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ORIGINAL RESEARCH

Seasonal variations in body composition, maximal oxygen uptake, and gas exchange threshold in cross-country skiers

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Introduction: In order to ensure that athletes achieve their highest performance levels during competitive seasons, monitoring their long-term performance data is crucial for understanding the impact of ongoing training programs and evaluating training strategies. The present study was thus designed to investigate the variations in body composition, maximal oxygen uptake (VO_{2max}), and gas exchange threshold values of cross-country skiers across training phases throughout a season.
Materials and methods: In total, 15 athletes who participate in international cross-country ski competitions voluntarily took part in this study. The athletes underwent incremental treadmill running tests at 3 different time points over a period of 1 year. The first measurements were obtained in July, during the first preparation period; the second measurements were obtained in October, during the second preparation period; and the third measurements were obtained in February, during the competition period. Body weight, body mass index (BMI), body fat (%), as well as VO_{2max} values and gas exchange threshold, measured using V-slope method during the incremental running tests, were assessed at all 3 time points. The collected data were analyzed using SPSS 20 package software. Significant differences between the measurements were assessed using Friedman's twoway variance analysis with a post hoc option.
Results: The athletes' body weights and BMI measurements at the third point were significantly lower compared with the results of the second measurement ($p<0.001$). Moreover, the incremental running test time was significantly higher at the third measurement, compared with both the first ($p<0.05$) and the second ($p<0.01$) measurements. Similarly, the running speed during the test was significantly higher at the third measurement time point compared with the first measurement time point ($p<0.05$). Body fat (%), time to reach the gas exchange threshold, running speed at the gas exchange threshold, VO_{2max}, amount of oxygen consumed at gas exchange threshold level (VO_{2GET}), maximal heart rate (HR_{max}), and heart rate at gas exchange threshold level (HR_{GET}) values did not significantly differ between the measurement time points ($p>0.05$).
Conclusion: VO_{2max} and gas exchange threshold values recorded during the third measurements, the timing of which coincided with the competitive season of the cross-country skiers, did not significantly change, but their incremental running test time and running speed significantly increased while their body weight and BMI significantly decreased. These results indicate that the cross-country skiers developed a tolerance for high-intensity exercise and reached their highest level of athletic performance during the competitive season.
Keywords: athletic performance, aerobic capacity, winter sport

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Introduction

The impact of training throughout a season, monitoring of the athletes' performances, and ensuring that they reach the highest level of performance during competitive periods are crucial in performance sports. Long-term endurance training programs are expected to improve the physiological characteristics of athletes.[1] Nevertheless, the athletes' performance can fluctuate during the training conducted throughout a season. Therefore, it is crucial that both coaches and athletes know the variations in their monthly and seasonal performances in relation to their training program, and that the athletes show high performance during competitive seasons. Such information can substantially contribute to the adjustment of the appropriate training strategies followed by the athletes.

Cross-country skiing takes place at moderate altitude and in cold environment, and it is among the sports that require the highest level of endurance.[2] The few studies conducted on elite cross-country skiers have reported that the maximal oxygen uptake (VO_{2max}) values of male athletes varied between 80 and 90 mL/kg/min.[3,4] These values underline the significance of aerobic capacity in cross-country skiing. In addition, by definition, cross-country skiing involves going uphill as well as coming downhill, which highlights the importance of technical competence, anaerobic power, and strength, as much as the importance of aerobic capacity.

VO_{2max} and gas exchange threshold values determined by using incremental running test protocols represent the most important parameters used to evaluate aerobic endurance.[5] Anaerobic threshold can be determined by measuring the lactate levels in blood, as well as by means of gas exchange measurements.[6]

Due to the nature of cross-country skiing, as described earlier, it is crucial for both athletes and coaches to know the possible variations in VO_{2max} and gas exchange threshold values, in addition to the variations in their body composition, after a whole season of training. Therefore, the aim of the present study was to investigate the changes in body composition, $VO_{2max,}$ and gas exchange threshold values of cross-country skiers after training conducted throughout a season.

Materials and methods

Voluntary participants of the study and experimental design

This study was performed in the Laboratory of Erciyes University High Altitude and Sports Science Research and Implementation Center. Approval was obtained from Erciyes University Ethics Committee for Clinical Research prior to the study (Decision No 2017/554; Kayseri, Turkey). Furthermore, before the study, the volunteers were informed about the necessary issues and signed an informed consent form. In total, 15 voluntary athletes who compete in international cross-country skiing competitions were included in the study. The mean height of the study group was 170.62±4.74 cm. The athletes' training periods were first preparation period (Prep-1), between June and August; second preparation period (Prep-2), between September and November; and competition period (Comp.), between December and May. The athletes underwent incremental treadmill running test at 3 different time points over a period of 1 year. The first measurements were obtained in July, during the Prep-1; the second measurements were obtained in October, during the Prep-2; and the third measurements were obtained in February, during the Comp. Body weight, body mass index (BMI), body fat (%), as well as VO_{2max} and gas exchange thresholds values measured during the incremental running tests were assessed at all 3 time points.

Body composition measurements

Body weights and body fat (%) of the athletes were measured using a Tanita BIA impedance analyzer (Tanita Corporation, Arlington Heights, IL, USA). BMI values were calculated by dividing the body weight by the square of height in meters (kg/m^2).

Incremental running test procedures

An incremental running test was performed to determine the VO_{2max} and gas exchange threshold values of the athletes. The test was initiated on a 5% incline with a running speed of 7 km/h, and the speed was increased by 1 km/h per minute. The exercise was continued until the athletes became exhausted. The athletes were considered to have reached VO_{2max} when the following criteria were met: maximal heart rate achieved during the test (220-age formula), respiratory exchange rate as defined by the instantaneous ratio of exhaled carbon dioxide (VCO_2) and consumed oxygen (VO_2) reaching levels higher than 1.10, and oxygen uptake maintained at a plateau despite increasing exercise intensity.[7] The highest oxygen uptake value over 15 seconds, during which at least 2 of these criteria were simultaneously met, was considered as VO_{2max} (mL/kg/min). Exhaustion time was defined by the total test duration.

Changes that occur in respiratory air during the test were measured and recorded breath-by-breath using the Cosmed Quark PFT-Ergo gas analysis system (Cosmed Srl, Rome, Italy). To ensure standardization, low sensor and components of the gas analyzer were calibrated as recommended by the manufacturer prior to each test. The heart rates were recorded during the test using a telemetric heart rate monitor (Polar RS800 SD' Polar, Kempele, Finland).

Data monitored by the device's software during the test were continuously followed and recorded. The results obtained from each athlete were reviewed numerically and graphically by means of the relevant software (Data Management Software; Cosmed), and necessary data adjustments were made following the test. Time-dependent graphs of per-minute ventilation (VE), oxygen uptake (VO_2), and carbon dioxide production (VCO_2) were reviewed, and lines indicating abnormal values (upper and lower extremes) resulting from reasons such as swallowing, sighing, or coughing during the test were identified and deleted. After the adjustments were made, the data were analyzed by obtaining mean values at 15-second intervals.[8]

The gas exchange threshold values of the athletes were determined noninvasively using the V-slope method.[9] After the graph of the VO_2 (to X-axis) curve corresponding to VCO_2 (to Y-axis) was constructed, linear regression analysis was made to generate 2 regression lines with a slope equal to 1 (or the closest) and higher than 1. The point of intersection of these 2 regression lines was considered as the gas exchange threshold. The VO_2 (mL/kg/min) value and running speed (km/h) corresponding to this gas exchange threshold was recorded. Two separate investigators conducted these steps independently to identify the gas exchange threshold value. When the results obtained by these 2 investigators were contradictory, a third investigator was consulted. Linear regression analyses were implemented using the Sigma Plot program (Sigma Plot 12.0; Systat Software Inc., Chicago, IL, USA).

Content of the training program

The athletes performed a total of 650 hours of training during a season. While 60% of this total time was spent in June and November, Prep-1 and Prep-2 preparation periods, the remaining 40% was spent in December and May, the competitive season. Endurance training accounted for 550 hours of the total training volume. Of all endurance training, 6%–8% was performed at high (>87% HR_{max}), 4%–6% at moderate (80%–87% HR_{max}), and 86%–89% at low (60%–80% HR_{max}) intensity. Strength training made up 85 hours of the total training volume. Also, the ski-specific speed training was conducted for a duration of 15 hours.

Statistical analysis

The collected data were analyzed using SPSS 20 package software (IBM Corporation, Armonk, NY, USA). Descriptive statistics were initially calculated. The Shapiro–Wilk test, skewness and kurtosis values, histograms, and Q–Q and P–P graphs were reviewed, and it was found out that the data were not normally distributed. Significant differences between the measurements were assessed using Friedman's two-way variance analysis with a post hoc option. The level of statistical significance was considered as $p<0.05$.

Results

Table 1 shows the body composition values of athletes. When the results of the nonparametric Friedman test were examined, it was observed that there were significant differences in the athletes' body weights among measurements ($X^{2(2)}=18.61$, $p<0.001$). Post hoc tests that were performed to identify the cause of differences indicated a significant difference between the values recorded at the second and third measurements ($p<0.001$). Similarly, BMI values were also significantly different at the respective measurements ($X^{2(2)}=18.62$, $p<0.001$). When the post hoc tests conducted in order to identify which measurements indicated a difference in BMI values were analyzed, it was observed that there were significant differences between the values recorded at the second and third measurements ($p<0.001$). Body fat (%) values were not significantly different at the respective measurements ($p>0.05$).

Table 2 shows maximal oxygen consumption and gas exchange threshold values of the athletes. Results of nonparametric Friedman test did not demonstrate a significant difference in the VO_{2max}, VO_{2GET}, $HR_{max,}$ and HR_{GET} values recorded at different measurements ($p>0.05$).

Table 1 Body composition characteristics of the athletes

Variables	Prep-1	Prep-2	Comp.	X^2	*p*-value
	Median (25%–75%)	**Median (25%–75%)**	**Median (25%–75%)**		
Body weight (kg)	64.50 (59.80–68.95)	67.00 (58.00–71.05)[a]	62.00 (55.75–65.80)[a]	18.61	<0.001*
BMI (kg/m²)	21.80 (20.38–23.33)	22.65 (19.81–24.10)[b]	20.96 (19.21–22.39)[b]	18.62	<0.001*
Body fat (%)	10.30 (9.00–11.25)	11.10 (9.60–11.40)	10.60 (9.80–11.75)	0.15	0.92

Notes: Prep-1: first measurement in July, during the first preparation period. Prep-2: second measurement in October, during the second preparation period. Comp.: third measurement in February, during the competition period. Data are presented as median (25%–75%). The same superscript letters indicate significant differences between measurements. *$p<0.001$.
Abbreviation: BMI, body mass index.

Table 3 shows the speed and duration values of the athletes during the incremental running tests. The results of the nonparametric Friedman test demonstrated significant differences in the test duration of the athletes recorded at different measurements ($X^{2(2)}$=13.06, p<0.01). Post hoc tests demonstrated that the difference in test duration resulted from the significant differences between the values recorded at the first and third (p<0.05), as well as at the second and third measurements (p<0.01). Similarly, test running speeds were also significantly different among measurements ($X^{2(2)}$=13.86, p<0.01). Post hoc tests that were performed to identify the cause of differences in test running speed indicated a significant difference between the values recorded at the first and third measurements (p<0.05). On the other hand, time to reach gas exchange threshold and running speed at gas exchange threshold did not significantly differ among the measurements (p>0.05).

Discussion and conclusion

Body composition of the athletes is crucial in terms of performance in cross-country skiing.[10] In fact, Niinimaa et al[11] previously reported a strong negative correlation between the body fat (%) and performance in intercollegiate male cross-country skiers. In another study, Larsson and Henriksson-Larsen[10] found significant correlations between performance time and body weight (r=–0.721; p<0.05) and fat-free mass (r= –830; p<0.01). In the same study, Larsson and Henriksson-Larsen[10] also found a positive correlation between total body weight and several stretches of speed (r=0.648–0.770; p<0.05 to p <0.01). Some studies reported that the negative impact of high body weight on performance is less in cross-country skiers compared with endurance runners.[12,13] Larsson and Henriksson-Larsen[10] reported a positive correlation between increased body weight and performance in cross-country skiing, particularly during downhill performance. A correlation was not observed between body fat mass and performance time. On the other hand, fat-free mass, particularly in the arms, was shown to be positively associated with performance time, especially during uphill climbing.[10] In the present study, both body weight and BMI were significantly lower at the Comp. compared with the Prep-2. This is crucial to increase the athletes' performance during competition season, and is considered to be an expected outcome of the modeling of their training program. On the other hand, body fat (%) values did not significantly differ at the 3 respective measurements. We believe that, as the athletes have been regularly conducting training for years, their body fat (%) values did not show large variations, and conducting the training in different periods did not result in a significant change in their body fat percentage.

It is clear that aerobic capacity is one of the most significant factors for the performance of cross-country skiers.[14] A cross-country skiing competition often lasts for 10–120 minutes, which requires skiers to have a high aerobic capacity.[15] During cross-country skiing, aerobic capacity is considered to be an important factor before switching to anaerobic

Table 2 Maximal oxygen consumption and gas exchange threshold values of the athletes

Variables	Prep-1	Prep-2	Comp.	X^2	p-value
	Median (25%–75%)	Median (25%–75%)	Median (25%–75%)		
VO_{2max} (mL/kg/min)	71.53 (67.33–73.52)	70.98 (70.83–72.19)	74.27 (67.98–74.70)	1.07	0.584
VO_{2GET} (mL/kg/min)	55.38 (52.06–58.68)	56.58 (53.82–59.60)	58.37 (54.78–61.13)	6.00	0.051
HR_{max} (beats/min)	202.00 (196.50–204.50)	202.00 (194.00–204.00)	199.00 (192.50–203.00)	4.12	0.127
HR_{GET} (beats/min)	172.00 (167.50–177.00)	179.00 (173–183)	180.00 (172.00–183.00)	2.92	0.232

Notes: Prep-1: first measurement in July, during the first preparation period. Prep-2: second measurement in October, during the second preparation period. Comp.: third measurement in February, during the competition period. Data are presented as median (25%–75%).

Abbreviations: VO_{2max}, maximal oxygen uptake; VO_{2GET}, amount of oxygen consumed at gas exchange threshold level; HR_{GET}, heart rate at gas exchange threshold level.

Table 3 Time and speed values of the athletes recorded during incremental running test

Variables	Prep-1	Prep-2	Comp.	X^2	p-value
	Median (25%–75%)	Median (25%–75%)	Median (25%–75%)		
Test duration (min)	10.15 (9.21–11.16)[a]	10.49 (9.51–10.77)[b]	11.16 (10.54–11.18)[a,b]	13.06	0.001*
Test running speed (km/h)	17.00 (16.00–17.00)[c]	17.00 (16.00–18.00)	18.00 (17.00–18.00)[c]	13.86	0.001*
Time to reach gas exchange threshold (min)	6.15 (4.42–6.27)	5.50 (5.25–6.15)	6.15 (5.45–6.30)	2.08	0.353
Running speed at gas exchange threshold (km/h)	13.00 (11.00–13.00)	12.00 (12.00–13.00)	13.00 (12.00–13.00)	2.09	0.350

Notes: Prep-1: first measurement in July, during the first preparation period. Prep-2: second measurement in October, during the second preparation period. Comp.: third measurement in February, during the competition period. Data are presented as median (25%–75%). The same superscript letters indicate significant differences between measurements. *p<0.01.

metabolism.[13] VO_{2max}, on the other hand, is important for endurance performance. In elite endurance athletes, each step of the oxygen-carrying system ensures adaptation to endurance training.[16] The effect of endurance training on both senior and junior cross-country skiers has often been evaluated through the changes in VO_{2max}.[1] Ingjer[17] reported that VO_{2max} varies during a complete season in elite senior cross-country skiers and the best athletes are those who have the highest level of yearly variations. Moreover, Ingjer[17] reported that the highest value of VO_{2max} was reached during the competitive season. In another study conducted by Losnegard et al,[1] no significant change was reported in VO_{2max} values of elite cross-country skiers recorded during preparation and competitive seasons. Furthermore, Losnegard et al[1] suggested that the cross-country skiers who voluntarily participated in the study of Ingjer[17] were more elite (world-class) athletes, and therefore significant variations were noted in their VO_{2max} values over a complete season. Meanwhile, in a study performed by Lucia et al[18] in world-class road bikers, (mean VO_{2max} values 75 mL/kg/min), a significant change was not reported in VO_{2max} values after 6 months of training. In the present study, although the VO_{2max} values did not significantly change throughout the entire season, it is observed that the highest values were achieved in the competitive season. In high-level athletes, VO_{2max} levels could have reached maximal values, as a result of many years of continuous training, to the extent allowed by their genetic potential.[1] This might also explain why VO_{2max} levels over a season did not significantly change in the present study.

In long-distance cross-country skiers, performance capacity is reported to be strongly associated with oxygen consumption at gas exchange threshold level, as much as it is related to VO_{2max}.[13,19] Sandbakk et al[20] found that the amount of oxygen consumed at ventilatory threshold (VO_2VT) value of cross-country skiers, which was 51.9±4.7 mL/kg/min before 8 weeks of training, reached 57.0±5.0 mL/kg/min after the training, and the difference between the 2 levels was statistically significant ($p<0.001$). Moreover, they reported that VO_2VT in % VO_{2max} value, which was 77.2±6.9 before training, reached 81.4±4.4 after the training and that the difference was significant ($p<0.01$).[20] In addition, a strong correlation was found between sprint performance and VO_{2max} (L·min) and VO_2VT.[20] In the present study, median VO_2 value at gas exchange threshold was found to be 55.38 (52.06–58.68) $mL \cdot kg^{-1} \cdot min^{-1}$, 56.58 (53.82–59.60) $mL \cdot kg^{-1} \cdot min^{-1}$, and 58.37 (54.78–61.13) $mL \cdot kg^{-1} \cdot min^{-1}$ at the Prep-1, Prep-2, and the Comp. measurements, respectively. Although the measurements showed a gradual increase, the difference was not statistically significant. This might be due to the fact that the athletes have already reached their maximal performance level after long years of regular training programs.

Although the median values for maximal heart rate in the present study slightly decreased from 202.00 (196.50–204.50) beats/min, which was recorded at the Prep-1, to 199.00 (192.50–203.00) beats/min at the Comp. measurements, the difference was not statistically significant. In their study, Haymes and Dickinson[21] reported that the maximal heart rate during maximal running test was 195.4±8.5 beats/min in cross-country skiers. Another study reported the HR_{max} value for cross-country skiers as 189±6 beats/min.[22] In a study performed on cross-country skiers, Hedelin et al[23] reported that, after 7 months of training, maximal heart rate changed from 198 to 196, and that $HRsub_{max}$ value significantly decreased from 183 to 178 during incremental running test ($p<0.01$). It was noted that individuals with a high aerobic capacity have a higher respiration frequency and a higher variation in maximal heart rate, compared with those who have a lower level of aerobic capacity.[24] Long-term endurance training results increased work capacity by causing an increase in VO_{2max} and sports-specific performance, as well as by causing a decrease in heart rate and lactate accumulation at submaximal workload. The decrease in heart rate during resting and at submaximal workload is associated with increased blood volume and cardiac hypertrophy.[25] A previous study demonstrated that, following training program, although peak heart rate does not change during exercise, the heart rate was significantly lower at submaximal workload.[23] The decreases in resting heart rate and heart rate at submaximal workload indicate that the training period alters heart rate control both during rest and during exercise.[23] Some previous data indicated that endurance training reduces sympathetic activity on the sinoatrial node of the heart.[26,27] Smith et al[26] reported that sympathetic impact on heart rate slightly decreases in individuals performing endurance training, which eventually leads to a minor decrease in heart rate. It was also reported that central, reflex, and peripheral adaptations, which occur due to training, could also contribute to the decrease in heart rate during exercise.[28,29] In the present study, although not statistically significant, the maximal heart rate showed a slight decrease. We conclude that, as the athletes who took part in this study have been regularly training for years and have developed adaptation during their training, their maximal heart rate did not significantly change both during preparation and the competitive periods.

In this study, although the heart rate at gas exchange threshold increased between the respective measurements, the difference was not significant. Median values of the heart rate at the gas exchange threshold level were 172.00 (167.50–177.00) beats/min, 179.00 (173–183) beats/min, and 180.00 (172.00–183.00) beats/min on the Prep-1, Prep-2, and Comp. measurements, respectively. These data indicate an increase in the gas exchange threshold levels of the athletes. Gas exchange threshold is one of the most important factors determining the athletic performance. Athletes often determine their training intensity according to their heart rate at the gas exchange threshold level. A high level of gas exchange threshold means that it will take longer for the athlete to become fatigued; therefore, the gas exchange threshold is one of the important factors in determining the performance.[30] The heart rate values at the gas exchange threshold level recorded, which were measured at 3 different time points in this study, did not differ significantly. This can be explained by the fact that these athletes have already been training on regular basis for long years and have a high level of performance. Moreover, this result showed that the gas exchange threshold levels of athletes did not significantly change throughout the season. Even so, the slight increase observed in gas exchange threshold heart rates indicates that the athletes achieve their highest level of performance during the competitive season.

In this study, the median incremental running test duration was found to be 10.15 (9.21–11.16) min, 10.49 (9.51–10.77) min, and 11.16 (10.54–11.18) min at the Prep-1, Prep-2, and Comp. measurements, respectively. The Comp. measurement was significantly higher than both the Prep-1 and Prep-2 measurements ($p<0.05$). Similarly, the median running speed during the test was 17.00 (16.00–17.00) km/h, 17.00 (16.00–18.00) km/h, and 18.00 (17.00–18.00) km/h at the Prep-1, Prep-2, and Comp. measurements, respectively. The running speed recorded at the Comp. was significantly higher than the Prep-1 ($p<0.05$). The fact that both running speed and test duration were significantly higher at the Comp. indicates that the athletes reach their highest level of performance during the competition season. In a study performed by Hedelin et al[23] with cross-country skiers, the incremental running test duration increased from 18.5±1.9 to 19.4±1.7 minutes after 7 months of training, and the difference was statistically significant ($p<0.05$). The reason for the numeric differences between the test durations in that study and the durations in our study is different test protocols and grade were used in the respective studies. Although the incremental running test duration and speed significantly increased in the present study, VO_{2max} and gas exchange threshold values did not change significantly, indicating an increase in the athletes' exercise tolerance.

In conclusion, the present study has demonstrated a significant decrease in body weight and significant increases in the test duration and running speed of cross-country skiers at the Comp. measurement, which corresponds to the competitive season. In addition, although not statistically significant, BMI, body fat (%), and HR_{max} values were observed to be lower, and increases have been observed in the VO_{2max}, heart rate at gas exchange threshold, the running speed at gas exchange threshold, the time to reach gas exchange threshold, and the VO_2 value at gas exchange threshold, at the Comp. measurements, which coincided with the timing of competitive season, compared with the values obtained in the previous measurements. These results demonstrate that the cross-country skiers in this study developed tolerance to high-intensity exercises and reached their highest level of athletic performance during the competitive season.

Disclosure

The authors report no conflicts of interest in this work.

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