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Influence of high-intensity interval training on ventilatory efficiency in trained athletes

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ABSTRACT

The aim of this study was to investigate the effects of 3 weeks high-intensity interval training (HIIT) on ventilatory efficiency (V_E/VCO_2 slope) in endurance athletes. Sixteen male well-trained (67.72 ml kg min^{-1}) athletes participated in this study. Each participant performed an incremental exercise test with gas analysis (i.e. V_E, VO_2) and a 400 m running field test (T400m) before and after the 3 weeks intervention period. HIIT group (HIITG) performed 11 HIIT sessions consisting of four 4-min interval bouts at an exercise intensity of 90–95% of the VO_{2max}, separated by 4-min active recovery periods (work/rest ratio = 1:1). No significant differences were found in the parameters studied. Ventilatory efficiency (up to VT_2 and up to exhaustion) did not show any change in HIITG after training intervention (ES = 0.24 HIITG; ES = 0.21 CG). No significant changes were observed on ventilation (V_{Emax}; ES = 0.38). VO_{2max} and T400 m did not show a significant improvement after the training period (no interaction time × group, $p < .05$) (ES = 0.43 and ES = 0.75 respectively). These results do not support the hypothesis that 3 weeks of HIIT could modify the ventilatory efficiency response in well-trained athletes. Furthermore, they show the lack of relationship between ventilatory efficiency and sport performance.

1. Introduction

High-Intensity Interval Training (HIIT) is defined as either repeated short (< 45 s) to long (2–4 min) bouts of rather high-but not maximal intensity exercise, or short (< 10 s, repeated-sprint sequences (RSS)) or long (> 20–30 s, sprint interval session (SIT)) all-out sprints interspersed with recovery periods (Buchheit and Laursen, 2013). HIIT has increased its popularity during recent years as an effective method to improve exercise performance (Breil et al., 2010). The mechanisms proposed which could explain the improvements in sport performance after HIIT programs are: increments in VO_{2max} (Breil et al., 2010; Helgerud et al., 2007a), changes in plasma volume (Richardson et al., 1996), changes in hormonal and metabolic response (Wahl et al., 2014) or increments in skeletal muscle oxidative capacity (Egan et al., 2010; Gibala et al., 2006). However, the influence of HIIT on ventilatory parameters is still discussed controversially. Previous studies only analysed ventilation (V_E) response after HIIT (Czuba et al., 2013; Kilen et al., 2014). V_E determined at a fixed submaximal speed did not change after 12 weeks of HIIT in athletes (Kilen et al., 2014). Maximum ventilation (V_{Emax}) and maximal breathing frequency (f_{Rmax}) did not change after 3 weeks of HIIT neither in normoxia or hypoxia in basketball players (Czuba et al., 2013). Specifically, the influence of HIIT on ventilatory efficiency has only been studied in patients (Cardozo et al., 2015; Myers et al., 1999; Myers et al., 2012). Limited studies in this area reported that ventilatory efficiency generally improves after training in this population, although this is not an entirely consistent finding. Regular exercise training has been suggested as an effective stimulus likely affecting CO_2 chemosensitivity in athletes (Kelley et al., 1984; Miyamura and Ishida, 1990; Ohkuwa et al., 1980). There is an ongoing debate on the existence of a long-term modulation of the exercise ventilatory response in humans; however, the controversy may be related to the modest training protocols used in some of the studies (Babb et al., 2010). High ventilatory demands were described during HIIT training sessions (Williams and Kraemer, 2015). Inter-individual adjustment in breathing patterns was reported during high-exercise intensities as a way to deal with the metabolic demands at these intensities (Gravier et al., 2013). In this regard, controlled HIIT sessions may represent a powerful training stimulus potentially modifying the exercise ventilatory response and in consequence the relationship between the metabolic CO_2 production (VCO_2) and V_E. However, from our

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Table 1
Baseline age and physical characteristics of the training and the control group.

	HITG (n = 8)	CG (n = 8)
Age (years)	25.6 ± 3.2	25 ± 3.4
Height (cm)	181.6 ± 5.8	178.7 ± 4.9
Weight (kg)	74.2 ± 5.5	75.2 ± 6.3
VO_{2max} (ml kg min^{-1})	68.4 ± 2.7	67 ± 6.5

Data are presented as mean ± SD.

knowledge there are not studies which evaluated the influence of a HIIT program on ventilatory efficiency in sporty people.

In order to better clarify the influence of exercise on ventilatory efficiency, the present study aimed to investigate the effects of 3 weeks of HIIT on V_E/VCO_2 slope in athletes. We hypothesized that 3 weeks of HIIT could promote changes on the exercise ventilatory response, measured as V_E/VCO_2 slope, in athletes due to inter-individual adjustment in breathing patterns (Gravier et al., 2013) and the high ventilatory and metabolic requirements observed during HIIT sessions (Williams and Kraemer, 2015).

2. Materials and methods

2.1. Participants

Sixteen male well-trained sport students participated in the study (Table 1). Participants underwent a routine pre-participation screening prior to the baseline testing. Inclusion criteria were: a) experienced athletes (≥3 years of practice) and b) subjects with a VO_{2max} higher than 60 ml kg min^{-1}. Exclusion criteria were all types of acute and chronic diseases, taking medication on a regular basis or smoking. The study was carried out according to the Declaration of Helsinki and was approved by the Institutional Review Board of the Department of Sport Science (University Innsbruck). All participants gave written informed consent to participate in the study. Some of these participants were included previously in the sample size of other study (Menz et al., 2015). However, we carried out a new analysis about ventilatory efficiency and performance variables never published before.

2.2. Design

The study was designed as a randomized controlled training study including HIIT and control group (HIITG and CG, respectively) and two measurement times (pre-training vs post-training). Baseline measurements included a laboratory incremental treadmill test and a 400 m running field test. After baseline measurements, the participants were randomly assigned, stratified by VO_{2max} either to the HIITG or the CG. The HIITG started the 3-week running HIIT program whereas CG maintained their usual training during this period. In particular, they were advised not to include additional high-intensity training. The training data for the HIITG and the CG were recorded in a training log book and the total endurance training loads were determined according to (Foster et al., 2001) as perceived exertion × endurance training session time (Table 2).

2.3. Methodology

2.3.1. Treadmill and 400 m running test

The treadmill protocol was performed according to Burtscher et al. (2010). Gas analysis was performed using an open spirometric system (Oxycon Mobile, Care Fusion, Würzburg, Germany) which was calibrated before each measurement. Cardio-respiratory parameters (i.e. V_E, VO_2, VCO_2, HR) were recorded breath by breath during the ergospirometry. A test was considered maximal when three of the four criteria proposed by (Cunha et al., 2010) were fulfilled. Additionally, participants carried out a 400 m running filed test. The time to complete the 400 m was selected as a performance variable (T400m). Athletes were encouraged to achieve their best performance. Post-training measurements were the same as for the baseline condition (relative humidity: 45–65%; temperature: 24–25 °C) and were conducted 5 ± 2 days after the last HIIT session.

2.3.2. HIIT program

The HIITG performed 11 HIIT sessions during the 3-week HIIT period. Each HIIT session consisted of four 4-min interval-running bouts at an exercise intensity of 90–95% of the VO_{2max}, separated by 4-min active recovery periods (work/rest ratio = 1:1). During the first week, athletes completed three HIIT sessions. In the following two weeks athletes performed four HIIT sessions each week. Training intensity was controlled by continuous heart rate (HR) monitoring (Polar, Kempele, Finland) and was equivalent to the HR at 90–95% of their VO_{2max} (García-Pallarés and Morán-Navarro, 2012). The rating of perceived exertion (RPE) was determined according to the Borg scale (6–20) (Borg, 1982).

2.3.3. Ventilatory efficiency calculation

The V_E/VCO_2 slope was calculated from the slope of the relationship between VCO_2 and V_E during each incremental exercise test. V_E/VCO_2 slope was calculated from the beginning of the test until the second ventilatory threshold (VT_2) and up to exhaustion. VT_2 was identified by an increase in the ventilatory equivalent of CO_2 ($EqCO_2$) and a decrease in end tidal partial pressure of carbon dioxide ($PETCO_2$) (Lucía et al., 2000).

2.4. Statistical analysis

Data are expressed as mean ± SD and with Cohen's d effect size (ES) for each variable. Normal distribution of data was tested by the Kolmogorov–Smirnov test. A two-way analysis (group × time) of variance (ANOVA) with repeated measurements was used to verify between-group changes. In case of significant differences, post-hoc testing with Bonferroni correction was applied. The relationships between ventilatory efficiency (V_E/VCO_2 slope) and performance variables (VO_{2max} and T400m) were assessed by regression analyses. The level of significance was set at $p < .05$ for each statistical analysis. An ES of < .2 was considered small, .5 medium and > .8 large. Because the influence of HIIT on ventilatory efficiency has never not been studied in athletes, power calculation (G*Power 3.1.7) was based on the present results (post-hoc test).

Table 2
Training data (all endurance training performed during the 3-week training period) for HITG and CG.

	HITG group (n = 8)			CG (n = 8)		
	Endurance (min)	Borg	Trimp	Endurance (min)	Borg	Trimp
Week 1	329.1 ± 134.5	13.7 ± 1.9	3570.1 ± 1914.8	331.2 ± 95.8	13.2 ± 0.9	4431.8 ± 1549.3
Week 2	248 ± 90.4	14.1 ± 1.7	3163.5 ± 1320.6	272.5 ± 196.2	14.1 ± 2.8	3522.2 ± 2718.2
Week 3	297.5 ± 123.2	14.5 ± 1.3	4062.1 ± 1632.3	390.7 ± 192.7	14.8 ± 4.1	5129.7 ± 2439.8
Total	874.6 ± 212.8	14.1 ± 1.1	13,098.8 ± 4734.5	994.5 ± 418.1	14 ± 2.3	12,326.7 ± 5706

Data are presented as mean ± SD. *TRIMP* training impulse (perceived exertion × endurance training session time).