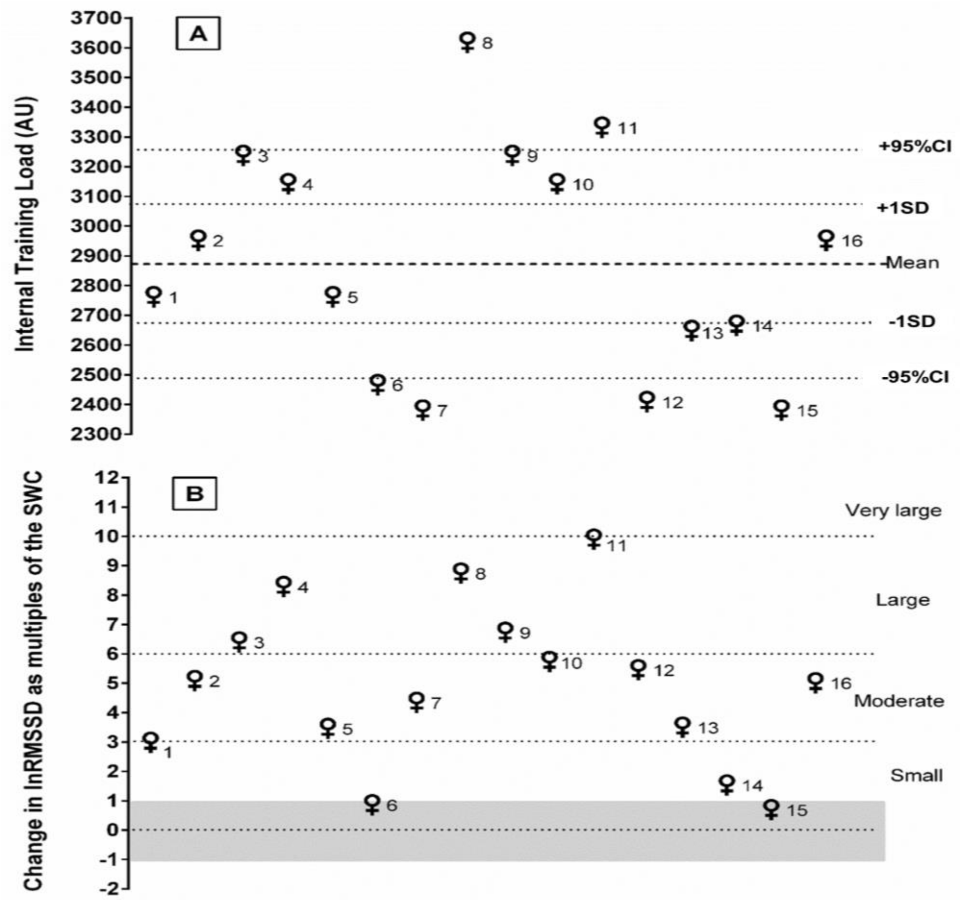

Figure 1. Individual comparison between subjects in internal training load (A) and change in lnRMSSD as a multiple of the SWC (see methods) after 12 sessions of aerobic training (B). The grey area in graphic B represents the zone trivial of the SWC
Notes: lnRMSSD = log-transformed root mean square of successive R-R intervals; SD= standard deviation; 95%CI= 95% confidence interval;♀1-16=Subject number.
Source: The authors

Figure 2 illustrates the correlation between $lnRMSSD_{baseline}$ and $ISWT_{distance}$ (2A), $lnRMSSD_{baseline}$ and HRVT (2B), $lnRMSSD_{baseline}$ and ITL (2C), individual change in lnRMSSD (measured in multiples of SWC) and ITL (2D). At baseline, large and very large correlations between $lnRMSSD_{baseline}$ vs HRVT (r = 0.67, 95% CI = 0.27 to 0.88, *P* = 0.004, r^2

= 0.45), and between $\ln RMSSD_{baseline}$ vs $ISWT_{distance}$ (r = 0.73, 95% CI = 0.37 to 0.90, *P* = 0.001, r^2 = 0.53) were observed, respectively. During the training period, a large correlation between $\ln RMSSD_{baseline}$ vs ITL (r = 0.62, 95% CI = 0.18 to 0.85, *P* = 0.011, r^2 = 0.38) was noticed. Finally, in response to training, a very large correlation between ITL vs individual changes in lnRMSSD (r = 0.81, 95% CI = 0.53 to 0.93, *P* = 0.0001, r^2 = 0.65) was observed, while no significant correlation between $\ln RMSSD_{baseline}$ vs individual change in lnRMSSD (r = 0.33, 95% CI = -0.19 to 0.71, *unclear*, *P* = 0.206, r^2 = 0.11) and between ETL and individual change in lnRMSSD (r = 0.25, 95% CI = -0.28 to 0.67, *unclear*, *P* = 0.343, r^2 = 0.06) were noted.

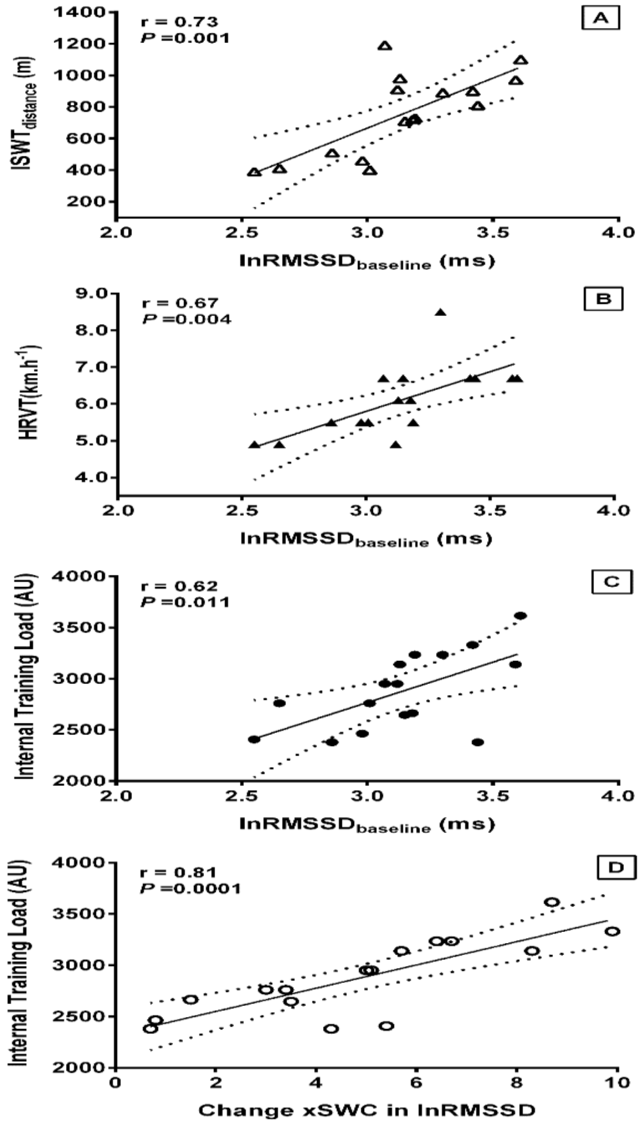

Figure 2. Result of individual values of correlation among $ISWT_{distance}$ and $\ln RMSSD_{baseline}$ (A, white triangles), HRVT and $\ln RMSSD_{baseline}$ (B, black triangles), $\ln RMSSD_{baseline}$ and ITL (C, black circle), ITL and individual SWC lnRMSSD after training (D, white circle). The dashed line represents the confidence interval at 95% and the continuous line represents the V-slope of the correlation between variables

Source: The authors

Discussion

The main aim of the present study was to investigate the relationship between ITL and changes in HRV in women submitted to a standardized training program based on their individual HRVT. The major findings in the present study were: 1) the strong association between the $lnRMSSD_{baseline}$ and pre-training aerobic performance (i.e., HRVT and $ISWT_{distance}$), 2) the strong relationship between $lnRMSSD_{baseline}$ and the potential to accumulate ITL during a standardized aerobic training program and, 3) the meaningful change in the group's mean HRV, which was very largely correlated with the accumulated ITL, but not to ETL.

In the present study, there were large positive correlations between $lnRMSSD_{baseline}$ and HRVT (r = 0.67; *P* < 0.05), and between $lnRMSSD_{baseline}$ and ISWT (r = 0.73; *P* < 0.05). The fact that higher individual $lnRMSSD_{baseline}$ implies in higher HRVT (Figure 2B) likely explains why larger cardiovagal modulation at rest is associated with greater "mechanical work" during aerobic exercise (i.e, distance in meters or watts) guided by the HRVT intensity. Hypothetically, basal HRV might indicate the readiness to accumulate ETL during training sessions, possibly needing consideration prior to the onset of training. In fact, some studies have suggested that higher parasympathetic activity at baseline was associated with higher responsiveness to the cardiorespiratory fitness to training[26,27]. The cardiovascular system of subjects with good vagal functioning may have a better capacity to adapt to various external stimuli (e.g., aerobic training) and this adaptive capacity may cause an improvement in overall cardiovascular performance[14]. Such hypothesis needs to be further addressed while prescribing training based on an exercise intensity determined by the withdrawal of vagal activity during progressive exercise (i.e., HRVT).

Larger distances covered by the participants during each training session was associated with greater sRPE. Accordingly, a progressive increase in sRPE was related to an increased distance walked during a 12-week training program in patients with chronic heart failure (CHF) [1]. Furthermore, sRPE was also significanty correlated to the distance walked during the 6 minute walking test (r = 0.85). Therefore, more mechanical work in exercise seems to be related to an increased sRPE score. This is related to the fact that the sense of effort is centrally generated by forwarding neural signals, termed corollary discharges from motor to sensory areas of the cerebral cortex[28]. Since ETL was guided by the HRVT, fitter participants who also possessed higher baseline vagal activity were capable of accumulating longer training distances (ranging between 29.455 to 51.515 meters in 12 sessions). Due to this greater accumulated "mechanical work", sRPE (and ITL) was predictably higher in the participants with higher HRVT.

The change in lnRMSSD was significantly associated with ITL accumulated throughout the 12 aerobic training sessions during the 4-week period (r = 0.62 and 0.81, respectively). This is a novel finding of our study. Previously, many investigations have reported significant relationships between accumulated ITL and increased VO_2max or performance[2,18,29–31]. Of note, ITL is modulated by both intensity and duration of exercise and despite different content (high-intensity and short duration vs low-intensity and long duration), training responses may be identical when ITL is equated[32]. These results suggest that improvements in HRV by aerobic training are related to ITL, but in our case it was associated with the amount of ITL accumulated across the participants. It remains to be determined whether ITL is associated with changes in VO_2max and with changes in lnRMSSD in the same sample. In fact, previous studies have found signicant correlations between changes in VO_2max/performance and changes in lnRMSSD[33,34].

However, no significant correlation between individual ETL and individual change in lnRMSSD (r = 0.25, *unclear*) was noted. These results are probably related to the standardization of training intensity based on individual HRVT of the subjects. Iellamo et al.[9] ensured that total ITL was similar between groups (i.e interval vs continuous aerobic training), without standardizing the “external” intensity. The ETL was adjusted every week to ensure similar ITL in both groups, therefore, the adaptations between groups were similar[9]. Ultimately, it is the ITL that determines the training outcome [4]. Indeed, it has already been demonstrated by Taylor et al.[35] that ITL (sRPE and TRIMP), but not ETL (total distance and high-speed distance >18 $km \cdot h^{-1}$), was significantly correlated to improvements in aerobic fitness. These results are in agreement to our study, confirming the hypothesis that there would be a dose-response relationship between the ITL and cardiovagal modulation (i.e., higher ITL leading to higher lnRMSSD after training), but not with ETL. In practical terms, aerobic training prescription to women should consider more heavily the internal, perceptual responses to each training session than distances covered in order to foresee the training-related adaptations (fitness and HRV).

In this sense, increase in lnRMSSD is associated with high parasympathetic modulation, low sympathetic output and high fitness (Baynard et al., 2014; Hautala et al., 2009). A poor cardiovagal modulation (low lnRMSSD) has been associated with sleep disturbance, chronic fatigue, depression, chronic pain and increased risk of cardiovascular disease and mortality[9,15,16]. The positive HRV change induced by training may be associated with a lower vagal withdrawal and/or less sympathetic-adrenal activation during rest[11]. These adaptations are important to increase cardiopulmonary performance resulting in a cardio-protective effect, as well as improving physical fitness[13].

Figure 1 showed individual comparisons among subjects regarding ITL and changes in lnRMSSD. This individual presentation of the data showed that subjects 6 and 15 presented trivial differences in HRV and lower ITL (2464 and 2379 AU) compared to the other subjects. It is common for individuals to show a wide range of responses to the same intervention[14,36]. Subjects 6 and 15 were also the ones that presented lower ITL, referring to the fact that the same training can promote different ITL responses (i.e. subjects 8 and 11; 3616 and 3330 AU; respectively). It is common for individuals to show a wide range of responses to the same intervention[14,36]. This phenomenon is typified by high responders and low responders (or high responsiveness and low responsiveness) to a standardized physical training intervention and may provide helpful insights into the mechanisms of training adaptation, as well as assisting with appropriate exercise prescription[36]. Thus, the negative response found for lnRMSSD in the present study is attributed to the fact that these subjects perceive less ITL than the others (figure 2D, r=0.81, P<0,05) and thus might be exposed to sub-optimal loads.

In interpreting the results of this study, readers should take into account its inherent limitations. The current study cannot provide information on possible gender-related differences, since subjects involved in the study were healthy females. Therefore, the presented data should be analysied with caution when interpreting and applying the current results to other populations. In addition, the study did not compare different quantification methods of ITL (i.e. TRIMP, TRIMPi[10](Manzi et al., 2009) or TLHRV[32]). For these reasons, the link between different methods of internal training load and improvement in physical fitness in sedentary women should be further elucidated.

Conclusions

The results of the current study suggest that the significant improvement in HRV is related to the accumulated ITL during short-term aerobic training. In addition, there is a strong relationship between the baseline cardiovagal modulation and the ITL. This means that the identification of lnRMSSD at the beginning of the training program for this population may indicate to practitioners which subject may achieve higher performance in aerobic test and subsequently sustain a higher ITL during the aerobic training program.

These measurements of HRV can easily be assessed in a practical setting, without requiring expensive equipment and level of expertise.

References

1. Iellamo F, Manzi V, Caminiti G, Vitale C, Massaro M, Cerrito A, et al. Validation of rate of perceived exertion-based exercise training in patients with heart failure: Insights from autonomic nervous system adaptations. Int J Cardiol 2014;176(2):394–398. Doi:10.1016/j.ijcard.2014.07.076
2. 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):531–538. Doi:10.1519/JSC.0000000000001482
3. Gomes R V, Moreira A, Lodo L, Nosaka K, Coutts AJ, Aoki MS. Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. Biol Sport 2013;30(3):173-180. Doi: 10.5604/20831862.1059169.
4. Borresen J, Lambert MI. The quantification of training load, the training response and the effect on performance. Sports Med 2009;39(9):779–795. Doi:10.2165/11317780-000000000-00000.
5. Foster C, Marroyo JAR, Koning JJ. Monitoring training loads: The Past, the Present, and the Future. Int J Sports Physiol Perform 2017;10(1):1–24. Doi:10.1123/ijspp.2016-0388.
6. Flatt AA, Esco MR. Heart rate variability stabilization in athletes: Towards more convenient data acquisition. Clin Physiol Funct Imaging 2016;36(5):331–336. Doi:10.1111/cpf.12233.
7. Manzi V, Bovenzi A, Franco Impellizzeri M, Carminati I, Castagna C. Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. J strength Cond Res 2013; 27(3):631–666. Doi:10.1519/JSC.0b013e31825dbd81.
8. Nunes JA, Moreira A, Crewther BT, Nosaka K, Viveiros L, Aoki MS. Monitoring training load, recovery-stress state, immune-endocrine responses, and physical performance in elite female basketball players during a periodized training program. J strength Cond Res 2014;28(10):2973-2980. Doi: 10.1519/JSC.0000000000000499..
9. Iellamo F, Manzi V, Caminiti G, Sposato B, Massaro M, Cerrito A, et al. Dose-response relationship of baroreflex sensitivity and heart rate variability to individually-tailored exercise training in patients with heart failure. Int J Cardiol 2013;166(2):334–339. Doi:10.1016/j.ijcard.2011.10.082.
10. Manzi V, Castagna C, Padua E, Lombardo M, D'Ottavio S, Massaro M, et al. Dose-response relationship of autonomic nervous system responses to individualized training impulse in marathon runners. Am J Physiol Heart Circ Physiol 2009;296(6):1733-1740. Doi:10.1152/ajpheart.00054.2009.
11. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol 2014;5:73. Doi:10.3389/fphys.2014.00073.
12. Esco MR, Williford HN, Flatt AA, Freeborn TJ, Nakamura FY. Ultra-shortened time-domain HRV parameters at rest and following exercise in athletes: An alternative to frequency computation of sympathovagal balance. Eur J Appl Physiol 2018;118(1):175–184. Doi:10.1007/s00421-017-3759-x.
13. Buchheit M, Gindre C. Cardiac parasympathetic regulation: respective associations with cardiorespiratory fitness and training load. Am J Physiol Heart Circ Physiol 2006;291(1):451-458. Doi:10.1152/ajpheart.00008.2006.
14. Hautala AJ, Kiviniemi AM, Tulppo MP. Individual responses to aerobic exercise: the role of the autonomic nervous system. Neurosci Biobehav Rev 2009;33(2):107–115. Doi:10.1016/j.neubiorev.2008.04.009.
15. Lu WC, Tzeng NS, Kao YC, Yeh CB, Kuo TBJ, Chang CC, Chang HA. Correlation between health-related quality of life in the physical domain and heart rate variability in asymptomatic adults. Health Qual Life Outcomes 2016;14(1):149. Doi:10.1186/s12955-016-0555-y.
16. Baynard T, Goulopoulou S, Sosnoff RF, Fernhall B, Kanaley JA. Cardiovagal modulation and efficacy of aerobic exercise training in obese individuals. Med Sci Sports Exerc 2014;46(2):369–375. Doi:10.1249/MSS.0b013e3182a66411
17. Flatt AA, Esco MR, Allen JR, Robinson JB, Bragg A, Keith CM, et al. Cardiac-Autonomic Responses to In-Season Training Among Division-1 College Football Players. J Strength Cond Res 2018;34(6):1649-1656. Doi:10.1519/JSC.0000000000002475.
18. Esco MR, Flatt AA, Nakamura FY. Initial Weekly HRV Response is related to the prospective change in VO2max in female soccer players. Int J Sports Med 2016;37(6):436–441. Doi:10.1055/s-0035-1569342.
19. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009;41(1):3–13. Doi:10.1249/MSS.0b013e31818cb278.
20. Harriss DJ, Macsween A, Atkinson G. Standards for ethics in sport and exercise science research: 2018 Update. Int J Sports Med 2017;38(14):1126-1131. Doi: 10.1055/s-0043-124001.

21. Kingsley M, Lewis MJ, Marson RE. Comparison of Polar 810s and an ambulatory ECG system for RR interval measurement during progressive exercise. Int J Sports Med 2005;26(1):39–44. Doi:10.1055/s-2004-817878.
22. Al Haddad H, Laursen PB, Chollet D, Ahmaidi S, Buchheit M. Reliability of resting and postexercise heart rate measures. Int J Sports Med 2011;32(8):598–605. Doi:10.1055/s-0031-1275356
23. Bloomfield DM, Magnano A, Bigger JT, Rivadeneira H, Parides M, Steinman RC. Comparison of spontaneous vs. metronome-guided breathing on assessment of vagal modulation using RR variability. Am J Physiol Heart Circ Physiol 2001;280(3):1145-1150. Doi: 10.1152/ajpheart.2001.280.3.H1145.
24. Dourado VZ, Banov MC, Marino MC, Souza VL, Antunes LCDO, McBurnie M. A Simple approach to assess VT during a field walk test. Int J Sports Med 2010;31(10):698–703. Doi:10.1055/s-0030-1255110.
25. Buchheit M. The numbers will love you back in return-I promise. Int J Sports Physiol Perform 2016;11(4):551–544. Doi:10.1123/IJSPP.2016-0214.
26. Hautala AJ, Mäkikallio TH, Kiviniemi A, Laukkanen RT, Nissilä S, Huikuri HV, et al. Cardiovascular autonomic function correlates with the response to aerobic training in healthy sedentary subjects. Am J Physiol Heart Circ Physiol 2003;285(4):1747-1752. Doi:10.1152/ajpheart.00202.2003.
27. Vesterinen V, Häkkinen K, Laine T, Hynynen E, Mikkola J, Nummela A. Predictors of individual adaptation to high-volume or high-intensity endurance training in recreational endurance runners. Scand J Med Sci Sports 2016;26(8):885–893. Doi:10.1111/sms.12530.
28. Marcora S. Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs. J Appl Physiol 2009;106(6):2060–2062. Doi:10.1152/japplphysiol.90378.2008.
29. Manzi V, Iellamo F, Impellizzeri F, D'Ottavio S, Castagna C. Relation between individualized training impulses and performance in distance runners. Med Sci Sports Exerc 2009;41(11):2090–2096. Doi:10.1249/MSS.0b013e3181a6a959.
30. Campos-Vazquez MA, Toscano-Bendala FJ, Mora-Ferrera JC, Suarez-Arrones LJ. Relationship between internal load indicators and changes on intermittent performance after the preseason in professional soccer players. J strength Cond Res 2017;31(6):1477–1485. Doi:10.1519/JSC.0000000000001613.
31. Iwasaki KI, Zhang R, Zuckerman JH, Levine BD. Dose-response relationship of the cardiovascular adaptation to endurance training in healthy adults: How much training for what benefit? J Appl Physiol 2003;95(4):1575–1583. Doi:10.1152/japplphysiol.00482.2003.
32. Saboul D, Balducci P, Millet G, Pialoux V, Hautier C. A pilot study on quantification of training load: The use of HRV in training practice. Eur J Sport Sci 201616(2):172–181. Doi:10.1080/17461391.2015.1004373.
33. Buchheit M, Chivot A, Parouty J, Mercier D, Al Haddad H, Laursen PB, Ahmaidi S. Monitoring endurance running performance using cardiac parasympathetic function. Eur J Appl Physiol 2010;108(6):1153–1167. Doi:10.1007/s00421-009-1317-x.
34. Da Silva DF, Verri SM, Nakamura FY, Machado FA. Longitudinal changes in cardiac autonomic function and aerobic fitness indices in endurance runners: A case study with a high-level team. Eur J Sport Sci 2014;14(5):443–451. Doi:10.1080/17461391.2013.832802.
35. Taylor R, Sanders D, Myers T, Abt G, Taylor CA, Akubat I. The dose-response relationship between training load and aerobic fitness in academy rugby union players. Int J Sports Physiol Perform 2017;10(1):1–22. Doi:10.1123/ijspp.2017-0121.
36. Mann TN, Lamberts RP, Lambert MI. High responders and low responders: Factors associated with individual variation in response to standardized training. Sports Med 2014;44(8):1113–1124. Doi:10.1007/s40279-014-0197-3.

ORCID number:
Tiago Volpi Braz: https://orcid.org/0000-0001-7463-6114
Michael Esco: https://orcid.org/0000-0002-9470-9680
Felipe Ornelas: https://orcid.org/0000-0002-8684-4671
Marlene Aparecida Moreno: https://orcid.org/0000-0003-4663-6234
Marcio Antônio Gonsalves Sindorf: https://orcid.org/0000-0002-8719-800X
Moisés Diego Germano: https://orcid.org/0000-0002-9136-5309
Charles Ricardo Lopes: https://orcid.org/0000-0003-4278-4969

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Author address: Tiago Volpi Braz. Rua Aurea Zanneti Penachione, 171, Bairro Jardim Terramerica 1, SP, CEP 13468-827.
E-mail: tiagovolpi@yahoo.br