applied sciences

Article

The Effects of Six-Month Subalpine Training on the Physical Functions and Athletic Performance of Elite Chinese Cross-Country Skiers

Zhihong Sun, Yan Zhang, Datao Xu, Yaqi Fei, Qiner Qiu * and Yaodong Gu *

Faculty of Sports Science, Ningbo University, Ningbo 315211, China; sunzhihong_nbu@foxmail.com (Z.S.); zhangyan3@nbu.edu.cn (Y.Z.); xudatao3@gmail.com (D.X.); feiyaqi_nbu@foxmail.com (Y.F.)
* Correspondence: qiuqiner@nbu.edu.cn (Q.Q.); guyaodong@nbu.edu.cn (Y.G.)

Abstract: Purpose: This study investigated the changes in the blood indices, specific athletic abilities, and physical fitness of outstanding cross-country skiers, trained in the subalpine; Methods: Twenty-eight athletes (twenty males and eight females) from the National Cross-country Ski Training Team completed sub-alpine training during the 2020–2021 snow season. The athletes′ physical functions were evaluated by collecting blood from elbow veins and measuring blood biochemical indexes. To compare the treadmill roller-skiing athletic ability and physical fitness of athletes before and after subalpine; Results: Male and female athletes showed different trends in red blood cells (RBC), hemoglobin (Hb), cortisol (C), Creatine Kinase (CK) and blood urea (BU) ($p < 0.05$ or $p < 0.01$). Overall, the female athletes' mean values of RBC, Hb, CK, and BU were lower than that of male athletes, while C was just the opposite. Comparing the athletic performance of athletes before and after the subalpine, it was found that blood lactate concentrations were significantly lower in both male and female athletes at the same load intensity ($p < 0.05$ or $p < 0.01$), whereas 10 km endurance running and 1 RM deep squat were significantly higher in both male and female athletes ($p < 0.05$ or $p < 0.01$). Conclusions: After 6 months of subalpine training, cross-country skiers improved their oxygen-carrying capacity and anabolism, and showed significant improvements in specific athletic ability, physical endurance, acid tolerance and 1 RM absolute strength for both male and female athletes.

Keywords: cross-country skiing; subalpine training; blood index; special training; strength training

Citation: Sun, Z.; Zhang, Y.; Xu, D.; Fei, Y.; Qiu, Q.; Gu, Y. The Effects of Six-Month Subalpine Training on the Physical Functions and Athletic Performance of Elite Chinese Cross-Country Skiers. *Appl. Sci.* **2022**, *12*, 421. https://doi.org/10.3390/app12010421

Academic Editors: Jesús García Pallarés and Francesco Cappello

Received: 30 October 2021
Accepted: 29 December 2021
Published: 2 January 2022

1. Introduction

It is well known that plateau training (1800–2500 m) is a way to improve aerobic performance in many endurance sports, as it deepens the body′s stress response under the stimulus of both exercise and natural hypoxia, and the body′s metabolic mechanisms come into play to increase the athlete's cardiopulmonary function and muscle tissue's ability to use oxygen [1,2]. However, athletes are usually affected by hypothermia, low pressure and plateau reactions in highland environments, which limits training and prevents them from achieving the desired training results [3,4]. For example, loss of speed is due to reduced muscle blood flow and low protein synthesis caused by a lack of oxygen and the thinning of muscle fiber and muscle atrophy, resulting in a loss of muscle strength [5,6]. The change of Earth's gravity, atmospheric pressure, and wind direction in the highland conditions may distort the athletes' movements and is not conducive to the optimization of special movements. Cross-country skiing is one of the most demanding of endurance sports, involving protracted competitions on varying terrain employing a variety of skiing techniques that require upper- and/or lower-body work to different extents [7]. Therefore, cross-country skiers need not only very good physical ability but also better technique and technique-specific power [8,9].

In recent years, many researchers in different sports have started to explore subalpine training (1300–1800 m). From the point of view of combining physiological functions and sports training [10], subalpine training provides a certain degree of hypoxia stimulation while maintaining the intensity of training on the plains, so that athletes receive sufficient intensity stimulation, avoiding the disadvantages of traditional plateau training in terms of degradation of athletic performance [11,12]. Research has demonstrated that subalpine training can improve the oxygen-carrying capacity of female athletes in the national modern pentathletes and swimmers, having a stimulating effect on their anabolism [13,14] and can enhance the aerobic capacity of rowers and figure skaters and have a positive effect on their physical function [15,16]. Currently, not much research has been conducted on cross-country skiing training on subalpine plateaus, except for some early reports on cross-country skiing training on plateaus, which demonstrated that plateau training can effectively promote cross-country skiers' physical function [17]. Grushin, A.A. et al. showed that when athletes stay at subalpine (1500–2000 m) day and night for training, it is very effective for athletes' improvement; it is recommended that when arranging subalpine cycle training, athletes need to follow the basic phase of pre-season training process when they reach the maximum (volume) training load. It is considered that usually the duration of subalpine training is generally 7 to 21 days, depending on the specific goals of the training [18].

In sports training, functional state refers to the level or state of readiness of the athlete's body for training or competition. For endurance sports, the scientific diagnosis of sports fatigue and monitoring of functional state is key to athletic performance, and the use of classical physiological and biochemical indicators to monitor athletes' functional states has become an integral part of training in endurance sports [19]. Athletic performance refers to the individual or common behaviors during sports participation that cover skills, abilities and, specific sports states, and also refers to the functional performance that is influenced by multidimensional factors such as genetic inheritance, motor skills, psychological skills and physical function, and is influenced by a combination of physiological, psychological and socialization factors [20]. Cross-country skiing is one of the most demanding of endurance sports, involving protracted competitions on varying terrain employing a variety of skiing techniques that require upper- and/or lower-body work to different extents [21]. Regular measurement of athletes' athletic performance can check the effectiveness of athletes' stage training and thus guide coaches to modify or enhance their training programs so that athletes can further improve.

In view of this, this study focused on the changes in blood biochemical indices, specific athletic ability and physical function of national cross-country skiers during subalpine training to investigate the effects of 6-month subalpine training on athletes' physical functional status and athletic performance [22] and determine if gender differences exist.

2. Methods

2.1. Subjects

Twenty-eight athletes from the national cross-country ski training team from October 2020 to March 2021 were the study subjects, of which 20 were male and eight were female; four were international level athletes, the rest were national level athletes (Table 1). All athletes involved were in good health and free of disease. Before the data collection, all participants provided written informed consent to voluntarily take part in the study. The participants were informed that they could withdraw from the study at any point in time without providing a reason for doing so.

Table 1. Basic information about the athletes of the national cross-country ski training team.

Gender	Age/(Years)	Height/(cm)	Weight/(kg)	BMI/(kg·m^{-2})	Training Years/(Years)
Male (n = 20)	22.22 ± 2.09	178.96 ± 5.90	69.16 ± 5.46	21.57 ± 0.97	3.99 ± 2.47
Female (n = 8)	23.63 ± 3.34	165.69 ± 5.82	55.75 ± 4.74	20.27 ± 0.49	8.82 ± 4.71

2.2. Subalpine Training Arrangements

The national cross-country ski training team conducted long-term subalpine training from October 2020 to March 2021 in preparation for the 2022 Beijing Winter Olympic Games, mainly at the national snow sports training base in BaShang, Chengde, Hebei Province (altitude 1510–1700 m). The Chinese coach was mainly responsible for the physical training and the corresponding auxiliary training, while the foreign coach was mainly responsible for the special training (ski training, roller-skiing training and ski training related support training) and the control of the overall training load [23]. The specific training intensity (Table 2), specific training content (Table 3), and strength training content (Table 4) were adjusted according to the training weight, physiological indicators, and fatigue status [24].

Athletes trained six days a week, with rest and adjustment on Sundays. Ski training intensity was divided into three categories according to the weekly plan: (1) The low intensity training week, mainly at a 1–2 level training intensity; the ski training accounted for 85–90% of the week's training time, the duration of each training session was usually more than 2–3 h, and a 90 min level 3 intensity training session was arranged once a week; (2) Medium intensity training week, generally based on a level 3 training intensity; ski training accounted for the week training time of 40–50%; each session of training time was 1.5–2 h, and was arranged once a week at a 4–5 level of intensity of the race; (3) High-intensity training week, at mainly a 4–5 level of training intensity; ski training accounted for 35–45% of the week's training time; each session of training time of 1–1.5 h was arranged for a level 5 of intensity of the race more than two times. The coaching team made the training plan for the next week based on the athletes′ heart rate during the current week's training and how well the training was completed.

Table 2. Training intensity levels for cross-country skiers.

Level	Lactate (mmol/L)	HRmax(%)	Intensity Type
1	0.8–1.5	55–72	Low intensity
2	1.5–2.5	75–82	Low intensity
3	2.5–4.0	82–87	Medium intensity
4	4.0–6.0	87–92	High intensity
5	6.0–10.0	92–97	High intensity

Table 3. Strength training content and load for cross-country skiers.

Category	Group	Training Movements	Rep	Set	Load	1 RM%	Total Load
muscular endurance training	A1	Straight leg half raise and bend leg raise	28	1	74	/	2072
	A2	Adductor Magnus bridge	20	1	20	/	400
	A3	Single-legged bridge (leg to the side and front)	20	1	10 (60 s)	/	200
	A4	Monkey walk + crab walk (45″ + 45″)	8	1	/	70%	0
	A5	Step over squats (8 + 8)	16	1	/	/	600–800
	A6	Med-ball squeezes (15″ × 5 positions)	30	1	4	/	/
	A7	Wide stand sumo squats	15	1	/	/	/
strength + power	B1	Hang Cleans (35 kg)	5	4	30–40	90%	540–720
		Body Weight jumps	3	4	/	/	120
strength + power	B2	Weighted Pull-ups (10 kg)	5	4	10	90%	200
		Med ball slams (4 kg)	5	4	4	/	80
	B3	Deadlift 65/85/75/75 kg	5	4	70–90	90%	200
		Skate power jumps (4 + 4)	4	4	/	/	80
Specialized strength	B4	Dumbbell Row/Low row (30 kg)	8	4	30–50	90%	960–1600
		Dumbbell floor press (12.5 × 2 kg)	8	4	15–20	/	480–640
core	B5	Different core exercises (abs) 5 min	30	5	10 (60 s)	/	1500

Table 4. Special training content and load of cross-country skiers.

Training Intensity	Running Training	Ski Training	Recovery Training
Low intensity	(1) 2 h 30 min Cross Country Running (2) 2 h–2 h 30 min Nordic Running	(1) Skate 150 min i1 + in the end 5–6 * 10 s-speed (2) Double Poling 150 min (3) Classic 120 min (4) Skate 90–100 min (30 min w/o poles) (5) Classic + Skating 240 min (5 * 10″ CrP in the end of both part) (6) 2 h Back-country Classic ski hiking (7) 2 h–2 h 30 min i1 Classic (15 + 15′ w/1 pole to work w/leg kick + 30 min DP) + 5 * CrPsprints (8) 1 h 30 min–2 h i1 Skate (20′ w/o poles) + corner technique w/5*CrP in last 30′	(1) 5 km run + stretching (2) 30 min swimming (3) 30 min run/swim/cycling + foam roller and stretching
Medium intensity	(1) 10 km Running competition 82–87% of max HR	(1) Interval Double Poling: 3 * 5/6 km (2) Skate intervals: 6 * 6 min (3) Classic intervals: (6–8) * 2 laps 85–90% (LA = 3.0–4.0) with 2 min breaks (4) Controlled LA Skate i3 interval training (5) i4 Skate intervals: 6 * 6 min w/2–3 min rest	
High intensity	(1) Up hill Running race w/poles 2 * (3 * 800 m) w/6′ rest 90–100% of max HR (2) Up hill Running race w/poles 2 * (4 * 600 m) w/5′ rest/i4 = 90–100% of max HR	(1) Classic ski uphill competition: 10 * 400 m (2) Classic ski uphill competition: 10 * 400 m	

Notes: (1) "i1–i5" = " level 1–5". (2) CrP = Rush sprint. (3) LA = Lactic acid. (4) DP = Double Poling.

In each week, the strength training program was scheduled for two sessions; each training session lasted for more than 90 min. The training was divided into different sessions by the physical trainer: strength building, endurance building and explosive strength building. Before the training, the coach made a form for all the athletes (Table 3), and the training movements and loads were then designed by him. In the process of training, if the athlete exceeded or did not complete the training load designed in advance, the coach made a record of it and prepared for the design of the next training session.

Specialized training mainly included traditional ski training, freestyle ski training, traditional roller-skiing training, freestyle roller-skiing training and different ways of running training. For different intensities and training sites, the coaches arranged the corresponding training according to Table 4, and the training time was finely adjusted according to each athlete's heart rate, blood lactate and morning pulse of the previous day. The trainers let the athletes have a 30-min recovery training after each day of training.

2.3. Blood Testing Indicators and Equipment

During the training period, due to the difficult training conditions, the blood index test was only conducted once a month. Each test was performed after the athlete had rested and adjusted, and 2 mL of blood was collected from the elbow vein on an empty stomach the next morning using a purple tipped EDTA anticoagulation tube for routine blood tests, including white blood cell (WBC), red blood cell (RBC) and hemoglobin (Hb). Then, 5 mL of blood was drawn using an inert isolated gel PR coagulation tube with a golden cap for hormonal and biochemical tests, including cortisol (C), blood urea (BU), and creatine kinase (CK). The WBC, RBC, and Hb were tested by the domestic Myriad BC-5180CRP automatic hematology analyzer; the C was tested by the Swiss Roche Cobase411 automatic electrochemiluminescence analyzer; the BU and CK were tested by the American Beckman Coulter AU480 automatic biochemical analyzer. All instruments were standardized using the original as well as matching reagents.

2.4. Test Protocol for Athletic Performance Ability

For the ability test of athletic performance, the same test was performed once before and after the subalpine training:

2.4.1. Specific Ability Test

The specific ability test was a running platform treadmill roller-skiing test, the test protocol of which was developed by a senior coach at the University of Tartu. The first five levels of the test were all 5 min long, all at a speed of 9 km/h, with the inclination angle of the running platform increasing by one degree from 3° to 7°; the last four levels were all 4 min long, with speeds of 11 km/h, 7 km/h, 7 km/h and 11 km/h, respectively. During the test, the average heart rate (b/min) at the end of each minute was recorded and the athletes used the V2 technique [25–27]. The athletes' blood lactate (mmol/L) levels were measured using an EKF blood lactate tester (Biosen, EKF Industrial Electronics, Magdeburg, Germany) and the athletes' average heart rates (b/min) and rating of perceived exertion (RPE) values were recorded for the entire level [28–30] (Figure 1). RPE represents proprioceptive exercise intensity, which is a numerical estimate of the intensity of someone's exercise. The rating was originally based on the Borg scale, which is a measure of the intensity of exercise and ranges from 6 (no exertion) to 20 (very hard). In the test, we used 1–15 instead of 6–20 to represent the athlete's proprioception.

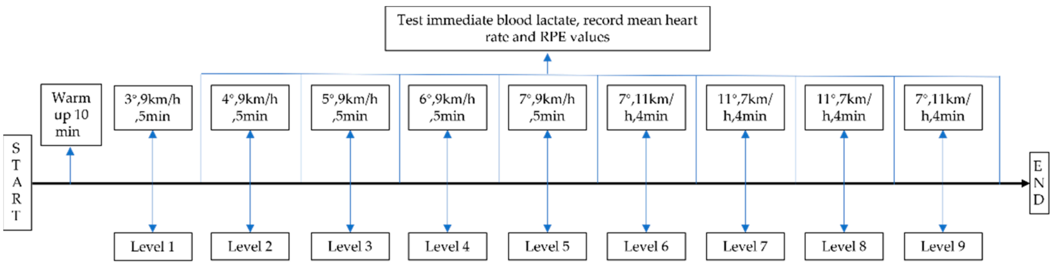


Figure 1. Flow chart of treadmill roller-skiing tests.

2.4.2. Fitness Test

One RM upper body strength bench press and one RM lower body strength squat test: the fitness coach led the athlete through a dynamic warm-up before the test, then the athlete performed 95% of the attempts with a 1 RM load on the same test apparatus, with the athlete being protected by a professional on the left and right sides of the body for each attempt. The weight was increased by 1–5 kg after each successful attempt until the subject was unable to complete the standard movement after two to three attempts and a rest period of 2–5 min was allowed before each attempt [31]. Short distance 30 m run test: recorded using SmartSpeed (Fusion Sport, Coopers Plains, Australia), one athlete was tested at a time and departed on the trainer's command. Endurance runs 10 km test: athletes set off collectively after hearing the coach's command, while the coach turned on the stopwatch, and after reaching the finish line the coach recorded the athletes' results individually.

2.5. Statistical Analyses

The experimental data were statistically processed using IBM SPSS 22.0 software and Excel 2019, and all data are presented in the form of mean ± standard deviation (M ± SD). By observing the changes in blood indices during 6 months of subalpine training in cross-country skiers, using training time as a within-group factor, the within-group effects were determined by repeated measures ANOVA and differences between male and female athletes were analyzed using independent samples *t*-tests. For the special tests and physical fitness tests before and after training in the subalpine the differences were analyzed using the independent samples *t*-test method. Differences were considered significant at $p < 0.05$ and highly significant at $p < 0.01$.

3. Results

3.1. Changes in Athletes' Physical Function Indicators during Subalpine Training

3.1.1. Changes in Leukocyte and Red Blood Cell-Related Indicators in Athletes' Blood

The results of the study revealed that there were highly significant differences ($p < 0.01$) and the number of WBC and Hb of female athletes was always significantly different ($p < 0.05$; Table 5). After male athletes entered subalpine training, the number of WBC increased slightly, until after 3 months of training, the number of WBC increased significantly ($p < 0.01$) and the number of WBC began to fluctuate after 3 months. After 6 months of continuous training, there was a significant increase ($p < 0.05$); the content of RBC and Hb in male athletes increased slowly with training time, and WBC and Hb were in place, respectively. There was a significant increase in the first month and the second month ($p < 0.01$), and the increase in Hb appeared earlier than RBC (Figure 2; Table 5).

Table 5. Results of leukocyte and red blood cell-related indicators in athletes′ blood.

Time	WBC/(10^9/L)		RBC/(10^{12}/L)		Hb/(g/L)	
	Male	Female	Male	Female	Male	Female
Before training	4.80 ± 0.91	4.97 ± 1.49	5.30 ± 0.24	4.46 ± 0.35	153.28 ± 7.78	136.13 ± 11.12
1st month	4.94 ± 0.81	4.78 ± 1.17	5.18 ± 0.26 ^{a}	4.54 ± 0.34	156.08 ± 7.25	131.38 ± 12.35
2nd month	5.15 ± 1.03	4.85 ± 1.23	5.08 ± 0.29 ^{aa}	4.35 ± 0.37	157.72 ± 7.39 ^{aa}	137.50 ± 11.41
3rd month	5.57 ± 1.08 ^{aa,cc}	5.43 ± 1.50	5.13 ± 0.33 ^{a}	4.39 ± 0.34	157.48 ± 8.13 ^{a}	138.50 ± 11.60 ^{b}
4th month	5.34 ± 1.10	5.09 ± 0.99	5.00 ± 0.32 ^{aa,bb}	4.38 ± 0.35	158.76 ± 8.88 ^{aa}	137.50 ± 10.86
5th month	5.71 ± 1.41 ^{aa,c}	5.96 ± 1.21	5.07 ± 0.28 ^{aa}	4.23 ± 0.35	161.56 ± 6.51 ^{aa,bb,cc}	137.75 ± 11.67 ^{b}
6th month	5.31 ± 1.03 ^{a}	4.79 ± 0.99 ^{f}	5.04 ± 0.29 ^{aa,bb}	4.39 ± 0.39 ^{a,bb}	158.72 ± 6.76 ^{aa,f}	141.00 ± 11.15 ^{bb}
Time effects	$p = 0.001$	$p = 0.017$	$p = 0.001$	$p = 0.009$	$p = 0.001$	$p = 0.014$

Notes: (1) a, aa means $p < 0.05$, $p < 0.01$ compared with before subalpine training. (2) b, bb means $p < 0.05$, $p < 0.01$ compared with the first month of subalpine training. (3) c, cc means $p < 0.05$, $p < 0.01$ compared with the second month of subalpine training. (4) d, dd means $p < 0.05$, $p < 0.01$ compared with the third month of subalpine training. (5) e, ee means $p < 0.05$, $p < 0.01$ compared with the fourth month of subalpine training. (6) f, ff means $p < 0.05$ and $p < 0.01$ compared with the fifth month of subalpine training.

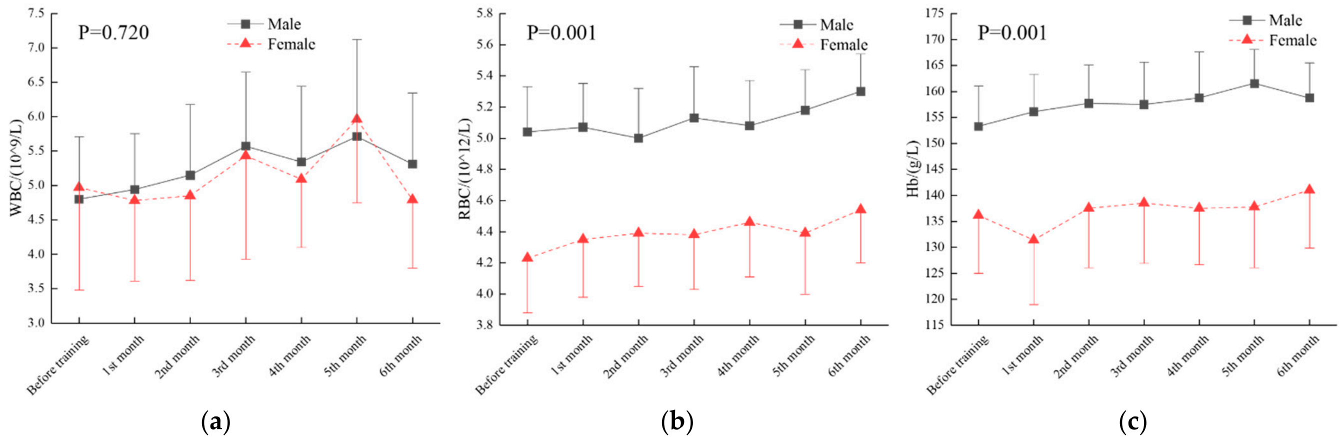


Figure 2. Graph showing the results of leukocyte and red blood cell-related indicators in the blood of athletes: (**a**) Changes of WBC in blood at different times; (**b**) Changes of RBC in blood at different times; (**c**) Changes of Hb in blood at different times. Data are mean ± SD.

After female athletes entered subalpine training, the number of WBC decreased in the 1st month, then began to rise slowly and not significantly in the next 2 months, fluctuated from the 3rd month, and decreased significantly ($p < 0.05$) from the 5th to the 6th month, with no significant change compared to before subalpine; the RBC and Hb of female athletes gradually increased with training time. After 6 months of subalpine training, Hb was significantly higher than before subalpine training ($p < 0.01$), while RBC was the opposite ($p < 0.05$; Table 5, Figure 2).

There is no significant difference in the WBC of different genders ($p > 0.05$), male and female have the same trend over time; there are significant differences in the RBC and Hb of different genders ($p < 0.01$), and the RBC and Hb of male athletes are higher than those of female athletes (Figure 2).

3.1.2. Changes in Blood Hormones and Serum Biochemical Indicators of Athletes

Using training time as a within-group factor, a repeated-measures ANOVA found that the three indicators of C, BU, and CK in the blood of male athletes were significantly different from training time ($p < 0.01$). C and BU increased significantly ($p < 0.01$), and CK increased significantly ($p < 0.05$) after entering the subalpine training. Then they began to decline slowly and began to rise significantly after the 5th month ($p < 0.01$); the fluctuations of C, BU, and CK in the blood of female athletes are relatively large, and the main effect of time is that C and BU were significantly different ($p < 0.01$). There is no significant difference in CK ($p > 0.05$). After 6 months of training, C and BU were significantly higher than before sub-altitude ($p < 0.05$ or $p < 0.01$). CK increased significantly in the first month and reached its peak; compared with the fourth and fifth months, it decreased significantly ($p < 0.05$; Table 6; Figure 3).

Table 6. The results of changes in C, BU, and CK in the blood of athletes.

Time	C/(nmol/l)		BU/(mmol/L)		CK/(U/L)	
	Male	Female	Male	Female	Male	Female
Before training	478.49 ± 79.96	572.15 ± 44.01	6.71 ± 1.03	5.67 ± 1.09	301.52 ± 138.96	181.00 ± 58.99
1st month	510.04 ± 61.24	526.63 ± 101.76	7.03 ± 0.89	6.49 ± 0.47	604.88 ± 201.12	754.87 ± 224.24
2nd month	518.20 ± 69.72	587.84 ± 56.92	7.95 ± 1.11 [aa,bb]	7.39 ± 1.77 [aa]	483.96 ± 151.68	256.13 ± 97.73
3rd month	526.97 ± 73.96	659.48 ± 48.87	7.74 ± 1.28 [aa]	6.47 ± 1.15	273.36 ± 98.65	160.13 ± 33.63
4th month	545.66 ± 70.11 [a]	680.14 ± 93.56 [b]	8.19 ± 0.99 [aa,bb]	7.36 ± 1.15 [aa]	151.20 ± 41.69 [aa,bb,cc]	125.75 ± 38.45 [b]
5th month	569.35 ± 82.58 [aa,b]	640.63 ± 100.06	7.74 ± 1.01 [b]	7.22 ± 1.03 [aa]	140.56 ± 44.87 [aa,bb,cc]	100.38 ± 21.82 [b]
6th month	574.42 ± 86.96 [a,bb,d]	662.85 ± 84.60 [b]	8.06 ± 1.13 [aa]	7.02 ± 1.58 [a]	504.40 ± 148.71 [aa,cc,ee,ff]	257.75 ± 89.67
Time effects	$p = 0.002$	$p = 0.038$	$p = 0.001$	$p = 0.001$	$p = 0.001$	$p = 0.060$

Notes: (1) a, aa means $p < 0.05$, $p < 0.01$ compared with before subalpine training. (2) b, bb means $p < 0.05$, $p < 0.01$ compared with the first month of subalpine training. (3) c, cc means $p < 0.05$, $p < 0.01$ compared with the second month of subalpine training. (4) d, dd means $p < 0.05$, $p < 0.01$ compared with the third month of subalpine training. (5) e, ee means $p < 0.05$, $p < 0.01$ compared with the fourth month of subalpine training. (6) f, ff means $p < 0.05$ and $p < 0.01$ compared with the fifth month of subalpine training.

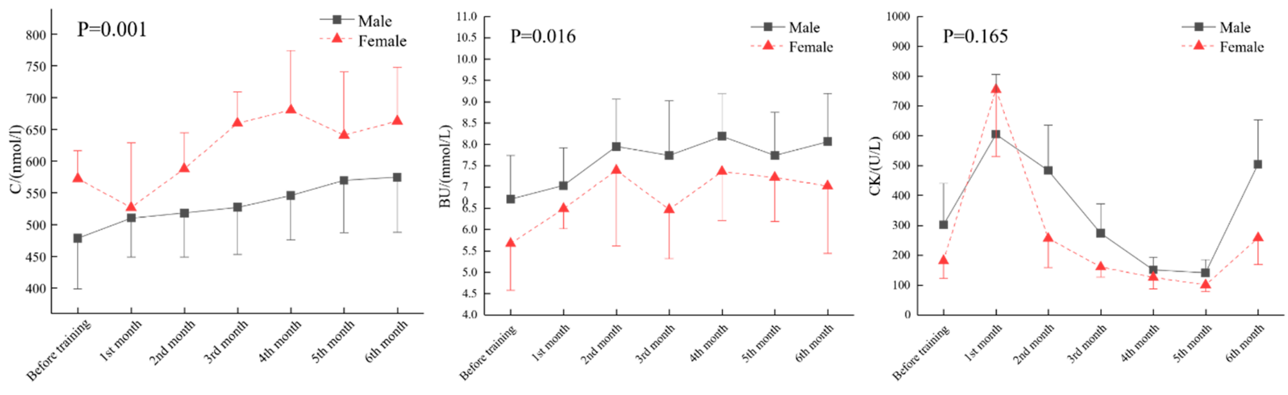


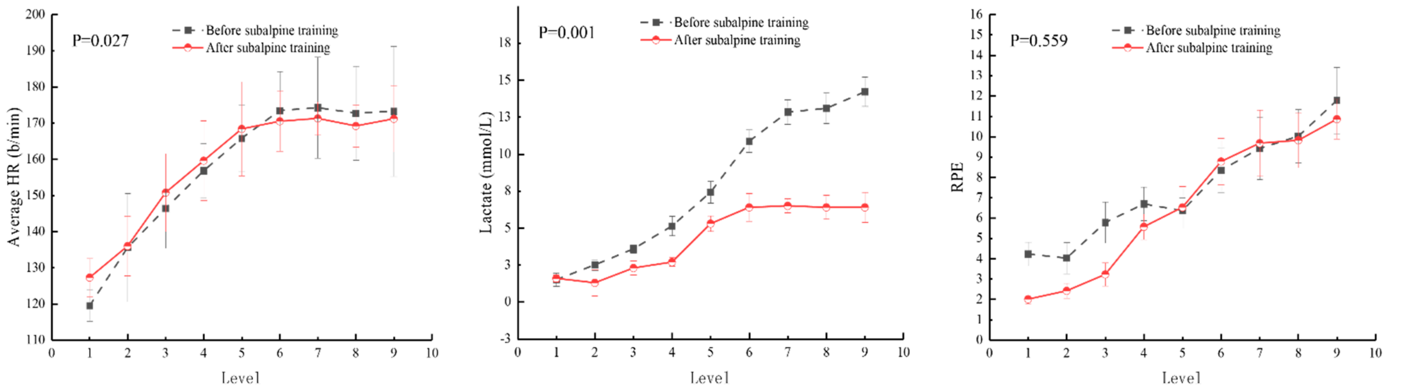
Figure 3. The results of changes in C, CK, and BU in the blood of athletes: (**a**) Changes of C in blood at different times; (**b**) Changes of BU in blood at different times; (**c**) Changes of CK in blood at different times. Data are mean ± SD.

There were significant differences ($p < 0.01$ or $p < 0.05$) in C and BU when comparing the different genders, with female athletes consistently having higher levels of C than male athletes and male athletes having higher levels of BU than female athletes; there were no significant differences indicated in CK trends and levels over time between men and women (Figure 3).

3.2. Effects of Athletic Performance before and after Subalpine Training

3.2.1. Changes in Specific Athletic Performance before and after Subalpine Training

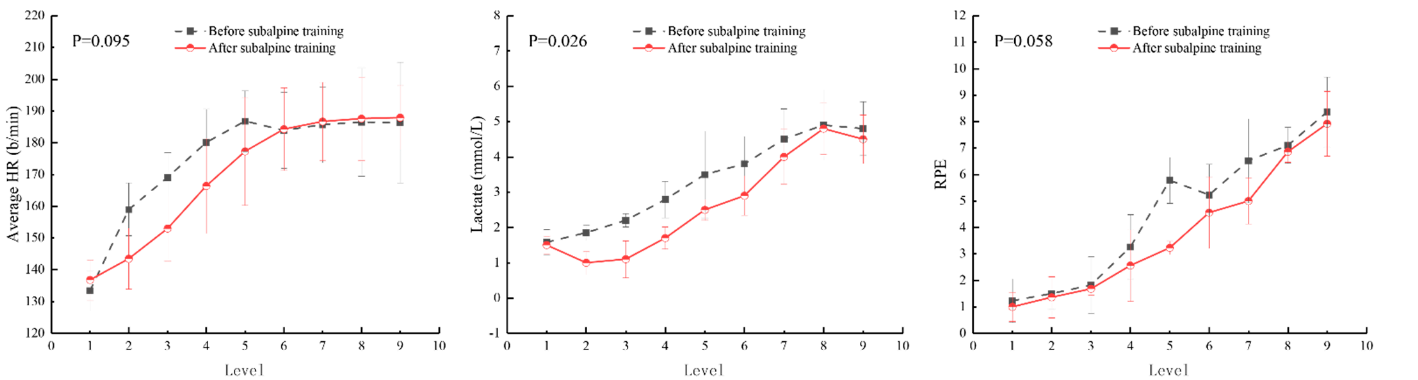
After subalpine training, male athletes showed corresponding changes in average heart rate, blood lactate, and RPE in each level of roller-skiing, with significant changes in average heart rate and blood lactate ($p < 0.05$ or $p < 0.01$), and insignificant changes in RPE. The average heart rate of the male athletes was slightly higher after the first five levels of subalpine training than before subalpine training and the opposite from the sixth level onwards (Table 7; Figure 4).



(**a**) (**b**) (**c**)

Figure 4. Male athletes' (**a**) mean heart rate by level; (**b**) blood lactate concentration by level; (**c**) RPE by level. Data are mean ± SD.

After subalpine training, female athletes showed a significant reduction in blood lactate concentration at each level ($p < 0.01$), with a more significant reduction between levels 2–8. However, there was no significant difference in the values of average heart rate, and RPE at each level, as can be seen in Figure 2, declined more significantly. Overall, the specific athletic performance of both male and female athletes showed varying degrees of reduction in blood lactate concentration, average heart rate, and RPE at different levels after subalpine training. (Table 8; Figure 5).



(**a**) (**b**) (**c**)

Figure 5. Female athletes' (**a**) mean heart rate by level; (**b**) blood lactate concentration by level; (**c**) RPE by level. Data are mean ± SD.

Table 7. Indicators related to the specific athletic ability of male athletes.

Level	Angle/(Degree)	Testing Time/(min)	Speed/(km/h)	Average HR/(b/min)			Lactate/(mmol/L)			RPE		
				Before	After	*p*-Value	Before	After	*p*-Value	Before	After	*p*-Value
1	3	5	9	119.5 ± 4.3	127.3 ± 5.3 *	0.032	1.5 ± 0.5	1.6 ± 0.2	0.532	4.2 ± 0.6	2.0 ± 0.2 *	0.048
2	4	5	9	135.6 ± 15.0	136.0 ± 8.2	0.056	2.5 ± 0.4	1.3 ± 0.9	0.402	4.0 ± 0.8	2.4 ± 0.4	0.120
3	5	5	9	146.4 ± 11.0	150.8 ± 10.8	0.075	3.6 ± 0.3	2.3 ± 0.5 *	0.039	5.8 ± 1.0	3.2 ± 0.6 *	0.039
4	6	5	9	156.8 ± 7.5	159.6 ± 11.0 *	0.022	5.1 ± 0.7	2.7 ± 0.3 **	0.000	6.7 ± 0.8	5.6 ± 0.6	0.085
5	7	5	9	165.8 ± 9.3	168.4 ± 13.1	0.089	7.4 ± 0.8	5.3 ± 0.5 *	0.041	6.4 ± 0.6	6.5 ± 1.0	0.566
6	7	4	11	173.5 ± 10.7	170.5 ± 8.3 *	0.039	10.9 ± 0.8	6.4 ± 0.9 *	0.028	8.4 ± 1.1	8.8 ± 1.1	0.632
7	11	4	7	174.3 ± 14.0	171.3 ± 4.6 *	0.036	12.8 ± 0.8	6.5 ± 0.5 **	0.000	9.4 ± 1.5	9.7 ± 1.6	0.557
8	11	4	7	172.8 ± 13.0	169.2 ± 5.8 *	0.045	13.1 ± 1.0	6.4 ± 0.8 **	0.000	10.0 ± 1.3	9.8 ± 1.3	0.089
9	7	4	11	173.3 ± 18.0	171.2 ± 9.2	0.088	14.2 ± 1.0	6.4 ± 1.0 **	0.000	11.8 ± 1.6	10.9 ± 1.0	0.148

Notes: * and ** means $p < 0.05$ and $p < 0.01$ compared to before subalpine training.

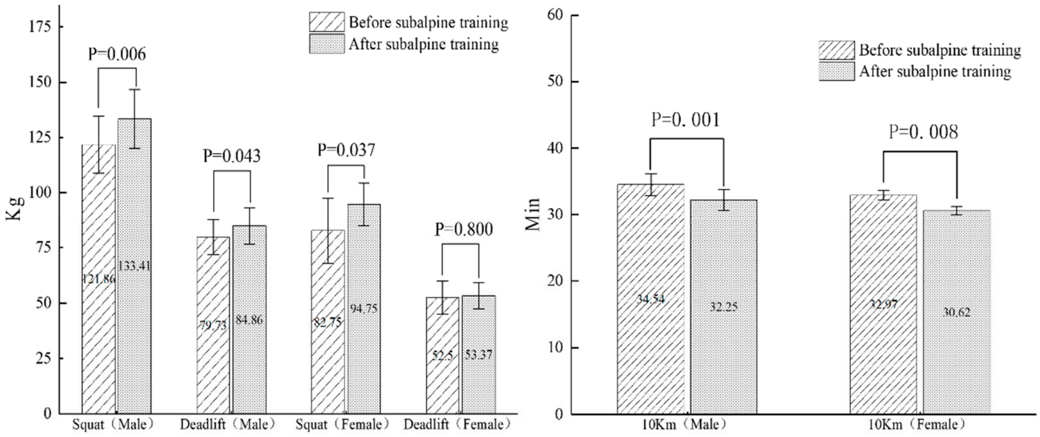
Table 8. Indicators related to the specific ability of female athletes.

Level	Angle/(Degree)	Testing Time/(min)	Speed/(km/h)	Average HR/(b/min)			Lactate/(mmol/L)			RPE		
				Before	After	*p*-Value	Before	After	*p*-Value	Before	After	*p*-Value
1	3	5	9	133.4 ± 6.2	136.8 ± 6.3	0.067	1.6 ± 0.4	1.5 ± 0.3	0.362	1.2 ± 0.8	1.0 ± 0.6	0.498
2	4	5	9	159.0 ± 8.3	143.5 ± 9.6 **	0.005	1.8 ± 0.2	1.0 ± 0.3 *	0.034	1.5 ± 0.6	1.4 ± 0.8	0.279
3	5	5	9	169.1 ± 7.8	153.0 ± 10.3 **	0.000	2.2 ± 0.3	1.1 ± 0.5 *	0.029	1.8 ± 1.1	1.7 ± 0.2	0.670
4	6	5	9	180.1 ± 10.5	166.4 ± 15.0 *	0.023	2.8 ± 0.5	1.7 ± 0.3	0.056	3.3 ± 1.2	2.6 ± 1.4	0.056
5	7	5	9	186.8 ± 9.6	177.3 ± 17.0 *	0.035	3.5 ± 1.2	2.5 ± 0.3	0.062	5.8 ± 0.9	3.2 ± 0.3 **	0.000
6	7	4	11	183.9 ± 12.0	184.3 ± 13.0	0.078	3.8 ± 0.8	2.9 ± 0.6 *	0.043	5.2 ± 1.2	4.6 ± 1.4	0.173
7	11	4	7	185.7 ± 11.9	186.7 ± 12.3	0.145	4.5 ± 0.9	4.0 ± 0.8	0.107	6.5 ± 1.6	5.0 ± 0.9 *	0.041
8	11	4	7	186.5 ± 17.0	187.6 ± 13.1	0.085	4.9 ± 1.1	4.8 ± 0.7	0.284	7.1 ± 0.7	6.9 ± 0.4	0.297
9	7	4	11	186.3 ± 19.0	187.9 ± 10.1	0.326	4.8 ± 0.8	4.5 ± 0.7	0.367	8.4 ± 1.3	7.9 ± 1.2	0.658

Notes: * and ** means $p < 0.05$ and $p < 0.01$ compared to before subalpine training.

3.2.2. Changes in Physical Exercise Capacity before and after Subalpine Training

Male athletes showed significant improvements in 1 RM'deep squat, 1 RM'bench press, and 10 km run after subalpine training ($p < 0.01$ or $p < 0.05$), female athletes showed significant improvements in 1 RM'deep squat and 10 km run ($p < 0.05$) and no significant differences in 1 RM'bench press (Figure 6). However, there were no significant changes in 30 m run performance for either male or female athletes (Table 9).



(**a**) (**b**)

Figure 6. Before and after training values for (**a**) deep squat and bench press; (**b**) 10 km run.

Table 9. Changes in athletes' physical and athletic performance indicators before and after subalpine training.

Project	Male			Female		
	Before	After	*p*-Value	Before	After	*p*-Value
30 m running/s	4.23 ± 0.17	4.23 ± 0.16	0.899	4.84 ± 0.11	4.83 ± 0.11	0.847
Squat/kg	121.86 ± 12.97	133.41 ± 13.22	0.006	82.75 ± 14.89	94.75 ± 9.71	0.037
Deadlift/kg	79.73 ± 7.91	84.86 ± 8.37	0.043	52.50 ± 7.45	53.37 ± 6.02	0.800
10 km running/min	34.54 ± 1.65	32.25 ± 1.56	0.000	32.97 ± 0.73	30.62 ± 0.61	0.008

4. Discussion

4.1. Effects of Subalpine Training on the Physical Functions of Cross-Country Skiers

4.1.1. The Impact of Subalpine Training on Athletes' White Blood Cells, Red Blood Cells, and Hemoglobin

Leukocytes are an important component of the body′s defenses and protection functions, and the leukocyte count can reflect the body′s immune function. Under normal conditions, the total number of leukocytes in the body is relatively stable, and changes in it can reflect the body′s disease and immune stress status to a certain extent [32]. The effects of exercise training on leukocytes and their subpopulations have been widely reported, and exercise can cause an increase in peripheral blood leukocytes, depending on the intensity of the exercise and the level of training, with low-intensity exercise unlikely to result in significant changes in the number of leukocytes and their subpopulations [33]. It has been suggested that an important feature of the body′s immune system response after acute exercise is an increase in the number of leukocytes in the peripheral blood, and Pedersen et al. concluded that the effect of exercise in a hypoxic environment on leukocyte immune function is more pronounced during altitude training [34]. Pyne et al. reported that ten Australian swimmers and eight non-athletes who participated in the 1996 Atlanta Olympics spent 3 weeks at an altitude of 2102 m, and both groups had reduced leukocyte counts, but the athlete group was more pronounced [35]. The different results of the above studies may be related to factors such as duration and intensity of training at altitude. This study found that the number of leukocytes in male athletes increased slowly with the duration of subalpine training, with a significant increase beginning in month 3 compared to the pre-subalpine period and peaking at month 5, suggesting that subalpine training can cause a significant increase in the number of leukocytes in male cross-country skiers; In female athletes, the changes were not significant in the first two months, but there were significant fluctuations between months 3–6, with a peak in leukocyte count in month 5, which may be related to changes in training intensity or duration of training. The trend of change with each time point was the same for both male and female athletes, indicating that there was no significant difference in the effect of subalpine training by gender.

Red blood cells mainly reflect the number of red blood cells in athletes′ circulating blood, while hemoglobin is the main component of red blood cells and an important ferritin in red blood cells, which is one of the important indicators to measure blood oxygen carrying capacity and body function [36]. The most critical factors affecting oxygen transport in blood are blood oxygen capacity and hemoglobin affinity. Increasing the number of red blood cells and hemoglobin results in greater oxygen delivery which helps to improve the aerobic exercise ability of athletes. It is generally believed that, during subalpine training, changes in erythropoietin and hemoglobin are stimulated by hypoxia at altitude, leading to an increase in erythropoietin (EPO) secretion, which promotes the body's ability to carry oxygen and improve aerobic metabolism [37]. Numerous studies have shown that subalpine training can increase erythrocytes and hemoglobin, mainly through an increase in altitude, which causes a decrease in blood oxygen content and oxygen saturation, promoting the body′s ability to carry oxygen [38]. This study found that the number of erythrocytes in both male and female cross-country skiers tended to decrease slowly with training time and that there was a highly significant difference in the main effect of time, with male athletes starting to experience a significant decrease from month 2 compared to the pre-altitude period, and female athletes only experiencing a significant decrease from the pre-altitude period at month 5. However, the trends at each time point were significantly different for each gender, suggesting that the changes at each time point were different for male and female athletes, except that, overall, long-term subalpine training for cross-country skiers resulted in a decrease in red blood cell counts for both genders, contrary to previous research in this area, which may be due to differences between sports. There was also a significant difference in the time-dependent effect of hemoglobin concentration for both male and female athletes, which coincided with the opposite trend in erythrocyte count, with a significant increase in the second month for male athletes and a significant increase in the first, fifth and sixth months for female athletes, in line with many of the studies above. However, there were significant differences in the trends between male and female athletes at each time point. More studies have concluded that female athletes have better elevation and sustained effects than males [39,40]. In the present study, the same conclusion was not reached and may be influenced by climate, subalpine dehydration, training volume, duration, and intensity of training in different regions.

4.1.2. Effects of Subalpine Training on Cortisol, Blood Urea, and Creatine Kinase in Athletes

The biological function of cortisol is to participate in material metabolism, maintain the normal progress of glucose metabolism in the body, maintain the relative stability of blood glucose concentration, and at the same time promote the decomposition of extra-hepatic tissue proteins, inhibit the entry of amino acids into extra-hepatic tissues, and increase the blood amino acid content, and strengthen the glycogenesis. In addition, cortisol can promote the decomposition and oxidation of adipose tissue in the limbs. Cortisol has a certain regulatory effect on the nervous system and reduces the stress level of the nervous system to external stimuli. A small amount of cortisol can cause euphoria, and too much cortisol can cause poor thinking and irritability [36]. Numerous studies have shown that long-term subalpine training can maintain cortisol at a high level [12,13]. In this study, after long-term subalpine training, the time-oriented effects all had significant changes and were significantly higher compared to the pre-subalpine period, with male athletes showing a significant increase at month 4 and female athletes showing a significant increase at month 2 versus months 4 and 6, with female athletes averaging 100 nmol/L higher than male athletes. From the trend of change, both male and female athletes had different trends with significant differences, the most obvious performance was the 1st month of entering the subalpine, male athletes had a slight increase, while female athletes had a more obvious decrease.

Blood urea (BU) is a product of the catabolism of proteins and amino acids. In general, BU is a good indicator of the amount of exercise and how well the body is recovering from training. The level of BU is influenced by the synthesis of urea in the liver and the excretion function of the kidneys. Only after a longer load will protein and amino acids be broken down in large quantities for energy, causing a rise in BU [41]. Some studies have shown that of the two factors, exercise intensity and exercise volume, the magnitude of BU change is more sensitive to exercise volume, with the higher the exercise volume, the more pronounced the increase in blood urea and the slower the recovery of BU values the following morning [19]. In this study, under long-term training in a subalpine environment, both male and female athletes showed a tendency to increase with training time, and after the third month of training in the subalpine, the values of BU for both sexes decreased. After the 3rd month of training, and then fluctuated, probably because the BU values gradually changed in line with the training volume as the athletes adapted to the subalpine environment. The female athletes showed a slow decline from the 4th month onwards, but the men were still fluctuating, and it is possible that the female athletes recovered better than the male athletes in the later stages.

The role of serum CK is to catalyze the reversible transfer of high-energy phosphate bonds between adenosine triphosphate and creatine phosphate and is the catalytic enzyme for energy replenishment during short periods of intense exercise and for the post-exercise ATP recovery reaction. Creatine kinase is associated with skeletal muscle energy metabolism and serum CK is commonly used to assess the intensity of loading, reflecting the degree of fatigue and damage to skeletal muscle [42]. Studies have shown that athletes' serum CK is up-regulated in the early stage of sub-altitude training [13]. The main reasons are: exercise stretch and increase metabolites increase the permeability of muscle cells, increased catecholamines, and tissue cell damage. Both exercise intensity and load affected serum creatine kinase activity, and it is generally accepted that the effect of load intensity on CK activity is greater than that of load, with the most pronounced increase when both are increased [27]. In this study, serum CK was significantly increased in both male and female athletes during the first month of subalpine training, due to increased permeability of the body's cell membranes caused by hypoxic stimulation [43], followed by a gradual adaptation to subalpine training conditions. After the athletes gradually adapted to the subalpine training conditions, they began to decline and showed a significant increase in the 5th month, which was caused by the increase in training intensity that slowed the athletes' recovery. There was no significant difference between the male and female athletes, indicating that the intensity of training remained the same during the training period and that the intensity of training had the same effect on both male and female athletes, guiding the direction of the next training program.

4.2. Effects of Subalpine Training on the Athletic Performance of Cross-Country Skiers

4.2.1. The Effect of Subalpine Training on Athletes' Specific Sport Performance Abilities

The V2 technique is very important for cross-country skiing in freestyle and is also a technique that is used more often in cross-country skiing competitions [44]. To better control the speed, slope, and test time of the athletes, the V2 technique was chosen to test the athletes' ability to glide at nine levels before and after the subalpine, with the average heart rate, immediate blood lactate, and RPE for each level completed. The accumulation of blood lactate is a product of anaerobic metabolism during exercise and its accumulation can cause a certain degree of decline in muscle performance [45,46]. The elimination of lactate is mainly through oxidative metabolic pathways and the rate of elimination is somewhat reflective of the athlete′s aerobic metabolic capacity [47]. After subalpine training, the blood lactate concentration of both male and female athletes showed a significant decrease under the same intensity of special training on treadmill roller-skiing, indicating that the athletes' ability to disperse blood lactate and lactate tolerance had greatly improved [48].

After long-term subalpine training, for the same special roller-skiing intensity, the average heart rate of both male and female athletes showed a significant difference, the male athletes' heart rate increased at the 2nd–5th level, and then the heart rate slowly stabilized, indicating that the athletes had a lower heart rate response than before in special training, and can grasp the rhythm of special training at different intensities. This helps athletes not to be disturbed after overtaking their opponents in a competition and to be able to distribute their energy rationally and optimize their performance. After subalpine training, female athletes showed a significant decrease in average heart rate between levels 1–6, indicating that female athletes have improved their ability for this level and the athletes had a lower heart rate response than before subalpine training.

There was no significant difference in RPE values between male and female athletes after subalpine training, however, we can see from Figure 5 that the change in RPE values was the same as the change in blood lactate, indicating that the athletes had a more accurate assessment of themselves, which would be of great help in controlling their training load in the following training.

4.2.2. The Influence of Sub-Altitude Training on Athletes' Performance in Strength and Speed Endurance

After subalpine training, in terms of strength, the absolute value of 1RM' squat of both male and female cross-country skiers showed a significant increase, indicating that during subalpine training, the lower limb strength of athletes improved significantly; the 1RM' bench press of male athletes increased significantly, while that of female athletes increased only slightly and was not statistically significant, indicating that subalpine training improved the upper limb strength of male athletes much more than that of female athletes. It is much higher than that of female athletes. The change was significantly higher in male athletes than in female athletes, an idea also argued by Hegge et al., who found the male athletes demonstrated 87%, 97%, and 103% higher power output than the female during whole-body (WP), upper-body (UP), and arm poling (AP) respectively [49].

For the 30 m fast sprint, after subalpine training, there was no significant change for male or female athletes, indicating there was no impact on speed or explosive power; however, there was a significant increase in the 10 km endurance run for male and female athletes, indicating that the endurance training of athletes was greatly improved after subalpine training. This view is also evident from the significant decrease in blood lactate concentration immediately after special training.

4.3. Limitations of the Study

Our study has several limitations. First, there is some individual variability in athletes, with some variation in performance for different intensity training sports, which may have impacted the results. Second, for female athletes, our sample size may be insufficient. Third, strength training has a relatively large effect on the level of CK and BU in the blood of athletes, which may have some potential implications for us when interpreting ski training. Fourth, we may not have explained some unknown confounding terms. Finally, there are many uncertainties in the training process, so we cannot fully take these effects into account in the results.

5. Practical Applications

The coaches and related support staff have a preliminary understanding of the results of long-term subalpine training conducted by Chinese cross-country skiers. Referring to the training results in this paper, lays the foundation for the athletes to develop a better training program and make the next deployment in combination with the athletes' current physical performance status. It also provides data support for Chinese cross-country skiers to optimize their special training and physical training programs and lays a certain foundation for preparing for the 2022 Beijing Winter Olympic Games.

6. Conclusions

In summary, after 6 months of subalpine training, oxygen transport and oxygen utilization of cross-country skiing male and female athletes′ improved, so that the immune ability of male athletes has been promoted to a certain extent, and the degree of change of various indexes of men is better than that of female athletes. In terms of sports performance, the special ability and fitness level of both male and female athletes have been effectively improved after subalpine training, and the athletes' acid tolerance, the 1RM′ absolute strength, and special training level have been greatly improved; these improvements may be related to the training arrangement and training load. However, it can be clearly seen that the athletes need to strengthen the training in terms of speed and explosive power, which is conducive to the improvement of the final sprint ability in the competition.

Author Contributions: Conceptualization, Z.S., Y.G. and Q.Q.; methodology, Z.S. and Y.Z.; validation, Y.G. and Q.Q.; formal analysis, Z.S., Y.Z. and Y.F.; investigation, Z.S., Y.Z. and D.X.; resources, Y.G. and Y.Z.; data curation, Z.S., D.X. and Q.Q.; writing—original draft preparation, Z.S., D.X. and Y.F.; writing—review and editing, Z.S., D.X. and Y.Z.; visualization, Z.S. and D.X.; supervision, Y.G. and Q.Q.; project administration, Y.G. and Y.Z.; funding acquisition, Y.G. and Y.Z.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Key R&D Program "Science and Technology Winter Olympics" Key Special Project (2020YFF0304605).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from thecorresponding author, upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Flaherty, G.; O'Connor, R.; Johnston, N. Altitude training for elite endurance athletes: A review for the travel medicine practitioner. *Travel Med. Infect. Dis.* **2016**, *14*, 200–211. [CrossRef] [PubMed]
2. Lianshi, F. Altitude training and research status. *Sports Sci.* **1999**, *19*, 66–71.
3. Leon-Lopez, J.; Calderon-Soto, C.; Perez-Sanchez, M.; Feriche, B.; Iglesias, X.; Chaverri, D.; Rodriguez, F.A. Oxidative stress in elite athletes training at moderate altitude and at sea level. *Eur. J. Sport Sci.* **2018**, *18*, 832–841. [CrossRef] [PubMed]
4. Chapman, R.F.; James, S.G.; Levine, B.D. Individual variation in response to altitude training. *J. Appl. Physiol.* **1998**, *85*, 1448–1456. [CrossRef]
5. Wilber, R.L. Current trends in altitude training. *Sports Med.* **2001**, *31*, 249–265. [CrossRef]
6. Jin, Z.; Ye, T. Effect of altitude and sub-altitude training on the maximum strength of skeletal muscle and Its mechanism in rowers of subaltitude inhabitants. *China Sports Sci.* **2008**, 55–60+75. [CrossRef]
7. Sandbakk, O.; Holmberg, H.-C. Physiological capacity and training routines of elite cross-country skiers: Approaching the upper limits of human endurance. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 1003–1011. [CrossRef]
8. Sandbakk, O.; Holmberg, H.-C.; Leirdal, S.; Ettema, G. Metabolic rate and gross efficiency at high work rates in world class and national level sprint skiers. *Eur. J. Appl. Physiol.* **2010**, *109*, 473–481. [CrossRef] [PubMed]
9. Sandbakk, O.; Holmberg, H.C.; Leirdal, S.; Ettema, G. The physiology of world-class sprint skiers. *Scand. J. Med. Sci. Sports* **2011**, *21*, E9–E16. [CrossRef]
10. Nagle, K.B. Cross-country skiing injuries and training methods. *Curr. Sports Med. Rep.* **2015**, *14*, 442–447. [CrossRef]
11. Turner, G.; Fudge, B.W.; Pringle, J.S.M.; Maxwell, N.S.; Richardson, A.J. Altitude training in endurance running: Perceptions of elite athletes and support staff. *J. Sports Sci.* **2019**, *37*, 163–172. [CrossRef]
12. Jin, Z.; Chuihui, K. The influence of subaltitude on sports coaching. *J. Beijing Sports Univ.* **2005**, 83–84+131. [CrossRef]
13. Garcia, I.; Drobnic, F.; Galera, T.; Pons, V.; Viscor, G. Lung diffusion in a 14-day swimming altitude training camp at 1850 m. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3501. [CrossRef]

14. Tao, Y.; Yun, C.; Peng, Z.; Han, L.; Qingzheng, L.; Junhong, H. Effects of sub-altitude training on the physiological function of the elite female weight lifters. *China Sport Sci.* **2016**, *36*, 67–71. [CrossRef]
15. Woods, A.L.; Sharma, A.P.; Garvican-Lewis, L.A.; Saunders, P.U.; Rice, A.J.; Thompson, K.G. Four weeks of classical altitude training increases resting metabolic rate in highly trained middle-distance runners. *Int. J. Sport Nutr. Exerc. Metab.* **2017**, *27*, 83–90. [CrossRef] [PubMed]
16. Gang, W.; Hongbing, G.; Huan, G.; Wei, G. The influence of sub-altitude training on aerobic capacity of different altitude training experience male rowing athletes. *China Sport Sci. Technol.* **2015**, *51*, 42–48. [CrossRef]
17. Ingjer, F.; Myhre, K. Physiological effects of altitude training on elite male cross-country skiers. *J. Sports Sci.* **1992**, *10*, 37–47. [CrossRef] [PubMed]
18. Grushin, A.A.; Nageykina, S.V. Elite female cross-Country skiers training for major international sport competitions in mid-altitude areas. *Teor. Prakt. Fiz. Kult.* **2016**, *5*, 66–69.
19. Lianshi, F. The functional diagnosis methods in elite athlete and problems. *Sport Sci. Res.* **2003**, *24*, 49–54.
20. Kellmann, M.; Bertollo, M.; Bosquet, L.; Brink, M.; Coutts, A.J.; Duffield, R.; Erlacher, D.; Halson, S.L.; Hecksteden, A.; Heidari, J.; et al. Recovery and performance in sport: Consensus statement. *Int. J. Sports Physiol. Perform.* **2018**, *13*, 240–245. [CrossRef] [PubMed]
21. Solli, G.S.; Tonnessen, E.; Sandbakk, Ø. The training characteristics of the world's most successful female cross-country skier. *Front Physiol.* **2017**, *8*, 1069. [CrossRef]
22. Talsnes, R.K.; Solli, G.S.; Kocbach, J.; Torvik, P.-O.; Sandbakk, O. Laboratory- and field-based performance-predictions in cross-country skiing and roller-skiing. *PLoS ONE* **2021**, *16*, e0256662. [CrossRef]
23. Seiler, K.S.; Kjerland, G.O. Quantifying training intensity distribution in elite endurance athletes: Is there evidence for an "optimal" distribution? *Scand. J. Med. Sci. Sports* **2006**, *16*, 49–56. [CrossRef] [PubMed]
24. Mujika, I. Quantification of training and competition loads in endurance sports: Methods and applications. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 9–17. [CrossRef]
25. Haugnes, P.; Kocbach, J.; Luchsinger, H.; Ettema, G.; Sandbakk, O. The interval-based physiological and mechanical demands of cross-country ski training. *Int. J. Sports Physiol. Perform.* **2019**, *14*, 1371–1377. [CrossRef]
26. Haddad, M.; Stylianides, G.; Djaoui, L.; Dellal, A.; Chamari, K. Session-RPE method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Front. Neurosci.* **2017**, *11*, 612. [CrossRef] [PubMed]
27. Pellegrini, B.; Zoppirolli, C.; Boccia, G.; Bortolan, L.; Schena, F. Cross-country skiing movement factorization to explore relationships between skiing economy and athletes' skills. *Scand. J. Med. Sci. Sports* **2018**, *28*, 565–574. [CrossRef] [PubMed]
28. Stoggl, T.; Bjorklund, G.; Holmberg, H.C. Biomechanical determinants of oxygen extraction during cross-country skiing. *Scand. J. Med. Sci. Sports* **2013**, *23*, e9–e20. [CrossRef]
29. Carlsson, M.; Carlsson, T.; Knutsson, M.; Malm, C.; Tonkonogi, M. Oxygen uptake at different intensities and sub-techniques predicts sprint performance in elite male cross-country skiers. *Eur. J. Appl. Physiol.* **2014**, *114*, 2587–2595. [CrossRef]
30. Ainegren, M.; Carlsson, P.; Laaksonen, M.S.; Tinnsten, M. The influence of grip on oxygen consumption and leg forces when using classical style roller skis. *Scand. J. Med. Sci. Sports* **2014**, *24*, 301–310. [CrossRef]
31. Xudan, C.; Lijuan, M.; Bei, Z.; Yongming, L.; Lianshi, F.; Xiaoping, F. The development of physical ability of talent transferring athletes from different sports in long term cross-country skiing training—Based on motor function monitorings. *China Sport Sci. Technol.* **2021**, *56*, 44–55. [CrossRef]
32. Neves, P.R.D.; Tenorio, T.R.D.; Lins, T.A.; Muniz, M.T.C.; Pithon-Curi, T.C.; Botero, J.P.; Do Prado, W.L. Acute effects of high- and low-intensity exercise bouts on leukocyte counts. *J. Exerc. Sci. Fit.* **2015**, *13*, 24–28. [CrossRef]
33. Tvede, N.; Kappel, M.; Halkjaer-Kristensen, J.; Galbo, H.; Pedersen, B.K. The effect of light, moderate and severe bicycle exercise on lymphocyte subsets, natural and lymphokine activated killer cells, lymphocyte proliferative response and interleukin 2 production. *Int. J. Sports Med.* **1993**, *14*, 275–282. [CrossRef] [PubMed]
34. Brines, R.; Hoffman-Goetz, L.; Pedersen, B.K. Can you exercise to make your immune system fitter? *Immunol. Today* **1996**, *17*, 252. [CrossRef]
35. Pyne, D.B.; Mcdonald, W.A.; Morton, D.S.; Swiggett, J.P.; Foster, M.; Sonnenfeld, G.; Smith, J.A. Inhibition of interferon, cytokine, and lymphocyte proliferative responses in elite swimmers with altitude exposure. *J. Interferon Cytokine Res.* **2004**, *20*, 411. [CrossRef]
36. Wilmore, J.; Costill, D.; Gleim, G.W. Physiology of sports and exercise. *Int. J. Sports Med.* **2005**, *27*, 792. [CrossRef]
37. Park, H.-Y.; Hwang, H.; Park, J.; Lee, S.; Lim, K. The effects of altitude/hypoxic training on oxygen delivery capacity of the blood and aerobic exercise capacity in elite athletes—A meta-analysis. *J. Exerc. Nutr. Biochem.* **2016**, *20*, 15–22. [CrossRef]
38. Garvican, L.; Martin, D.; Quod, M.; Stephens, B.; Sassi, A.; Gore, C. Time course of the hemoglobin mass response to natural altitude training in elite endurance cyclists. *Scand. J. Med. Sci. Sports* **2012**, *22*, 95–103. [CrossRef]
39. Heikura, I.A.; Burke, L.M.; Bergland, D.; Uusitalo, A.L.T.; Mero, L.A.; Stellingwerff, T. Impact of Energy Availability, Health, and Sex on Hemoglobin-Mass Responses Following Live-High-Train-High Altitude Training in Elite Female and Male Distance Athletes. *Int. J. Sports Physiol. Perform.* **2018**, *13*, 1090–1096. [CrossRef]
40. Carlsson, T.; Wedholm, L.; Nilsson, J.; Carlsson, M. The effects of strength training versus ski-ergometer training on double-poling capacity of elite junior cross-country skiers. *Eur. J. Appl. Physiol.* **2017**, *117*, 1523–1532. [CrossRef]

41. Li, Z.; Zhongliang, W.; Zhiqiang, H.; Chunguang, W.; Lianshi, F. Biochemical characteristics and functional assessment of Chinese classical wrestlers in pre-tournament training. *China J. Sports Med.* **2002**, *21*, 89–91+94. [CrossRef]
42. Zoppirolli, C.; Bortolan, L.; Schena, F.; Pellegrini, B. Double poling kinematic changes during the course of a long-distance race: Effect of performance level. *J. Sports Sci.* **2020**, *38*, 863–872. [CrossRef] [PubMed]
43. Gonzalez-Millan, C.; Perez-Brunicardi, D.; Salinero, J.J.; Lara, B.; Abian-Vicen, J.; Areces, F.; Ruiz-Vicente, D.; Soriano, L.; Del Coso, J. Physiological demands of elite cross-country skiing during a real competition. *J. Strength Cond. Res.* **2017**, *31*, 1536–1543. [CrossRef] [PubMed]
44. Losnegard, T.; Myklebust, H.; Hallen, J. No differences in O2-cost between V1 and V2 skating techniques during treadmill roller skiing at moderate to steep inclines. *J. Strength Cond. Res.* **2012**, *26*, 1340–1347. [CrossRef]
45. Magrini, D.; Khodaee, M.; San-Millan, I.; Hew-Butler, T.; Provance, A.J. Serum creatine kinase elevations in ultramarathon runners at high altitude. *Physician Sportsmed.* **2017**, *45*, 129–133. [CrossRef]
46. Halson, S.L. Monitoring training load to understand fatigue in athletes. *Sports Med.* **2014**, *44*, 139–147. [CrossRef]
47. Eisenman, P.A.; Johnson, S.C.; Bainbridge, C.N.; Zupan, M.F. Applied physiology of cross-country skiing. *Sports Med.* **1989**, *8*, 67–79. [CrossRef]
48. Egan, A.D.; Winchester, J.B.; Foster, C.; McGuigan, M.R. Using session RPE to monitor different methods of resistance exercise. *J. Sports Sci. Med.* **2006**, *5*, 289–295.
49. Hegge, A.M.; Bucher, E.; Ettema, G.; Faude, O.; Holmberg, H.-C.; Sandbakk, O. 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.* **2016**, *116*, 291–300. [CrossRef]