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Aerobic capacity and respiratory indices of junior cross-country skiers and biathletes during incremental exercise testing

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The present study compared the isocapnic buffering phase (ICB), hypocapnic hyperventilation phase, ventilatory threshold (VT), respiratory compensation point (RCP), and maximum oxygen uptake (VO_{2max}) among biathlon and cross-country ski athletes during an incremental exercise test. 37 male and 33 female Turkish National Team athletes volunteered to participate in the research. Body fat percentage, lean mass, and fat mass values of athletes were measured using the bioelectrical impedance analysis method, and oxygen consumption (VO_2) was measured with a portable cardiopulmonary exercise test system with a ramp protocol on the treadmill. In VT, RCP, and VO_{2max} phases, male athletes had higher VO_2 and speed values than female athletes ($p < 0.05$). In contrast, they had similar values across different categories of sports (biathlon and cross-country skiing) ($p > 0.05$). Additionally, XC skiers and males had higher absolute (Abs) VO_2 and mass-normalized (Rel) VO_2 values than biathletes and females in exhaustion times and ICBs ($p < 0.05$). In contrast, they had similar Abs VO_2 and Rel VO_2 values in hypocapnic hyperventilation phases ($p > 0.05$). In addition, XC skiers and males had higher absolute (Abs) VO_2 and relative (Rel) VO_2 values than biathletes and females in exhaustion times and ICBs ($p < 0.05$). In contrast, they had similar Abs VO_2 and Rel VO_2 values in hypocapnic hyperventilation phases ($p > 0.05$). These results indicate significant differences in physiological profiles between male and female athletes and between XC skiers and biathletes.

Keywords Buffering capacity, Maximal oxygen uptake, Respiratory compensation point, Performance, Ski

Biathlon and cross-country skiing (XC skiing) are endurance sports where competitors ski over various distances and terrain, with the skiing and shooting components significantly different. For instance, biathlon skiing during competition is intermittent, being stopped by 1-minute breaks on the shooting range, unlike XC skiing, which comprises non-stop skiing from start to finish[1]. Winter Olympics endurance sports include cross-country skiing and biathlon, where the latter combines cross-country skiing and accurate shooting. XC skiers and biathletes must have a good aerobic capacity because competitions typically last 10 to 120 min[2,3]. Physiological variables such as maximum oxygen uptake (VO_{2max}) and exercise intensity equivalent to the lactate or anaerobic threshold (AT) are believed to have an impact on endurance cycling performance[4–6]. These physiological variables indicate maintaining the highest potential power production and oxygen intake (VO_2) during the event[7]. According to Hawley et al.[8], successful endurance athletes can hold high VO_{2max} percentages for extended periods, develop high power outputs and maintain effective technique. Therefore, the sustained power output and, in turn, the relationship between performance on these tasks and the physiological outcomes of incremental exercise testing, such as VO_{2max} and AT, may be impacted by the difference in exercise duration and the physiological demands of the event[9]. It is common knowledge that men and women perform differently in sports. These disparities can be explained by several physiological justifications[10,11]. Specifically, males typically have more extensive anthropometric measurements, higher testosterone levels, greater capacity for type II fibre hypertrophy and

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reactivity to exercise. Additionally, males have a higher relative stroke volume and cardiac output, higher red blood cell mass, higher glycolysis enzyme activity and higher glycogen storage capacity. However, there are no differences between males and females in the composition, activation or strength of the same diameter muscle fibres[10].

On the other hand, females may have more vital coordination skills and more elastic connective tissue and tend to use fat more efficiently during aerobic exercise. It is well known that males have more prominent upper-body musculature and strength than females, whereas females have more body fat and lesser aerobic capacity. However, in world-class XC skiers, neither oxygen (O_2) debt nor gross efficiency varies between the sexes[12,13]. However, no published data demonstrates gender disparities among elite XC skiers and biathletes. Therefore, comparing these athletes' anthropometric, physiological, and training regimens is required to understand better the reported disparities in skiing speed between XC skiers and biathletes while considering gender. To prescribe an efficient endurance athlete's training program and track their progress, the ventilatory threshold and respiratory compensation point have been frequently employed to establish three training intensities[4]. Ventilatory threshold (VT) can be calculated using non-invasive gas exchange measures during incremental exercise as an alternative to measurements of the blood lactate concentration[14]. Due to the bicarbonate buffering of hydrogen ions (H^+) in response to the systemic increase in blood lactate above resting values, power or VO_2 at VT correlates with the nonlinear increase in carbon dioxide (CO_2) generation and ventilation[15]. During an incremental exercise test, the minute ventilation (VE), CO_2 production (VCO_2) and VO_2 all increase linearly as the exercise intensity rises until lactic acidosis sets in[15]. VCO_2 rises faster than VO_2 at exercise intensities above AT because non-metabolic VCO_2 from buffering lactic acid with bicarbonate is added to the metabolic VCO_2. Bicarbonate causes a drop in blood pH and stimulates the carotid bodies to augment the ventilatory drive, which causes hyperventilation when H^+ cannot be replaced by circulation[15]. As a result, VE initially rises proportionately to VCO_2 rise, but as exercise intensity increases above AT, it grows faster than VCO_2. The respiratory compensation point (RCP) is the term used to describe this increased ventilatory reaction. The isocapnic buffering phase (ICB) between AT and RCP compensates for exercise-induced metabolic acidosis[16].

The hypocapnic hyperventilation phase (HHV) is the period from RCP through the end of the exercise[17]. The duration of the ICB during an incremental exercise test is likely influenced by several physiological and biochemical factors, including the ratio of fast and slow-twitch muscle fibers, the oxidative capacities of fast-twitch muscle fibers, the activity of anaerobic glycolysis enzymes, hypertrophy of muscle fibers, muscle capillarization, and the power of monocarboxylate transporters such as MCT1 and MCT4[17,18]. Although buffering capacity may affect the ICB, its contribution to the variance of this indicator is minimal, potentially accounting for only 5–10%. The ICB phase is a useful index for evaluating athletes' aerobic capabilities. While it does not directly enhance aerobic capacity, it provides insights into the buffering capacity and tolerance to high-intensity exercise, which are critical components of overall aerobic performance In addition, it was hypothesised that the ICB helps athletes' aerobic capability[19], whereas another research reported that ICB is unrelated to endurance performance[20]. Recently, it was demonstrated that athletes' anaerobic and aerobic capacities might be predicted using the relative ICB[18]. The non-invasive assessment of the buffering capacity may benefit from knowledge gained through observing the ICB during incremental exercise testing, as this phase reflects critical physiological responses to increasing exercise intensity. The ICB, which spans from the VT to the RCP, indicates the body's ability to buffer lactate produced during high-intensity exercise. This buffering capacity is essential for sustaining performance in endurance sports. Studies have shown that athletes with a higher ICB tend to have better aerobic and anaerobic capacities, suggesting that observing the ICB can provide valuable insights into an athlete's overall metabolic adaptations and endurance capabilities[17]. Furthermore, non-invasive measurements during the ICB phase allow for continuous monitoring without the need for invasive blood sampling, making it a practical and effective method for assessing and optimizing training programs. A few studies compared the ICB of athletes who trained aerobically with those who trained anaerobically and discovered that anaerobic-trained athletes experienced higher lactate rises during the ICB than endurance-trained competitors[18,21].

Numerous incremental exercise methods, including measuring AT and VO_{2max}, have been used to assess exercise capacity. These procedures have varied, particularly regarding the length and strength of step increments. Nowadays, the most common method for determining AT and VO_{2max} is a ramp exercise test on a cycle ergometer. However, in trained runners, cycle ergometry has significantly underestimated VO_{2max} compared with moderately fit and active non-athletes[22]. There is limited research on the ICB of athletes with aerobic and anaerobic training. The athletes' ICB measurements can be used to assess the physiological demands of their sport and understand the physiological changes induced by exercise, which may contribute to the explanation of gender differences in training adaptation. Therefore, this study compares the isocapnic buffering, hypocapnic hyperventilation, ventilatory threshold and VO_{2max} in junior biathlon and cross-country ski male and female athletes during an incremental exercise test.

Methods
Participants
37 male and 33 female Turkish National Team athletes, including 17 female and 19 male cross-country skiers and 16 female and 18 male biathlon athletes, volunteered to participate in the study. Characteristics of athletes are presented in Table 1. The inclusion criteria for the study group were to have participated in competitions in national team classes in international tournaments and have not been injured in the past year. The study was approved by the Gazi University Faculty of Medicine Ethics Committee (E-77082166-604.01.02-538554) following the latest declarations of Helsinki. All testing procedures were thoroughly explained and written informed consent was obtained from each subject. This study was conducted at the Olympic Preparation Centre, the largest rehabilitation and performance measurement center in Turkey, located in Ankara and operated under

	Male		Female		
	Biathletes	XC skiers	Biathletes	XC skiers	
N	18	19	16	17	*p*
Age (yrs)	18.56 ± 2.2	19.77 ± 2.60	19.25 ± 1.60	18.72 ± 1.80	0.28
Experience (yrs)	4.37 ± 1.10	6.50 ± 0.80	5.60 ± 1.00	6.80 ± 1.10	0.25
Body mass (kg)	65.79 ± 8.60	69.60 ± 8.70	56.97 ± 5.50	51.32 ± 6.30	0.22
Body fat (%)	11.44 ± 3.90	11.80 ± 3.10	18.58 ± 3.00	19.00 ± 4.30	0.62
Fat mass (kg)	7.51 ± 2.60	8.20 ± 2.20	10.72 ± 2.60	9.84 ± 2.70	0.78
Muscle mass (kg)	55.36 ± 7.80	58.32 ± 7.80	43.91 ± 3.10	39.36 ± 4.50	0.15

Table 1. Characteristics of the biathletes and XC skiers (mean ± standard deviation).

the Ministry of Youth and Sports of the Republic of Turkey. The center offers state-of-the-art facilities designed to optimize athlete performance.

Bioelectrical impedance analysis (BIA)
The athletes' body fat percentage, lean mass and fat mass values were measured using the bioelectrical impedance analysis method (MC 980, 1000 kHz, Tanita Corporation, Tokyo, Japan) after 12 h of fasting. With the help of hand and foot electrodes in the device, the electric current passing through the body provides a comprehensive body analysis.

VO_{2max} test
Oxygen consumption was measured with a portable cardiopulmonary exercise test K5 system (Cosmed, Rome, Italy), capable of automatic gas analysis from each expiratory air, with a ramp protocol[23] performed on a treadmill. Before each test, the portable metabolic gas analyser was calibrated using a sample of recognised gases (5.0% CO_2 and 16.0% O_2). To eliminate the adverse effects of room conditions on performance and VO_2 data during the tests carried out in the laboratory environment, the temperature was kept at 18–23 °C and the relative humidity below 70% with air conditioners[24]. Participants warmed up at 8 $km{\cdot}h^{-1}$ for 4 min. Then, the running speed progressively increased by 1 $km{\cdot}h^{-1}{\cdot}min^{-1}$ until volitional exhaustion. The breath-by-breath VO_2 was smoothed using a five-step average filter, then decreased to 5 s stationary averages for the incremental test to reduce noise in the data and improve the underlying features. The most excellent 15-second VO_2 value obtained during the incremental test was considered as VO_{2max}. The achievement of VO_{2max} needed to be confirmed as the plateauing of VO_2 (< 2.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ decrease) despite an increase in workload, a plateau in VO_2 despite the increasing speed and a respiratory exchange ratio (VCO_2/VO_2) above 1.10[25]. The duration of the run from the beginning to the point of exhaustion, or "time to exhaustion", was recorded (i.e., the time at which the subject could no longer maintain the treadmill's pace). Regarding the data obtained from the VO_{2max} test, absolute (Abs) VO_{2max} is simply the amount of O_2 breathed in litres per minute. Relative (Rel) VO_{2max} measures O_2 consumption in millilitres per minute per kilogram of body mass. In accordance with standard practices in physiological studies and to ensure that the regression analysis accurately reflects steady-state exercise conditions, the initial 5–6 min of data, corresponding to the warm-up phase, were excluded from the analysis. This exclusion is essential for maintaining the reliability and validity of VO_{2max} measurements by minimizing the confounding effects of initial physiological fluctuations[25].

Determination of the ventilatory threshold and respiratory compensation point
The V-slope approach by Beaver et al.[14] was used to calculate VT and RCP. The VO_2 value that falls within the intersection of two linear regression lines that were independently constructed from the data points below and above the breakpoint in the VCO_2 versus VO_2 and the VE versus the VCO_2 relationships, respectively, was identified as VT and RCP (Fig. 1). Additionally, the following visual identification method was utilised to improve the precision of the identification of VT and RCP. RCP corresponded to an increase in the VE/VCO_2 and a drop in the end-tidal CO_2 pressure. In contrast, VT was established using the criteria of an increase in the VE/VO_2 with no rise in the VE/VCO_2 and an increase in the end-tidal O_2 pressure with no decrease in the end-tidal CO_2 pressure. Two researchers analysed the data to diminish the variability of VT and RCP identification. In a disagreement, a third investigator's opinion was sought. Running speed ($km{\cdot}h^{-1}$), VO_2 ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)

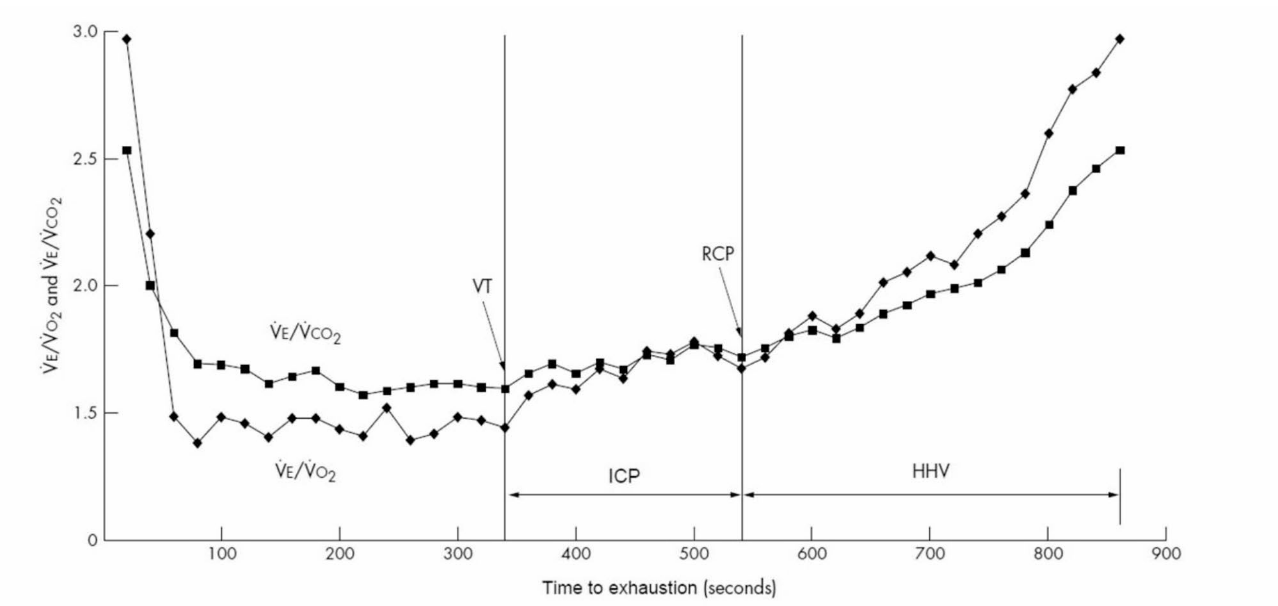

Fig. 1. Determination of VT and RCP phases in one subject.

and VO_2 as a percentage of VO_{2max} (%VO_{2max}) were all measured at VT and RCP. Figure 1 presents the phases of VT, ICP, and HHV[26].

Determination of the isocapnic buffering and hypocapnic hyperventilation phases
The ICB phase was calculated as the difference in VO_2 between the RCP and VT and was expressed in either absolute or relative values (expressed as a percentage of the RCP previously described by Röcker et al.)[27]. The HHV phase was calculated as the difference in VO_2 between the end of exercise and the RCP and was expressed in either absolute or relative values (expressed as a percentage of VO_{2max})[23]. The calculation methods for the ICB and HHV phases are presented below:

ICB;
Abs VO_2 : RCP-VT.
Rel VO_2 : (RCP-VT) ÷ RCP × 100.
HHV;
Abs VO_2 : VO_{2max} - RCP.
Rel VO_2 : (VO_{2max} -RCP) ÷ VO_{2max} × 100.

Statistical analysis
Data are reported as the means ± standard deviation. Statistical analyses were performed using the SPSS software (IBM SPSS Statistics, Version 21.0, Chicago, USA; https://www.ibm.com/support/pages/spss-statistics-210-available-download). The normality of the data was examined by performing the Shapiro-Wilk test on all measured variables. The two groups made comparisons using independent t-tests or the Mann-Whitney U test according to the distribution. Simple linear regression analysis was used to determine the success of the prediction. Effect sizes were also calculated using Cohen's d to allow a better interpretation of the results. Effect sizes were interpreted as negligible ($d \leq 0.2$), small ($0.2 < d \leq 0.5$), medium ($0.5 < d \leq 0.8$) or large ($0.8 > d$). Linear regression analyses were performed using the Sigma Plot program (SigmaPlot, Version 12.0, Systat Software, Chicago, USA; https://grafiti.com). Statistical significance was accepted at $p < 0.05$. The mixed 2 × 2 (category) analysis of variance (ANOVA) with repeated measures was used to compare variables related to different genders and categories. Partial eta squared values (η_p^2) were calculated for the effect size in the ANOVA, and effect sizes were classified as small ($\eta_p^2 \leq 0.01$), medium ($\eta_p^2 \leq 0.06$) and large ($\eta_p^2 \leq 0.14$).

Results
Regarding body composition, no significant differences were recorded between male and female athletes (Table 1, $p > 0.05$).

Ventilatory threshold point
For VO_2, the gender effect ($F_{(1;38)} = 55.247$, $p = 0.000$, $\eta^2 = 0.456$) and gender×category interaction ($F_{(1;38)} = 11.077$, $p = 0.001$, $\eta^2 = 0.144$) were significant, whereas category effect was not significant (Table 2, $p > 0.05$).

By %VO_{2max}, the gender ($F_{(1;38)} = 7.385$, $p = 0.008$, $\eta^2 = 0.101$) and category effects ($F_{(1;38)} = 8.589$, $p = 0.005$, $\eta^2 = 0.115$) and gender×category interaction ($F_{(1;38)} = 55.247$, $p = 0.011$, $\eta^2 = 0.094$) were significant.

Based on speed, the gender effect ($F_{(1;38)} = 57.998$, $p = 0.000$, $\eta^2 = 0.468$) was significant, whereas category effect and gender×category interaction were not significant ($p > 0.05$).

According to heart rate (bpm), the gender effect ($F_{(1;38)} = 6.677$, $p = 0.012$, $\eta^2 = 0.093$) and gender×category interaction ($F_{(1;38)} = 9.297$, $p = 0.003$, $\eta^2 = 0.125$) were significant, whereas category effect was not significant ($p > 0.05$).

Respiratory compensation point
For VO_2, the gender effect ($F_{(1;38)} = 98.694$, $p = 0.000$, $\eta^2 = 0.599$) and gender×category interaction ($F_{(1;38)} = 7.362$, $p = 0.008$, $\eta^2 = 0.100$) were significant, whereas category effect was not significant ($p > 0.05$).

By %VO_{2max}, gender×category interaction ($F_{(1;38)} = 10.391$, $p = 0.002$, $\eta^2 = 0.136$) was significant, whereas category and gender effects were no significant ($p > 0.05$).

Based on speed, the gender effect ($F_{(1;38)} = 96.381$, $p = 0.000$, $\eta^2 = 0.594$) was significant, whereas category effect and gender×category interaction were not significant ($p > 0.05$).

According to heart rate, gender×category interaction ($F_{(1;38)} = 13.065$, $p = 0.001$, $\eta^2 = 0.165$) was significant, whereas gender and category effects were not significant ($p > 0.05$).

Maximum oxygen uptake phase
For VO_{2max}, the gender effect ($F_{(1;38)} = 91.584$, $p = 0.000$, $\eta^2 = 0.581$) was significant, whereas category effect and gender×category interaction were not significant ($p > 0.05$).

Based on the time of exhaustion, the gender ($F_{(1;38)} = 58.744$, $p = 0.000$, $\eta^2 = 0.471$) and category effects ($F_{(1;38)} = 7.566$, $p = 0.008$, $\eta^2 = 0.103$) were significant, whereas gender×category interaction was not significant ($p > 0.05$).

Based on RQ, the gender and category effects and gender×category interaction were not significant ($p > 0.05$).

Based on max speed, the gender effect ($F_{(1;38)} = 149.065$, $p = 0.000$, $\eta^2 = 0.693$) was significant, whereas category effect and gender×category interaction were no significant ($p > 0.05$).

According to max heart rate, gender×category ($F_{(1;38)} = 12.824$, $p = 0.001$, $\eta^2 = 0.163$) interaction was significant, whereas gender and category effects were no significant ($p > 0.05$).

	Biathletes		XC skiers		Gender	Category	Gender× category interaction
	Male	Female	Male	Female			
Ventilatory threshold							
VO_2 (ml·kg·min^{-1})	57.31 ± 5.27	45.83 ± 6.30	52.95 ± 4.60	48.57 ± 5.20	F = 55.247*	F = 0.580	F = 11.077*
% VO_{2max}	82.75 ± 3.00	82.83 ± 5.90	78.10 ± 4.60	82.57 ± 3.40	F = 7.385*	F = 8.589*	F = 6.855*
Speed (km·h^{-1})	12.50 ± 1.20	10.67 ± 1.50	12.10 ± 0.90	10.43 ± 1.00	F = 57.998*	F = 1.923	F = 0.114
HR (bpm)	183.13 ± 5.60	182.33 ± 5.50	175.55 ± 5.40	180.48 ± 9.50	F = 6.667*	F = 1.955	F = 9.297*
Respiratory compensation point							
VO_2 (ml·kg·min^{-1})	65.88 ± 5.10	52.03 ± 5.60	64.11 ± 5.50	56.21 ± 5.40	F = 98.694*	F = 1.463	F = 7.362*
%VO_{2max}	96.78 ± 2.70	94.21 ± 3.30	93.92 ± 3.70	95.27 ± 1.10	F = 0.312	F = 1.788	F = 10.391*
Speed (km·h^{-1})	14.12 ± 0.80	12.17 ± 1.00	14.20 ± 0.60	12.57 ± 1.10	F = 96.3810*	F = 1.724	F = 0.815
Heart rate (bpm)	193.88 ± 3.80	191.00 ± 5.60	190.80 ± 5.20	198.28 ± 8.40	F = 2.587	F = 2.158	F = 13.065*
VO_{2max}							
VO_2 (ml·kg·min^{-1})	68.07 ± 5.50	55.23 ± 5.80	68.25 ± 6.80	59.00 ± 5.60	F = 91.584*	F = 2.944	F = 2.421
Time to ex (minute)	15:48 ± 1:05	12:46 ± 1:18	16:24 ± 1:00	13:15 ± 1:28	F = 58.744*	F = 7.566*	F = 1.874
RQ	1.12 ± 0.05	1.12 ± 0.03	1.12 ± 0.08	1.08 ± 0.1	F = 3.140	F = 3.142	F = 3.498
Max speed (km·h^{-1})	16.14 ± 0.70	14.13 ± 0.90	16.48 ± 0.80	14.44 ± 1.00	F = 149.065*	F = 3.815	F = 0.007
Max HR (bpm)	201.88 ± 4.90	197.83 ± 6.90	199.3 ± 8.80	205.43 ± 8.30	F = 0.540	F = 3.125	F = 12.824*
Isocapnic buffering phase							
Abs VO_2	8.57 ± 2.30	6.20 ± 1.30	11.16 ± 2.30	7.64 ± 1.80	F = 31.479*	F = 19.668*	F = 1.932
Rel VO_2	13.02 ± 4.40	11.92 ± 4.20	17.41 ± 4.80	13.61 ± 3.90	F = 7.111*	F = 15.862*	F = 4.332*
Hypocapnic hyperventilation phase							
Abs VO_2	2.19 ± 1.80	3.20 ± 1.40	4.15 ± 2.10	2.79 ± 0.60	F = 1.490	F = 3.382	F = 8.498*
Rel VO_2	3.21 ± 2.40	5.79 ± 2.70	6.08 ± 2.70	4.73 ± 0.90	F = 1.241	F = 10.150	F = 10.806*

Table 2. Physiological variables corresponding to the ventilator threshold, respiratory compensation point, maximal values, isocapnic buffering and hypocapnic hyperventilation phases of the men and women biathletes and XC skiers. Values are mean ± standard deviation. VO_2 and running speed are expressed in (ml·kg·min^{-1}) and km·h^{-1}, respectively. *Time to ex* time to exhaustion (min), VO_{2max} maximal oxygen uptake, *Abs* absolute, *Rel* relative, *Max speed* maximal running speed, *RQ* respiratory quotient. *$p < 0.05$.

Isocapnic buffering phase

Based on Abs VO_2, the gender ($F_{(1;38)} = 31.479$, $p = 0.000$, $\eta^2 = 0.323$) and category effects ($F_{(1;38)} = 19.668$, $p = 0.000$, $\eta^2 = 0.230$) were significant, whereas gender×category interaction was not significant ($p > 0.05$).

Based on Rel VO_2, the gender ($F_{(1;38)} = 7.111$, $p = 0.010$, $\eta^2 = 0.097$) and category effectd ($F_{(1;38)} = 15.862$, $p = 0.000$, $\eta^2 = 0.194$) and gender×category interaction ($F_{(1;38)} = 4.332$, $p = 0.042$, $\eta^2 = 0.061$) were significant.

Hypocapnic hyperventilation phase

Based on Abs VO_2, gender×category interaction ($F_{(1;38)} = 8.498$, $p = 0.005$, $\eta^2 = 0.114$) was significant, whereas gender and category effects were no significant ($p > 0.05$).

Based on Rel VO_2, gender×category interaction ($F_{(1;38)} = 10.806$, $p = 0.002$, $\eta^2 = 0.141$) was significant, whereas gender and category effects were no significant ($p > 0.05$).

Discussion

This study examined the aerobic capacity indices, such as the ICB, HHV phase, VT, RCP, and VO_{2max}, among junior biathlon and cross-country ski athletes during an incremental exercise test. The results of this study indicated that males and females in both groups had similar body composition analyses. In VT, RCP and VO_{2max} phases, male athletes had higher VO_2 and speed values than female athletes, whereas they had similar values by category. In addition, XC skiers and males had higher Abs VO_2 and Rel VO_2 values than biathletes and females in exhaustion times and ICBs, whereas they had similar Abs VO_2 and Rel VO_2 values in HHV.

VO_{2max} and VT are the essential physiological variables to evaluate athletes' aerobic endurance[28]. Therefore, cross-country skiers are expected to have high VT and VO_{2max}. Different physiological adaptations develop in the body depending on the intensity and duration of the training[29]. Cross-country skiers typically practice most of their training sessions at intensities below the VT[30]. According to some theories, lower-intensity exercise at levels just below AT primarily causes central adaptations, which raise AT and enhance physiological functions such as pulmonary diffusion, haemoglobin affinity and cardiac output[29]. The genetic makeup of this group could be another reason for the increased VT values of XC skiers compared with biathletes. The proportion of slow-twitch muscle fibres and the muscle fibres' ability to breathe may be critical factors in determining the relative VT[31]. According to Ivy et al.[31], there is a direct link between the percentage of slow-twitch muscle fibres, the muscle's respiratory capacity and LT values[31]. Interestingly, VO_{2max} values did not differ between XC skiers and biathletes. It was unexpected because a previous study found that XC skiers' VO_{2max} values were significantly greater than biathletes[32]. The fact that biathletes had the same volume[33] but a higher ratio of high-intensity training in the total endurance training volume may help explain this part. However, XC skiers had better cardiovascular capacity (i.e., cardiac output index and threshold oxygen pulses), likely due to increased low-intensity training and moderate-intensity training volumes.

Previous studies have compared ICB between aerobic- and anaerobic-trained athletes. These studies showed a higher relative ICB in anaerobic-trained athletes than endurance-trained athletes[1,12,18]. Unlike previous studies, the present study compared male and female athletes with high aerobic endurance values in two branches. Chicharro et al.[17] reported that rigorous anaerobic-based training sessions increase buffering capacity, which causes RCP to shift towards higher intensities and lengthen ICB. Conversely, aerobic-based training sessions may cause a similar change in both VT and RCP[17]. According to these findings, RCP appears more affected by high-intensity training sessions than AT. As a result of training athletes in both groups, there were no appreciable variations in relative RCP values between the biathletes and XC skiers in our study. For their lower relative VT, team sport athletes may have a more significant ICB than other athletes[1]. Increased buffer capacity in anaerobic-trained athletes may improve their ability to operate in anaerobic conditions[34]. Previous studies have indicated that training intensity can differ between genders, even when the overall training volume is similar. For instance, Laaksonen et al. (2018) found that biathletes and XC skiers may prioritize different training intensities based on their specific physiological demands[35]. Additionally, the tendency for females to engage in lower intensity training could be due to different physiological and metabolic adaptations that influence their endurance and strength training processes. More research is needed to explore these differences in greater detail and their implications on performance.

Some researchers suggested that ICB helps athletes' aerobic capability[19]. Previous research showed that athletes' VO_{2max} and ICBs correlate[19,36]. On the other hand, another study suggested that ICB is unrelated to endurance athletes' performance[20]. Even though the endurance athletes' VO_{2max} was higher in this study, ICB was higher in team sport participants. Oshima et al.[19] demonstrated that ICB had a stronger correlation with VO_{2max} than AT in athletes. Differences in the physiology and movement abilities of females would be partially impacted. As a result of specific metabolic adaptations developed with anaerobic training, buffer capacity may develop and exercise can be continued for a relatively more extended period after the respiratory threshold thanks to this improvement. The more extended ICB in anaerobically trained athletes may be essential in increasing tolerance to high-intensity exercise[18].

Conclusions

The present study found that %VO2max values were significantly higher in cross-country skiers (XC skiers) compared to biathletes, whereas relative respiratory compensation point (RCP) values were similar between the two groups. Among female athletes, both XC skiers and biathletes exhibited similar values. These findings suggest that gender variations in athletic performance are predominantly influenced by genetic factors. The elevated ICB values observed in male XC skiers may indicate an enhanced buffering capacity, which could be attributed to their rigorous anaerobic training regimens. This training likely improves their ability to manage H^+ ions, thereby allowing them to sustain higher intensities for longer durations. Although our study did not directly measure the impact of anaerobic training on buffering capacity, previous research has shown that such training can lead to significant physiological adaptations that enhance performance in high-intensity sports[17]. Additionally, the data suggests that male athletes and XC skiers generally exhibit higher VO_2 and speed values across various physiological phases, highlighting the impact of gender and sport-specific training on these physiological variables.

Data availability

The datasets analysed during the current study are available from the corresponding author.

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References

1. Myakinchenko, E. B. et al. Physiological profiles and training loads of international level male and female cross-country skiers and biathletes. *Sci. Sports* **37**, 490–e1 (2022).
2. Hoffman, M. D. & Street, G. M. Characterization of the heart rate response during biathlon. *Int. J. Sports Med.* **13**, 390–394 (1992).
3. Staib, J. L., Im, J., Caldwell, Z. & Rundell, K. W. Cross-country ski racing performance predicted by aerobic and anaerobic double poling power. *J. Strength. Cond. Res.* **14**, 282–288 (2000).
4. Coyle, E. F., Coggan, A. R., Hopper, M. K. & Walters, T. J. Determinants of endurance in well-trained cyclists. *J. Appl. Physiol.* **64**, 2622–2630 (1988).
5. Coyle, E. F. et al. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med. Sci. Sports Exerc.* **23**, 93–107 (1991).
6. Olds, T. S. et al. Modeling road-cycling performance. *J. Appl. Physiol.* **78**, 1596–1611 (1995).
7. Coyle, E. F. Integration of the physiological factors determining endurance performance ability. *Exerc. Sport Sci. Rev.* **23**, 25–63 (1995).
8. Hawley, J. A., Myburgh, K. H., Noakes, T. D. & Dennis, S. C. Training techniques to improve fatigue resistance and enhance endurance performance. *J. Sports Sci.* **15**, 325–333 (1997).
9. Bentley, D. J., McNaughton, L. R., Thompson, D., Vleck, V. E. & Batterham, A. M. Peak power output, the lactate threshold, and time trial performance in cyclists. *Med. Sci. Sports Exerc.* **33**, 2077–2081 (2001).
10. Issurin, V. *Building the Modern Athlete: Scientific Advancements and Training Innovations* (Ultimate Athlete Concepts, 2015).
11. Lundberg, T. R. et al. The International Olympic Committee framework on fairness, inclusion and nondiscrimination on the basis of gender identity and sex variations does not protect fairness for female athletes. *Scand. J. Med. Sci. Sports* **34**, e14581 (2024).

12. Hegge, A. M. et al. Gender differences in power production, energetic capacity and efficiency of elite cross–country skiers during whole–body, upper–body, and arm poling. *Eur. J. Appl. Physiol.* **116**, 291–300 (2016).
13. Sandbakk, O., Ettema, G. & Holmberg, H. C. Gender differences in endurance performance by elite cross-country skiers are influenced by the contribution from poling. *Scand. J. Med. Sci. Sports* **24**, 28–33 (2014).
14. Beaver, W. L., Wasserman, K. & Whipp, B. J. A new method for detecting anaerobic threshold by gas exchange. *J. Appl. Physiol.* **60**, 2020–2027 (1986).
15. Wasserman, K. The anaerobic threshold measurement to evaluate exercise performance. *Am. Rev. Respir. Dis.* **129**, S35–S40 (1984).
16. Meyer, T., Faude, O., Scharhag, J., Urhausen, A. & Kindermann, W. Is lactic acidosis a cause of exercise induced hyperventilation at the respiratory compensation point? *Br. J. Sports Med.* **38**, 622–625 (2004).
17. Chicharro, J. L., Hoyos, J. & Lucía, A. Effects of endurance training on the isocapnic buffering and hypocapnic hyperventilation phases in professional cyclists. *Br. J. Sports Med.* **34**, 450–455 (2000).
18. Hasanli, M., Nikooie, R., Aveseh, M. & Mohammad, F. Prediction of aerobic and anaerobic capacities of elite cyclists from changes in lactate during isocapnic buffering phase. *J. Strength. Cond Res.* **29**, 321–329 (2015).
19. Oshima, Y. et al. Relationship between isocapnic buffering and maximal aerobic capacity in athletes. *Eur. J. Appl. Physiol. Occup. Physiol.* **76**, 409–414 (1997).
20. Bentley, D. J., Vleck, V. E. & Millet, G. P. The isocapnic buffering phase and mechanical efficiency: relationship to cycle time trial performance of short and long duration. *Can. J. Appl. Physiol.* **30**, 46–60 (2005).
21. Hirakoba, K. & Yunoki, T. Blood lactate changes during isocapnic buffering in sprinters and long distance runners. *J. Physiol. Anthropol. Appl. Hum. Sci.* **21**, 143–149 (2002).
22. Pannier, J. L., Vrijens, J. & Van Cauter, C. Cardiorespiratory response to treadmill and bicycle exercise in runners. *Eur. J. Appl. Physiol. Occup. Physiol.* **43**, 243–251 (1980).
23. Scheer, V., Ramme, K., Reinsberger, C. & Heitkamp, H. C. VO2max testing in trail runners: is there a specific exercise test protocol? *Int. J. Sports Med.* **39**, 456–461 (2018).
24. Tanner, R. & Gore, C. *Physiological Tests for Elite Athletes* (Human kinetics, 2012).
25. Poole, D. C. & Richardson, R. S. Determinants of oxygen uptake. Implications for exercise testing. *Sports Med.* **24**, 308–320 (1997).
26. Girard, O. et al. Specific incremental test in elite squash players. *Br. J. Sports Med.* **39**(12), 921–926 (2005).
27. Röcker, K., Striegel, H., Freund, T. & Dickhuth, H. H. Relative functional buffering capacity in 400-meter runners, long-distance runners and untrained individuals. *Eur. J. Appl. Physiol. Occup. Physiol.* **68**, 430–434 (1994).
28. Helgerud, J. Maximal oxygen uptake, anaerobic threshold and running economy in women and men with similar performances level in marathons. *Eur. J. Appl. Physiol. Occup. Physiol.* **68**, 155–161 (1994).
29. Docherty, D. & Sporer, B. A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. *Sports Med.* **30**, 385–394 (2000).
30. Seiler, K. S. & Kjerland, G. Ø. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an optimal distribution? *Scand. J. Med. Sci. Sports* **16**, 49–56 (2006).
31. Ivy, J. L., Withers, R. T., Vanhandel, P. J., Elger, D. H. & Costill, D. L. Muscle respiratory capacity and fiber type as determinants of the lactate threshold. *J. Appl. Physiol.* **48**, 523–527 (1980).
32. Laaksonen, M. S., Finkenzeller, T., Holmberg, H. C. & Sattlecker, G. The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: a review. *J. Sport Health Sci.* **7**, 394–404 (2018).
33. Myakinchenko, E. & Kuzmichev, V. Comparison of testing procedures for peak oxygen consumption, aerobic and anaerobic thresholds in elite biathletes. *Vestnik Sportivnoy Nauki* **2**, 41–46 (2017).
34. Parkhouse, W. S., McKenzie, D. C., Hochachka, P. W. & Ovalle, W. K. Buffering capacity of deproteinized human vastus lateralis muscle. *J. Appl. Physiol.* **58**, 14–17 (1985).
35. Laaksonen, M. S., Finkenzeller, T., Holmberg, H. C. & Sattlecker, G. The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: a review. *J. Sport Health Sci.* **7** (4), 394–404 (2018).
36. Oshima, Y. et al. Effects of endurance training above the anaerobic threshold on isocapnic buffering phase during incremental exercise in middle-distance runners. *Jpn. J. Phys. Fit. Sports Med.* **47**, 43–51 (1998).

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Declarations

Competing interests
The authors declare no competing interests.

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