High-Intensity Intermittent Exercise and Autonomic Modulation: Effects of Different Volume Sessions

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ABSTRACT
The aim of this study was to compare heart rate variability (HRV) recovery after 2 sessions of high-intensity intermittent exercise at different volumes (1.25 km [HIIE1.25] and 2.5 km [HIIE2.5]). 13 participants determined their maximal aerobic speed (MAS) and completed 2 HIIE (1:1 at 100 % MAS) trials. The heart rate was recorded before and after each session. HRV indicators were calculated according to time (RMSSD and SDNN) and frequency (LF, HF and LF/HF ratio) domains. SDNN and RMSSD presented effect of test (F = 20.97; p < 0.01 and F = 21.00; p < 0.01, respectively) and moment (F = 6.76; p < 0.01 and F = 12.30; p < 0.01, respectively), without interaction. Even though we did not find an interaction effect for any HRV variables, the HIIE2.5 presented a delay of only 5 min in HRV recovery, when compared to HIIE1.25. However, the effects of the test (SDNN, RMSSD, LF-log, and HF-log) indicate higher autonomic stress during the entire recovery period. These findings may indicate that exercise volume interferes with HRV recovery. If so, physically active subjects may choose a lower volume exercise (i.e., HIIE1.25) in order to promote similar physical fitness adaptations with lower loading on autonomic modulation.

Introduction
Heart rate variability (HRV) has become an accepted method for measuring cardiovascular autonomic modulation [25, 3, 14, 24], and the evaluation of HRV recovery has been presented as an important method to analyze autonomic behavior related to different modes of exercise [13, 29, 11]. Moreover, delayed HRV recovery is considered a predictor of mortality and risk of sudden death [17, 25].

Different studies have proposed to investigate HRV recovery after exercises with different intensity and volume [12, 20, 21], similar volumes [8], and similar energy expenditure [31] among trained or physically active subjects [8, 33, 30]. These studies have shown that higher exercise intensity leads to slower HRV recovery among physically active subjects, which is an important finding for exercise prescription.

Our group recently found that 5 kilometers (km) of high-intensity intermittent exercise (HIIE) delays HRV recovery (during 60 min of recovery, root mean square of successive differences [RMSSD] stayed lower) when compared to a session of moderate-intensity exercise with the same volume [8]. When compared to moderate intensity, HIIE seems to be more efficient to improve body composition and physical fitness [5, 6, 15]; in addition, subjects reach their goals faster with HIIE when compared to moderate-intensity exercise (time efficiency). Studies that investigated the effect of HIIE usually use 10 bouts of 1-min exercise at maximal aerobic speed (MAS) [34, 32], and physically active subjects would run approximately 2.5 km when performing this training. Nevertheless, the HRV recovery after a 2.5-km HIIE (HIIE2.5) has not been investigated yet; moreover, it is not known whether HRV recovery changes when performing half-distance HIIE (HIIE1.25).

Thus, the aim of the present study was to compare HRV recovery after an HIIE of 2.5 and 1.25 km. Our hypothesis was that HIIE2.5 would cause slower HRV recovery than HIIE1.25.
Methods

Subjects

13 male athletes volunteered for the present study. The subjects were college recreational athletes of different sports (4 rugby players, 4 gymnasts, 3 runners, 1 soccer player, and 1 swimmer); all participants had experience running and were able to complete study protocol. All procedures performed in the study were in accordance with (i) ethical standards of the Ethics Research Committee, and (ii) ethical standards of this journal described by Harris and Atkinson [18]. Consent forms were obtained from all participants after they were informed about the purpose and risks of the study.

Experimental design

Participants completed 3 experimental trials at the laboratory. The first visit aimed to determine peak oxygen uptake (VO$_{2\text{Peak}}$) and Maximal Aerobic Speed (MAS). However, 3 subjects performed just the MAS test without the VO$_{2\text{Peak}}$.

During the remaining 2 visits, all subjects were randomly submitted into 2 protocols of HIIE (HIIE 2.5 and HIIE1.25) separated by at least 72 h. To avoid the influence of circadian rhythm on HRV, all tests were performed at the same time of the day (between 9:00-11:00 a.m), and the average temperature of the room was between 20 °C and 24 °C [1]. The participants were instructed not to perform any strenuous exercise for at least 24 h prior to each exercise session and were encouraged to maintain their usual dietary routine. Moreover, they were also asked not to ingest stimulants (tea, coffee, soda, chocolate, chocolate powder), or alcoholic beverages during this period.

Incremental test

The participants were submitted to an incremental test on a treadmill (Inbramed MASTER CI, Inbrasport®, Porto Alegre, Brazil). The initial speed was set at 8 km·h$^{-1}$, increasing by 1 km·h$^{-1}$ every 2 min until exhaustion. Verbal encouragement was given during the test. Oxygen uptake was measured by Quark PFT (Cosmed®, Rome, Italy), and verbal encouragement was given during test. The MAS was assumed as the final speed in the incremental test. If the last stage was incomplete, the speed was expressed as follows: MAS = speed of final completed stage + [(time, in seconds, remaining at the final incomplete stage/120) * 1 km·h$^{-1}$] [23].

High-intensity exercise sessions

For both exercise trials, the participants performed a warm-up consisting of running at 50 % of MAS for 5 min at 1 % inclination. The HIIE were performed intermittently with 1 min running at MAS [28], followed by 1 min of passive recovery (without exercise) until they had completed both 2.5 and 1.25 km.

Heart rate variability recovery

To analyze HRV recovery, the heart rate was recorded in a quiet room before and after each exercise session. For data collection, a recording strap was placed on the participant’s sternum and the heart rate monitor Polar S810i (Polar Electro Oy Kempele, Finland – model S810i) on the wrist. The participant was instructed to remain in a supine position, resting, awake, silent and breathing spontaneously for 20 min. After this period, the participant performed the exercise protocol and returned to the supine position for 60 more minutes.

To analyze HRV, intervals between each heart beat (RR intervals) were extracted from the resting period immediately after exercise (0 min point (M1) and every 5 min until 1 h (M2 to M13)). The RR intervals were submitted to a digital filter using Polar Precision Performance software (Polar Electro, Finland) [22], complemented by manual filtering, in order to eliminate artifacts and premature ectopic beats that could interfere with the HRV analysis. Only series with more than 95 % of sinus beat were used in the study. All excerpts contained at least 256 RR intervals.

The HRV was calculated in time and frequency using Kubios HRV software (Kubios, Biosignal Analysis and Medical Image Group, Department of Physics, University of Kupio, Finland) [27]. During the time domain, the following indicators were used: root mean square of successive differences between adjacent normal RR intervals (RMSSD), in milliseconds, and the standard deviation of normal-to-normal RR intervals (SDNN), in milliseconds [35].

For the frequency domain, fast Fourier transform analysis was used to calculate low frequency (LF) band (0.04 to 0.15 Hz) and high frequency (HF) band (0.15 to 0.40 Hz), as well as the LF/HF ratio.

Statistical analyses

Statistical analyses were performed using SPSS 17.0. The normality of data was tested and confirmed using the Shapiro-Wilk test. LF and HF index were log-transformed to control for skewed distributions (LF-log and HF-log). Comparison of HRV recovery between moments, and between HIIE1.25 and HIIE2.5 was performed using a mixed model (analysis of variance). Exercise and moment were specified as fixed factors, and the participants as repeated factors. If a significant main effect or interaction was found, it was further explored through multiple comparison analyses with the Sidak adjustment. In the result section, Fisher’s value was presented. The comparison between HIIE characteristics was made by Student’s t test. The significance level was set at 5 %.

Results

Table 1 shows the characteristics of the participants and their responses to HIIE1.25 and HIIE2.5 protocols.

Regarding HRV, SDNN and RMSSD presented effect of test (F = 20.97; p < 0.01 and F = 21.00; p < 0.01, respectively) and time (F = 6.76; p < 0.01 and F = 12.30; p < 0.01, respectively), without interaction (F = 0.60; p = 0.83 and F = 0.31; p = 0.98). The recovery of SDNN after HIIE 2.5 was demonstrated recovery of SDNN after HIIE 2.5 and HIIE1.25. No difference was found in SDNN for HIIE1.25, whereas a significant difference was found between rest values at the 10th and 15th minute of recovery for HIIE2.5, RMSSD remained lower until the 45th minute for HIIE1.25, and the 50th minute for HIIE2.5 (Fig. 1b).

LF-log and HF-log also presented test (F = 11.62; p < 0.01 and F = 34.17; p < 0.01, respectively), and time effect (F = 10.75; p < 0.01 and F = 15.15; p < 0.01, respectively), without interaction (F = 0.96; p = 0.48 and F = 0.79; p = 0.65). After HIIE1.25, LF-log stayed lower than rest for 10 min, whereas after HIIE2.5, LF-log stayed lower than rest for 15 min (Fig. 2a). HF-log remained lower until the 25th minute of recovery after HIIE1.25, and until the 30th minute after...
HIIE 2.5 (▶ Fig. 2b). LF/HF did not present effect of time, test, or interaction.

**Discussion**

The aim of the present study was to compare HRV recovery after HIIE with different volumes (2.5 km and 1.25 km). The main findings showed that HRV (time and frequency domain) was reduced after both exercise protocols, but greater volume of HIIE created higher stress on the autonomic nervous system during recovery. RMSSD stayed lower until the 50th minute of recovery after HIIE 2.5 and until the 45th minute after HIIE 1.25. No difference was observed for SDNN after HIIE 1.25, although it remained lower until the 15th minute (compared to rest) after HIIE 2.5. Regarding the frequency domain of HRV variables, LF-log returned to rest values after 10 and 15 min of recovery after HIIE 1.25 and HIIE 2.5, respectively. Moreover, HF-log remained lower than rest until the 25th and 30th minute after HIIE 1.25 and HIIE 2.5, respectively.

In order to increase heart rate during exercise, HRV decreases through withdrawal of the parasympathetic system and increased activity of the sympathetic system [17]. During recovery, HRV is kept low for a few minutes according to exercise intensity, duration, and mode [9, 25, 33]. HRV recovery is widely used to determine acute stress response to different modes of exercise in both trained and untrained individuals [4, 8, 33]. This information is relevant for exercise prescription, and because HIIE has become widely used for different populations, understanding the stress responses of the autonomic nervous system after HIIE of similar intensities but different volumes is important.

SDNN increased immediately after both HIIE 1.25 and HIIE 2.5. This result agrees with the study performed by Caetano-Santos et al. [7], which demonstrated that SDNN increased immediately after HIIE and moderate-intensity exercise of 5 km. This increase is likely due to the initial recovery of the heart rate through parasympathetic reactivation [7, 10, 19], which increases the variation of RR interval, consequently enhancing SDNN. SDNN showed no difference in rest values after HIIE 1.25, indicating that the stress response of autonomic modulation after this exercise training protocol is lower than HIIE 2.5, in which SDNN returned to rest values after 15 min of recovery. This is supported by the group effect between HIIE 1.25 and HIIE 2.5 (*94.48 ± 53.23 ms and 83.97 ± 54.88 ms, respectively; p < 0.01). Similar results were found for RMSSD (HIIE 1.25 62.31 ± 53.90 ms and HIIE 2.5 44.55 ± 32.92 ms; p < 0.01) indicating that the entire exercise recovery exhibited lower parasympathetic activation after HIIE 2.5. In comparison to rest, RMSSD remained lower until the 45th minute after HIIE 1.25 and the 50th minute after HIIE 2.5.

Considering the frequency domain, LF-log stayed lower for 10 and 15 min after HIIE 1.25 and HIIE 2.5, respectively. Similarly, HF-log

**Table 1** Characteristics of study participants (n = 13).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>22.99 ± 6.84</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>80.36 ± 10.02</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.79 ± 0.08</td>
</tr>
<tr>
<td>BMI (kg · m²)</td>
<td>25.16 ± 2.07</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>17.96 ± 4.34</td>
</tr>
<tr>
<td>VO₂ peak (ml · kg · min⁻¹)</td>
<td>59.94 ± 9.38</td>
</tr>
<tr>
<td>MAS (km · h⁻¹)</td>
<td>13.85 ± 1.33</td>
</tr>
<tr>
<td>Duration session HIIE 1.25 (min)</td>
<td>9.92 ± 1.03</td>
</tr>
<tr>
<td>Duration session HIIE 2.5 (min)</td>
<td>20.85 ± 2.05</td>
</tr>
<tr>
<td>Bouts per session HIIE 1.25</td>
<td>5.46 ± 0.51</td>
</tr>
<tr>
<td>Bouts per session HIIE 2.5</td>
<td>10.92 ± 1.03</td>
</tr>
<tr>
<td>Heart rate rest (bpm)</td>
<td>62.31 ± 8.46</td>
</tr>
<tr>
<td>Heart rate final HIIE 1.25 (bpm)</td>
<td>173.08 ± 8.25</td>
</tr>
<tr>
<td>Heart rate final HIIE 2.5 (bpm)</td>
<td>177.92 ± 8.69</td>
</tr>
</tbody>
</table>

BMI = body mass index; VO₂peak = peak oxygen uptake; Maximal Aerobic Speed bpm = beat per minutes; HIIE 1.25 and HIIE 2.5 = high-intensity intermittent exercise of 1.25 and 2.5 km respectively.

**Fig. 1** Heart rate variability recovery of time domain indexes (a SDNN and b RMSSD) after HIIE 1.25 (●), and HIIE 2.5 (■). * significantly different from rest value for HIIE 2.5; # significantly different from rest value for HIIE 1.25.
Our results revealed that HIIE volume also determined stress of autonomic modulation behavior. Cabral-Santos et al. [8] observed that SDNN recovered 30 min after 5-km HIIE and RMSSD did not recover until the 60th minute. Our results revealed that HIIE volume also determined stress of autonomic modulation after exercise, because SDNN did not present a significant difference from rest values after HIIE1.25, and recovered in 15 min after HIIE2.5. When we take into account RMSSD, it did not recover in 1 h after a 5-km HIIE, as previously observed [8]; however, it recovered at the 45th and 50th minute after HIIE1.25 and HIIE2.5. These findings highlight the importance of HIIE volume on autonomic modulation behavior.

When comparing the effects of HIIE and a moderate-intensity training protocol on physical fitness variables, HIIE seemed to induce better or similar adaptations with significantly lower volume [6, 15]. Studies that use HIIE training usually perform 10 bouts of 1 min at MAS [2, 32], and the mean bouts of HIIE2.5 were 10.92 ± 1.03. To our knowledge, there is no study comparing the effects of lower volume HIIE training (≈ 5 bouts or 1.25 km for physically active subjects). If HIIE1.25 exerts a similar fitness adaptation to HIIE2.5 training, a lower volume of HIIE would be more appropriate due to: (i) time efficiency and (ii) lower stress of autonomic modulation. Therefore, since 10 × 1 min at MAS (HIIE2.5) has already shown to be effective in increasing physical fitness [2, 16], other studies may be needed to compare adaptations after HIIE with different volumes (5 km and 1.25 km). If a similar physical fitness adaptation occurs after low-volume HIIE (1.25 km), this exercise training should be selected because it presents smaller stress response of autonomic modulations than higher volumes.

Our study has some limitations that need to be addressed. The absence of a training load control as well as participants’ characteristics are relevant limitations because athletes and sedentary subjects can present different HRV responses after HIIE. Therefore, other studies with different populations (sedentary, athletes, women) are necessary.

In summary, we conclude that HIIE2.5 and HIIE1.25 change HRV recovery. Even though the HRV recovery is similar between both training protocols (delay of approximately 5 min after HIIE2.5), the total HRV during recovery was lower after HIIE2.5, which seems to present greater autonomic stress than HIIE1.25. These results must be taken into account when planning exercise prescription for physically active subjects, and other studies are necessary to verify whether HIIE1.25 is as effective as HIIE2.5, to improve physical fitness variables, such as cardiorespiratory endurance, muscular strength and speed. If so, HIIE1.25 (i.e., ≈ 5 × 1 min at MAS; 9 min of training) could be a better choice when thinking of exercise prescription, since it presents lower autonomic modulation stress.

Conflict of interest

The authors have no conflict of authors to declare.
References


