

A comparison of isocapnic buffering phase of cross-country skiers and alpine skiers

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Abstract

Purpose: The purpose of this study was to compare the isocapnic buffering phase in cross-country skiers and alpine skiers during an incremental treadmill exercise test.

Material: International level male junior skiers including twelve cross-country skiers and ten alpine skiers took part in the study. All participants performed an incremental treadmill exercise test to determine ventilatory threshold (VT), respiratory compensation point (RCP), and maximal oxygen uptake (VO_{2max}). The isocapnic buffering phase was calculated as the difference in VO_2 (ICB_{VO_2}) and running speed (ICB_{SPEED}) between RCP and VT and expressed in either absolute or relative values.

Results: VO_{2max} , maximal running speed, time to exhaustion, both absolute and relative VT values and absolute RCP values were higher in the cross-country skiers than in the alpine skiers ($P < 0.05$), whereas relative RCP showed similar values in both group ($p > 0.05$). Absolute ICB_{VO_2} and ICB_{SPEED} showed similar values in both group ($p > 0.05$), whereas relative ICB_{VO_2} and ICB_{SPEED} were found to be significantly higher in alpine skiers than in cross-country skiers ($P < 0.05$). Maximal respiratory exchange ratio was higher in alpine skiers than in cross-country skiers.

Conclusions: The current findings suggest that anaerobic training may induces specific metabolic adaptations leading to increase in buffering capacity which may be a contributing factor to continue to exercise for relatively longer periods of time above the VT. Longer ICB phase in the anaerobic-trained athletes may an important factor in relation to the enhance high-intensity exercise tolerance.

Keywords: buffering capacity, maximal oxygen uptake, ventilatory threshold, respiratory compensation point, training.

Introduction

The ventilatory threshold and respiratory compensation point have been widely used to monitor the training status and prepare the training programs in the endurance athletes [1]. During incremental exercise, anaerobic threshold (AT) can be estimated from non-invasive gas exchange measurements alternative to the measurements of blood lactate concentration (lactate threshold), in this case referred to as the ventilatory threshold (VT) [2, 3]. VT corresponds to the nonlinear increase in carbon dioxide production and ventilation due to the bicarbonate buffering of hydrogen ions (H^+) in response to the systematic increase of blood lactate above resting values [3]. When H^+ can no longer be compensated by circulating bicarbonate leads to a decrease in blood pH and stimulates the carotid bodies to increase ventilatory drive results in hyperventilation [3]. This additional ventilatory response is called the respiratory compensation point (RCP) [4]. The region between AT and RCP is defined as isocapnic buffering (ICB) phase and represent a phase of compensation for the exercise induced metabolic acidosis [5]. The region between RCP and the end of exercise is defined as the phase of hypocapnic hyperventilation (HHV) [6, 7].

The length of the ICB phase may be related to buffering capacity, lactate kinetics as well as the sensitivity of the carotid bodies to exercise induced metabolic acidosis [5,

8, 9, 10]. Some researchers suggested that the ICB phase contribute to the aerobic capacity in athletes [7, 11]. On the other hand, according to some researchers, the ICB is not related to endurance performance [12]. Recently it has been shown that the relative ICB phase can be useful for predict both the aerobic and anaerobic capacity in the athletes [8].

The observation of the ICB phase during incremental exercise testing may provide useful information on the non-invasive estimation of buffering capacity. The length of the ICB phase among athletes from different sports may vary depending on their training regime [8, 11, 13]. A few studies have compared the ICB phase between aerobic and anaerobic trained athletes. These studies have been shown that the greater lactate increase during ICB phase in anaerobic-trained athletes than in endurance-trained athletes [8, 11, 13]. However, to our knowledge, no investigation has attempted to compare the VO_2 during ICB phase between anaerobic-trained athletes and endurance-trained athletes.

A cross-country skiing competition often lasts for 10 to 120 minutes, which requires skiers to have a high aerobic capacity [14]. Aerobic endurance training has always been the major component of training program in cross-country skiing [1, 15, 16]. On the other hand, anaerobic power is the best predictor of performance during alpine ski races lasting between 45 s and 3 min [17]. Traditionally, alpine skiers are trained with anaerobic exercises such as resistance training, speed, change of

direction and plyometric training [18, 19]. Measurements of athletes' ICB phase values can help to understanding the physiological adaptations in response to physical training. To our knowledge, no studies examining the ICB phase of cross-country skiers and alpine skiers. The purpose of this study was to compare the ICB phase in cross-country skiers and alpine skiers during an incremental treadmill exercise test.

Material and methods

Participants

International level twenty-two male junior skiers including twelve cross-country skiers and ten alpine skiers from the Turkey national team took part in the study. The demographic characteristics of cross-country and alpine skiers are given in Table 1. Erciyes University Medical Faculty Ethics Committee approved the study (217/554). All testing procedures were fully explained, and written informed consent was obtained for each subject. All measurements took place at the High Altitude and Sports Science Research and Implementation Center at Erciyes University.

Table 1. The physical characteristics of the alpine skiers and cross-country skiers (Mean \pm SD).

	Alpine skiers	Cross country skiers	p	d
Age (year)	17.4 \pm 2.4	16.8 \pm 1.8	0.54	0.3
Height (cm)	175.6 \pm 3.7	168.7 \pm 5.6*	0.004	1.5
Body Mass (kg)	67.3 \pm 9.1	59.6 \pm 5.6*	0.02	1.09

Incremental treadmill test

Maximal oxygen uptake (VO_{2max}), VT and RCP were determined from a progressive intensity and continuous effort treadmill protocol. All tests were performed on a motorized treadmill (h/p/Cosmos Quasar med, Nussdorf-Traunstein, Germany). Oxygen uptake (VO_2), carbon dioxide output (VCO_2) and minute ventilation (VE) were measured online using a breath-by-breath cardiopulmonary exercise testing system (Quark PFT Ergo, CosmedSrl, Rome, Italy). Before each test, ambient conditions were measured and the gas analyzers and turbine flowmeter were calibrated with known certified gas concentrations (16 % O_2 , 5 % CO_2 , and balance N_2) and a 3 L calibration syringe, respectively, following the manufacturer's instructions.

Breath-by-breath VO_2 was smoothed using a five-step average filter and then reduced to 15 s stationary averages for the incremental test to reduce the noise so as to enhance the underlying characteristics. To make sure the athletes were properly warmed up, prepared, and accustomed to the treadmill, each athletes had to warm up for 6 min at their own pace. Then the athletes were

allowed to stop and stretch for about 3 min. Following the warm-up, athletes started running at 7 km/h with speed increments of 1 km/h (at constant 5% incline) every minute until they could no longer keep pace. The athletes were instructed to run until voluntary exhaustion, and given strong verbal encouragement throughout the test to elicit their best performance.

The VO_{2max} was defined as the highest 15 s VO_2 value reached during the incremental test. Achievement of VO_{2max} was considered as the attainment of at least two of the following criteria: 1) a plateau in VO_2 despite increasing speed, 2) a respiratory exchange ratio (VCO_2/VO_2) above 1.10, and 3) a HR (heart rate) within 10 beats per minute of age-predicted maximum HR (220 – age). The VO_{2max} value was expressed as a relative value (milliliters per minute per body mass; $ml\ kg^{-1}\ min^{-1}$). Time to exhaustion was recorded as the time from the start of the run until the point of exhaustion (the time at which the subject could no longer maintain the pace of the treadmill). Maximal respiratory exchange ratio (RER_{max}) was expressed as the highest 15 s average value obtained during the last stage of the incremental exercise test.

Determination of ventilatory threshold and respiratory compensation point

The VT and RCP were determined using the V-slope method described by Beaver et al. [2]. The VT and RCP were defined as the VO_2 value corresponding to the intersection of two linear regression lines derived separately from the data points below and above the breakpoint in the VCO_2 versus VO_2 , and VE versus VCO_2 relationships, respectively (Figure 1). Additionally, to increase the accuracy of the identification of VT and RCP, a visual identification technique was used as described below. VT was determined using the criteria of an increase in VE/VO_2 with no increase in VE/VCO_2 and an increase in end-tidal O_2 pressure with no fall in end-tidal CO_2 pressure, whereas RCP corresponded to an increase in VE/VCO_2 and decrease in end-tidal CO_2 pressure. To reduce the variability connected with the identification of VT and RCP, analyses were performed by two independent investigators. Each of the following variables was recorded at both the VT and the RC; running speed ($km\ h^{-1}$), VO_2 ($ml\ kg^{-1}\ min^{-1}$) and VO_2 as a percentage of VO_{2max} ($\%VO_{2max}$). Linear regression analyses were performed by using the Sigma Plot program (Sigma Plot 12.0, Systat Software Inc., Chicago, USA).

Determination of isocapnic buffering and hypocapnic hyperventilation phases

ICB phase was calculated as the difference in VO_2 (ICB_{VO_2}) and running speed (ICB_{SPEED}) between RCP and VT [20], and expressed in either absolute or relative values (expressed as a percentage of RCP previously described by Röcker et al.) [13]. HHV phase was calculated as the difference in VO_2 (HHV_{VO_2}) and running speed (HHV_{SPEED}) between the end of exercise and RCP [20], and expressed in either absolute or relative values (expressed as a percentage of VO_{2max} and maximal running speed).

Statistical analyses

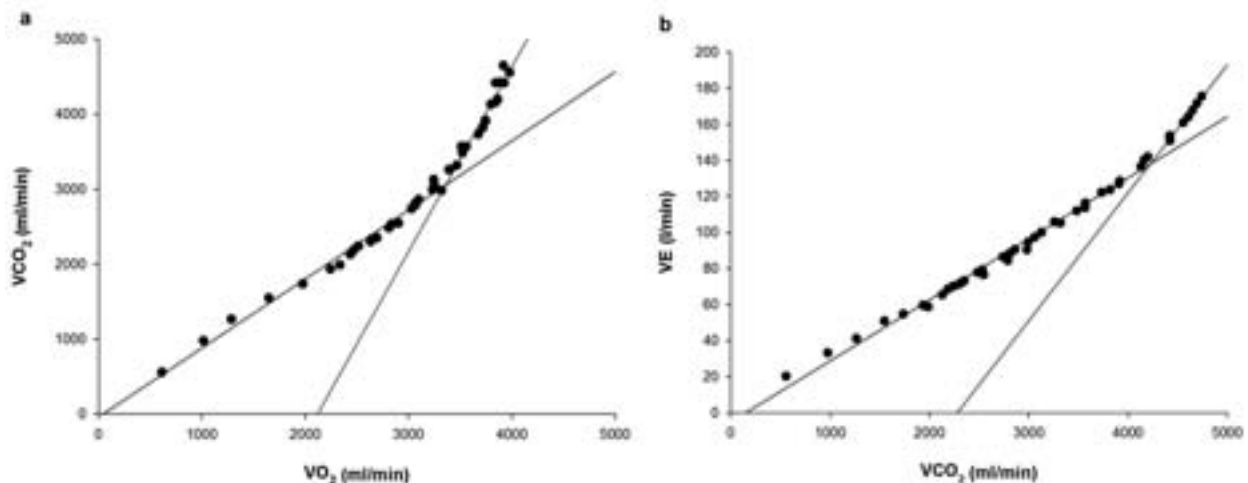


Figure 1. Examples showing methods of determining the ventilatory threshold (a) and the respiratory compensation point (b) in one subject.

Data are reported as means \pm standard deviation (SD). Statistical significance was accepted at $p < 0.05$. The normality of the data was examined by assessing the Shapiro-Wilk test on all measured variables. Ages, Speed_{max}, VT_{SPEED}, VT_{VO2}, absolute ICB_{SPEED} and absolute HHV_{SPEED} data were not normally distributed and so comparisons between the groups were made using the Whitney-U test. As the other data showed normal distribution, the differences in measures between groups were evaluated by unpaired t-test. To allow a better interpretation of the results, effect sizes were also calculated using Cohen's d [21]. Effect sizes were interpreted as negligible ($d \geq 0.2$), small ($0.2 \leq d \leq 0.5$), medium ($0.5 \leq d \leq 0.8$) or large ($0.8 \geq d$). IBM SPSS 21 software (IBM SPSS Statistics 21 Inc. Chicago, IL) was used for the statistical analysis.

Results

There was no significant difference between the two groups for age ($p > 0.05$), while a significant difference was found for height and body mass ($p < 0.05$). VO_{2max}, maximal running speed, time to exhaustion, VO₂ at VT and RCP, running speed at VT and RCP were higher in the cross-country skiers than in the alpine skiers ($p < 0.001$). There were no significant differences between the two groups in HR_{max}, HR at VT and RCP. RER_{max} was higher in alpine skiers than in cross-country skiers ($p < 0.05$).

The VT expressed as % VO_{2max} and maximal running speed were significantly higher in the cross-country skiers than in alpine skiers ($P < 0.05$), whereas RCP expressed as % VO_{2max} and maximal running speed showed similar values in both groups ($p > 0.05$). Absolute ICB_{VO2} and ICB_{SPEED} showed similar values in both group ($p > 0.05$), whereas relative ICB_{VO2} and ICB_{SPEED} were found to be significantly higher in alpine skiers than in cross-country skiers ($P < 0.05$). There were no significant differences between the two groups in the relative HHV_{VO2}, and absolute and relative HHV_{SPEED} ($p > 0.05$), while absolute HHV_{VO2} were higher in the cross-country skiers than in the alpine skiers ($P < 0.05$).

Discussion

This study compared ICB phase between cross-country skiers and alpine skiers. The results of this study indicated that VO_{2max}, maximal running speed, time to exhaustion, both absolute and relative VT values (expressed as VO₂ and running speed) were higher in the cross-country skiers than in the alpine skiers, reflecting the cross-country skiers have higher aerobic capacity. On the other hand, relative ICB phase values were higher in alpine skiers than in cross-country skiers. Our findings suggest that anaerobic training stimulus in alpine skiers may have enhanced the ICB phase which may be attributable to improve of the buffering capacity contributing factor to continue to exercise for relatively longer periods of time above the VT.

Because published literature is sparse, the current study compared ICB phase of anaerobic trained athletes and aerobic trained athletes. To our knowledge, only three studies have compared the ICB phase between aerobic and anaerobic trained athletes. Our findings were consistent with those of Röcker et al. reported that the ICB phase which the difference between the running speed at LT and at RCP expressed as a percentage of RCP was higher in elite 400-m runners than in aerobic trained group [13]. On the other hand, in their study, VO_{2max} and maximal running speed did not differ between 400-m runners and aerobic trained group. Similarly, Hasanli et al. found that although the relative lactate changes during ICB phase was higher in sprint-trained cyclists than in endurance-trained cyclists, no significant differences in VO_{2max} between the two groups [8]. Our study can be considered to be an appropriate model for the investigation of ICB phase in anaerobic and aerobic trained athletes.

It has been demonstrated that the longer ICB phase in trained subjects was associated with RCP occurring at higher intensities of exercise [22]. In our study, relative RCP values were no significant difference between in alpine skiers and cross-country skiers. Therefore, the longer ICB phase in the alpine skiers may be attributable to the lower relative VT. The alpine skiers were able

Table 2. Physiological variables corresponding to the ventilator threshold, respiratory compensation point, maximal values, isocapnic buffering and hypocapnic hyperventilation phases of the alpine skiers and cross-country skiers.

Variables	Alpine skiers	Cross country skiers	p	d
Ventilatory threshold				
VO ₂	41.6 ± 5.7	55.5 ± 3*	0.001	3.3
% VO _{2max}	79.5 ± 4.5	83.3 ± 3.1*	0.03	1.05
% Speed _{max}	66.4 ± 3.9	72.5 ± 4.8*	0.005	1.45
Speed (km h ⁻¹)	9.5 ± 0.7	12.2 ± 0.6*	0.001	4.38
HR (beat min ⁻¹)	173.6 ± 17.4	178.4 ± 12.3	0.48	0,34
Respiratory compensation point				
VO ₂	49.3 ± 5.7	62.1 ± 3.4*	0.001	2.7
% VO _{2max}	94.4 ± 2.3	93.1 ± 1.8	0.8	0.67
% Speed _{max}	85.3 ± 3.6	85.8 ± 4.8	0.16	0.12
Speed	12.2 ± 0.6	14.5 ± 0.6*	0.001	4.02
HR	188.6 ± 13	194.1 ± 9.4	0.29	0,52
Maximal				
VO _{2max}	52.2 ± 5.5	66.7 ± 3.9 *	0.001	3.24
Speed _{max}	14.3 ± 0.6	16.9 ± 0.6*	0.001	5.24
Time to ex	7.6 ± 0.6	10.2 ± 0.6*	0.001	4.54
RER _{max}	1.2 ± 0.03	1.1 ± 0.03*	0.04	3.5
HR _{max}	211.3 ± 14.9	208.8 ± 17.7	0.74	0.16
Isocapnic buffering phase				
Abs VO ₂	7.7 ± 1.4	6.5 ± 1.6	0.09	0.83
Rel VO ₂	15.8 ± 3.2	10.5 ± 2.3*	0.001	2.03
Abs Speed	2.7 ± 0.6	2.2 ± 0.6	0.06	0.87
Rel speed	22 ± 5	15.4 ± 3.7*	0.002	1.6
Hypocapnic hyperventilation phase				
Abs VO ₂	2.8 ± 1.2	4.5 ± 1.3*	0.005	1.2
Rel VO ₂	5.5 ± 2.3	6.8 ± 1.8	0.16	0.67
Abs Speed	2.1 ± 0.5	2.4 ± 0.9	0.44	0.42
Rel Speed	14.6 ± 3.6	14.1 ± 4.8	0.8	0.12

Values are mean ± standard deviation. VO₂ and running speed are expressed in ml kg min⁻¹ and km h⁻¹, respectively. * Significantly different from alpine skiers. Maximal = maximal values of physiological variables, Time to ex= Time to exhaustion (min), VO_{2max} = maximal oxygen uptake, RER_{max} = maximal respiratory exchange ratio, Abs= absolute, Rel = relative, Speed_{max} = maximal running speed.

to continue to exercise for relatively longer periods of time above the VT during the incremental treadmill test. Increase buffer capacities in the anaerobic-trained athletes may be a contributing factor to enhance anaerobic performance capacities [23].

VO_{2max} together with VT are the most important physiological variables used in the evaluation of aerobic endurance [24]. Therefore, it is expected that the VT values are high in the cross-country skiers. Different the physiological adaptations are provided depending on the intensity and duration of the training program. Traditionally, cross country skiers are trained at intensities below the VT in most of their training sessions [1]. It has been suggested that lower intensity training at slightly below AT induces mainly central adaptations, which provide the increase of AT, such as improvements in pulmonary diffusion, hemoglobin affinity and cardiac output [25]. Another possible explanation for high VT

values of the cross-country skiers (vs. alpine skiers) may be related to genetic makeup of this group. The percentage slow-twitch muscle fiber and the respiratory capacity of muscle may play an important role in determining the relative AT [26]. Ivy et al., reported a strong positive correlation between the lactate threshold (LT) values and the percentage slow-twitch muscle fiber and muscle's respiratory capacity [26].

Probably depending on differences in the metabolic pathways used during training sessions, AT, RCP and consequently the ICB phase varies between aerobic and anaerobic trained athletes. According to some researchers, intense training sessions involving anaerobic metabolism improves the buffering capacity leading to a shift in RCP towards higher intensities, and consequently extending the ICB phase [6]. On the other hand, training sessions involving aerobic metabolism may induces a similar shift in both VT and RCP [6]. Therefore, it appears that effect

of the high intensity training sessions on RCP may greater than AT. Alpine ski training stimulates the predominantly anaerobic energy pathways [18]. A large accumulation of lactate and H^+ during high intensity exercise may provide an important stimulus for adaptations of the muscle pH regulating systems [27]. This is supported by increases in muscle buffer capacity in response to high-intensity interval training [28]. In addition, sprint training has been reported to increase the muscle buffer capacity, whereas endurance training had no effect [29]. The current findings suggest that anaerobic training stimulus in alpine skiers may have been improved the buffering capacity leading to a shift in RCP without change in VT, and consequently enhancing the ICB phase.

Another possible explanation for longer ICB phase of alpine skiers may be related to the percentage of fast-twitch muscle fibers. Fast-twitch muscle fibers may have a higher buffering capacity than the slow-twitch muscle fibers [30]. Previous studies significant relationships were observed between muscle buffering capacity and percentage of fast-twitch muscle fibers in mixed group of untrained, sprint and endurance trained athletes [30, 31]. The increased in buffer capacity after training has been attributed to an increased the concentration of carnosine which is mainly present in fast-twitch muscle fibers [31]. It has been shown that the greater muscle buffering capacity in anaerobic-trained athletes than in endurance athletes [32]. During the ICB phase, more H^+ has been reported buffered by the non-bicarbonate buffer system in sprint-trained cyclists than in endurance cyclists [8].

Higher RER_{max} values recorded despite shorter running time to exhaustion in alpine skiers than in cross-country skiers. Although we could not directly measure blood lactate levels, higher RER_{max} values in alpine skiers may reflect a greater accumulation of lactate than cross-country skiers [33]. It has been demonstrated that increase in lactate during the ICB phase was higher in anaerobic trained athletes than in aerobic trained athletes

[8, 11, 13]. In addition, negative relationships reported between the relative lactate changes during ICB phase and aerobic fitness (VO_2 at LT, and VO_{2max}) [8, 11]. This may be indicates that different physiological adaptations have developed to the physical training depending on the contribution of the aerobic or anaerobic energy production. The major metabolic results of the adaptations of muscle to endurance exercise training are less lactate production during exercise of a given intensity [34]. On the other hand, it has been shown that the anaerobic training led to a greater accumulation of lactate both in the muscle and blood during exhaustive exercise [29, 35]. These higher lactate concentrations after anaerobic training may be explained by the increase of the muscle buffer capacity and glycolytic enzymes [29, 35].

Conclusions

Relative VT values were found to be significantly higher in cross-country skiers than in alpine skiers, while relative RCP values were similar in both groups. Therefore, the longer ICB phase in the alpine skiers may be attributable to the lower relative VT. The current findings suggest that anaerobic training may induces specific metabolic adaptations leading to increase in buffering capacity which may be a contributing factor to continue to exercise for relatively longer periods of time above the VT. It can be suggested that longer ICB phase in the anaerobic-trained athletes may an important factor in relation to the enhance high-intensity exercise tolerance.

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Conflicts of interest

The authors have no conflicts of interest relevant to this study.

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