

Adaptation of skiers at sports camps at different altitudes

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Abstract:

A key focus in the training process for athletes in cyclic sports is the development of aerobic endurance. In cross-country skiing, physical activities are used to enhance athletes' functional reserves. **Purpose:** To evaluate the functional state of the cardiorespiratory system in cross-country skiers of varying sports qualifications and to provide tailored training camp recommendations for these athletes under low-altitude and mid-altitude conditions. **Materials and methods:** The project involved 32 young males aged 15–16 participating in freestyle cross-country skiing. The Highly skilled (HS) group (n = 16) consisted of qualified athletes holding a sports category or title, while the Unqualified athletes (UA) group (n = 16) included those in their second year of cross-country skiing training. Both groups followed the training program outlined by the Russian federal standard. Half of the athletes from both the HS and UA groups participated in training camps at a ski base located in low-altitude conditions. The remaining athletes, representing both skill levels, trained under mid-altitude conditions. At the beginning and end of the training camp, the cardiorespiratory system and anthropometric measurements of all participants were assessed to calculate functional index indicators. **Results:** In low-skilled athletes, training loads under low-altitude conditions are accompanied by high reactivity of the hemodynamic and external respiration systems, indicating a positive adaptation response consistent with the developmental phase of the adaptation process. In contrast, skilled athletes training under mid-altitude conditions did not exhibit reduced cardiorespiratory reserves or signs of impaired adaptation, unlike novice athletes. In beginners, the adaptation to oxygen deficiency at mid-altitude progresses slowly and requires prior hypoxic conditioning. **Conclusions:** Conducting training camps in mid-mountain conditions for novice skiers is impractical owing to the deterioration of the functional fitness of their bodies.

Key Words: endurance, functional testing, cross-country skiers, training, sports training

Introduction

Achieving high athletic performance in cross-country skiing is possible only when the athlete's body develops the capacity to endure prolonged, intense physical exertion over the course of long-term training (Wang et al., 2021; Talsnes et al., 2024). This is primarily achieved by enhancing the athlete's functional reserves (Mishica et al., 2023; Bocharin et al., 2023), which are largely determined by the functional state of the cardiovascular and respiratory systems (Guzii et al., 2021; Bocharin et al., 2022). The condition of the cardiorespiratory system serves as a key prognostic factor in cross-country skiing (Lee et al., 2016; Kudryavtsev et al., 2024; Osipov et al., 2024). Understanding how the cardiorespiratory system responds to physical exertion enables the individualization of the training process, which considerably improves athletic performance (Christiani et al., 2021).

It is widely recognized that the effectiveness of the training process is a key factor in improving athletic performance in skiing (Vandbakk et al., 2017; Talsnes et al., 2024). To achieve this, a wide range of training methods and tools is available to skiers (Andersson et al., 2021).

Training under conditions of reduced partial oxygen pressure is one of the key approaches to optimizing athletic performance (Hauser et al., 2018; Hrozanova et al., 2021; Li et al., 2025; Tyupa, et al., 2021;). According to G. Turner et al. (2019), a survey of elite English long-distance runners who competed in the 2012

Olympic Games revealed that 98% had used altitude or hypoxic training. Approximately 75% of these athletes considered hypoxic training an important component of their preparation. The most commonly used format was training camps held at altitudes of 1500–2500 m, typically lasting 3–4 weeks.

One of the mechanisms leading to hypoxia can be an athlete's exposure to mountainous conditions, while another method involves simulating altitude exposure (Brocherie et al., 2023; Bouten et al., 2023; Vorozheikin et al., 2020).

Hypoxia influences an individual's capacity for physical exercise in various ways. Exposure to normobaric hypoxia leads to the rapid onset of muscle fatigue, a reduction in $\text{VO}_{2\text{max}}$, and decreased pulmonary ventilation. It also results in lower systolic blood ejection and cardiac output, while slowing the body's recovery processes (Faiss et al., 2024).

Despite the known negative effects of low partial oxygen pressure, researchers have demonstrated that repeated sprint loads under such conditions lead to a substantial increase in anaerobic performance, even at altitudes as low as 1500 m above sea level (Gutknecht et al., 2022). It has been concluded that repeated training in hypoxic environments is a more effective method for improving physical performance compared to equivalent training under normoxic conditions (Bouten et al., 2023). A review of the literature shows that 77% of scientific studies report a positive impact of hypoxia on athletic training (Faiss et al., 2024). An increase in red blood cell and hemoglobin levels has been observed in athletes' blood, even when these parameters were already high at the start of the experiment (Hauser et al., 2018). This adaptation to hypoxia leads to a considerable improvement in the body's oxygen saturation.

Improvement in aerobic performance and fatigue resistance in athletes using hypoxia in the training process was minimal, possibly due to increased muscle oxygenation (Pramkratok et al., 2022; Brocherie et al., 2023). Hypoxic training is mainly used in endurance sports. However, there is scientific evidence for the use of hypoxic training in professional basketball players (Ibáñez et al., 2024). According to the authors, the high-altitude block effectively overloaded the training, providing motivation to improve the physical fitness of athletes. At the same time, defenders began to move at high speed more often, and center players demonstrated higher cardiovascular performance.

There is information in the scientific literature related to the study of the effects of hypoxia on the state of the training process in various sports. However, the literature does not fully reflect information on the use of mountain conditions for training skiers, in the context of their level of sports qualification. The lack of such knowledge can lead to a decrease in the effectiveness of training in athletes or cause serious consequences for their health when using such a powerful tool as hypoxia. The study of this issue will allow us to provide scientific differentiated recommendations for cross-country skiers who have different levels of sports qualification when using hypoxic training in mountainous terrain.

Research aim. To evaluate the functional state of the cardiorespiratory system in cross-country skiers of different sports qualifications and to provide tailored recommendations for their training camps conducted under low-altitude and mid-altitude conditions.

Material & methods

The research was performed during the winter of 2024 at the sports facilities of the Olympic Reserve College in the Siberian Federal District, Russia. The study involved 32 male students aged 15–16 years (mean age 15.8 ± 1.4) engaged in freestyle cross-country skiing, representing different levels of sports qualifications. The Highly skilled (HS) group ($n = 16$) consisted of athletes competing at the highest level of sports mastery, with 62.5% holding the 1st sports category and 32.5% being candidates for the master of sports. The Unqualified athletes (UA) group ($n = 16$) comprised novice athletes.

They had been engaged in cross-country skiing for two years in the preparatory training group. In both experimental groups, educational and training sessions were performed following a program aligned with the federal standard for the sport (Federal standard of sports training in cross-country skiing, 2022). Training sessions for each group were performed separately, tailored to their qualifications and physical fitness levels, and fully compliant with the federal training standard.

At the end of the winter training season, eight athletes from each of the HS and UA groups were randomly selected to participate in 14-day training camps under low-altitude and mid-altitude conditions. Eight athletes from each group trained at the Olympic Reserve School ski base, located at a low altitude of 102 m above sea level. The remaining members of both the HS and UA groups trained at a sports facility located at mid-altitude, 1842 m above sea level.

Before the experiment, parents of all adolescent participants provided written consent in accordance with the protocol requirements of the 2008 Helsinki Declaration. Researchers and specialists from multiple universities across Russia, Kyrgyzstan, and Kazakhstan contributed to this study.

A comprehensive examination was performed twice to assess the cardiovascular and respiratory systems, along with anthropometric measurements of body length and weight, which were used to calculate functional indices. The parameters measured included resting respiratory rate (RR, breaths per minute), vital lung capacity (VLC, ml), and hypoxic tests of Stange and Genchi (s). Resting heart rate (HR, beats per minute) and systolic (SP) and diastolic (DP) blood pressure (mmHg) were recorded using an automatic OMRON M2 Comfort tonometer (ALRU, Japan). Additionally, handgrip strength for both hands was measured in kilograms using a dynamometer.

The following indices were calculated: body mass index (BMI, kg/m²); strength index (SI), defined as hand strength / body weight × 100% (%); vital index (VI), calculated as VLC / body weight (ml/kg); Robinson index (RI): HR × SP / 100 (arbitrary units) (Robinson, 1967); and Hildebrandt index (HI) calculated as HR/RR (arbitrary units) (Doeltgen, & Ridding, 2010). Statistical analysis was performed using Statistica 6.0 software (Russia). Arithmetic mean values with standard errors (M ± m) were reported, and differences were considered statistically significant at p < 0.05.

Results

The values of morphological and functional indicators in skiers of different qualification levels show marked differences during training camps in low-altitude conditions (Table 1).

Table 1. Dynamics of morphofunctional indicators in skiers at the beginning and end of training camps under low-altitude conditions, M ± m

No	Indicators	Experimental group			
		UA (Unqualified athletes), n = 16		HS (Highly skilled), n = 16	
		Beginning of training	End of training	Beginning of training	End of training
	Body length, cm	173.3±0.8	173.3±0.8	174.2±0.8	174.2±0.8
	Body weight, kg	64.8±1.38	63.5±1.32	65.2±1.25	64.4±1.18
	BMI, kg/m ²	21.7±0.33	21.2±0.30	21.5±0.36	21.2±0.34
	Right-hand strength, kg	41.8±1.07	43.4±1.02	44.3±1.10	46.8±1.15*
	SI (right hand), %	64.5±1.12	68.3±1.23*	67.9±1.42	72.6±1.54*
	Left-hand strength, kg	40.2±1.01	42.5±1.16 *	42.8±1.23	46.4±1.35 *
	SI (left hand), %	62.0±1.10	66.9±1.23*	65.6±1.22	72.1±1.87*
	Stange test, s	67.0±2.84	72.5±3.12	70.4±3.03	77.6±3.45*
	Genchi test, s	38.3±2.10	43.6±2.67*	40.8±2.24	48.3±2.45
	RR, breaths/min	17.0±0.54	16.7±0.52	16.0±0.45	15.5±0.40
	VLC, ml	4124±89.6	4187±93.5	4405±95.5	4506±97.8
	VI, ml/kg	63.6±1.23	65.9±1.34	67.6±1.87	69.9±1.89
	HR, beats/min	72.5±2.57	68.0±1.82 *	65.3±1.56	61.4±1.22*
	SP, mm Hg	125.3±1.65	122.0±1.46	119.0±1.32	117.4±1.30
	DP, mm Hg	75.0±1.60	73.5±1.58	70.0±1.45	67.8±1.24
	RI, arbitrary units	90.1±2.12	82.9±1.72*	77.7±1.43	72.1±1.24*
	HI, arbitrary units	4.26±0.035	4.07±0.032*	4.0±0.027	3.96±0.016*

Note. * Indicates a significant difference in the indicator value compared to the beginning, p < 0.05.

At the beginning of the training camp under lowland conditions, body length and weight were similar between the UA and HS groups (p > 0.05). However, qualified athletes demonstrated significantly greater hand muscle strength, higher strength index, and better respiratory system functional indicators compared to novices (p < 0.05). They also exhibited significantly lower HR, RI, and HI than the novice skiers (p < 0.05). SP and DP values were comparable between the two groups.

After the 14-day sports training camp, a repeat assessment was performed for athletes in both experimental groups. Morphological indicators showed no significant changes in either group. However, substantial improvements were observed in functional indicators. Both groups exhibited significant increases in hand dynamometry and strength index values (p < 0.05), with the HS group showing a more pronounced improvement compared to the UA group. Regarding respiratory function, increases were recorded in VLC, VI, and performance on the hypoxic Stange and Genchi tests, particularly in the HS group.

Regarding central hemodynamics, a significant decrease in HR was observed in athletes from both groups compared to the start of the training camp, indicating greater cardiovascular efficiency. This effect was

especially pronounced in the skilled skiers. Adaptation of the cardiorespiratory system to physical activity was further confirmed by a significant reduction in RI and HI, particularly among HS group skiers ($p < 0.05$). Significant differences in morphofunctional indicators between skiers of different qualifications were observed under mid-altitude conditions (Table 2).

Table 2. Values of morphofunctional indicators in skiers of different qualifications at the beginning and end of training camps in mid-altitude conditions, $M \pm m$

No	Indicators	Experimental group			
		UA, n = 16		HS, n = 16	
		Beginning of training	End of training	Beginning of training	End of training
	Body length, cm	173.0 $\pm$ 0.7	173.0 $\pm$ 0.7	173.4 $\pm$ 0.8	173.4 $\pm$ 0.8
	Body weight, kg	63.4 $\pm$ 1.19	62.2 $\pm$ 1.18	63.3 $\pm$ 1.27	63.8 $\pm$ 1.29
	BMI, kg/m ²	21.2 $\pm$ 0.31	20.8 $\pm$ 0.27	21.1 $\pm$ 0.33	21.2 $\pm$ 0.32
	Right-hand strength, kg	40.5 $\pm$ 1.10	41.0 $\pm$ 1.03	42.0 $\pm$ 1.20	49.5 $\pm$ 1.45*
	SI (right hand), %	63.9 $\pm$ 1.34	65.9 $\pm$ 1.23	66.6 $\pm$ 1.34	77.5 $\pm$ 1.67*
	Left-hand strength, kg	40.0 $\pm$ 1.04	40.5 $\pm$ 1.2	42.5 $\pm$ 1.15	48.8 $\pm$ 1.39 *
	SI (left hand), %	63.1 $\pm$ 1.10	65.1 $\pm$ 1.12	65.6 $\pm$ 1.22	76.4 $\pm$ 1.93*
	Stange test, s	69.0 $\pm$ 2.87	69.5 $\pm$ 2.92	71.2 $\pm$ 3.12	82.3 $\pm$ 3.85*
	Genchi test, s	39.5 $\pm$ 2.33	39.6 $\pm$ 2.17	42.5 $\pm$ 2.20	48.7 $\pm$ 2.82*
	RR, breaths/min	17.0 $\pm$ 0.63	17.0 $\pm$ 0.75	16.0 $\pm$ 0.53	13.0 $\pm$ 0.36*
	VLC, ml	4067 $\pm$ 88.3	4070 $\pm$ 92.3	4500 $\pm$ 95.3	4570 $\pm$ 98.5
	VI, ml/kg	64.1 $\pm$ 1.42	65.4 $\pm$ 1.42	71.1 $\pm$ 2.87	71.6 $\pm$ 2.45
	HR, beats/min	71.0 $\pm$ 2.24	78.0 $\pm$ 1.81 *	66.2 $\pm$ 1.75	60.0 $\pm$ 1.20*
	SP, mm Hg	124.4 $\pm$ 1.48	132.0 $\pm$ 1.55*	118.0 $\pm$ 1.34	116.2 $\pm$ 1.27
	DP, mm Hg	77.0 $\pm$ 1.82	85.5 $\pm$ 1.62*	68.0 $\pm$ 1.32	66.5 $\pm$ 1.22
	RI, arbitrary units	88.3 $\pm$ 2.36	99.0 $\pm$ 1.94*	78.1 $\pm$ 1.54	69.7 $\pm$ 1.24*
	HI, arbitrary units	4.17 $\pm$ 0.027	4.33 $\pm$ 0.062*	4.13 $\pm$ 0.022	4.0 $\pm$ 0.012*

Note. * Indicates a significant difference in the indicator value compared to the beginning, $p < 0.05$.

At the beginning of the study, morphological indicators were similar in both groups ($p > 0.05$), unlike the functional indicators. Athletes in the HS group demonstrated significantly higher values across all functional indicators compared to novice athletes ($p < 0.05$), reflecting greater functional readiness. By the end of the camp, the UA group showed a non-significant decrease in body weight (from 63.4 ± 1.19 to 62.2 ± 1.18 kg) and BMI (from 21.2 ± 0.31 to 20.8 ± 0.27 kg/m²) ($p > 0.05$), along with a slight, non-significant increase in hand strength and strength index ($p > 0.05$).

At the end of the training camp, athletes in the UA group exhibited a slight increase in hypoxic tolerance, reflected by increases of 0.7% and 0.1% in the Stange and Genchi test values, respectively, compared to the beginning of the camp ($p > 0.05$).

However, unfavorable changes in cardiovascular indicators were observed by the end of the camp. HR increased by 9.8% (from 71.0 ± 2.24 to 78.0 ± 1.81 beats per minute), accompanied by significant increases in both SP and DP ($p < 0.05$).

The deterioration in RI and HI values indicates a decline in the athletes' physical performance and a disruption of cardiorespiratory synchrony. We attribute these negative changes in the morphofunctional indicators of the UA group to the physical demands of training in mid-mountain conditions, where the partial pressure of oxygen is reduced.

At the end of the training camp, athletes in the HS group showed positive improvements in functional body characteristics.

This was evidenced by significant increases in both absolute and relative hand muscle strength, as well as in the results of the hypoxic Stange and Genchi tests ($p < 0.05$). A key indicator of improved adaptation in the HS group was a significant decrease in HR, RI, and HI ($p < 0.05$).

Comparative dynamics of changes in selected functional indicators in athletes after completing the camp at different altitudes above sea level are shown in Figure 1.

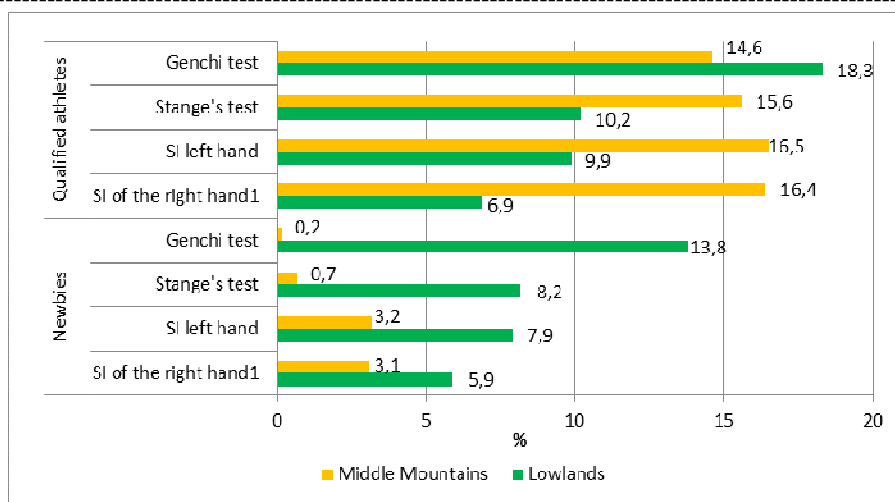


Fig. 1. Increase in SI values and hypoxic test results at the end of the training camp

At the end of the training camp, beginner skiers showed a more pronounced increase in strength index values and hypoxic test results under low-altitude conditions compared to mid-altitude conditions. In qualified athletes, the most significant improvements in strength and respiratory system indicators (with the exception of the Genchi test) were observed after the camp in mid-altitude rather than low-altitude conditions.

Figure 2 shows the comparative dynamics of hemodynamic changes in athletes of different qualifications after the training camps at different altitudes above sea level. At the end of the training camp for beginner skiers, the increase in the SI values and hypoxic test results is more pronounced in low-altitude conditions compared to mid-altitude conditions. In qualified athletes, the most pronounced values of strength and respiratory system testing indicators (except for the Genchi test) after the camp in mid-altitude conditions compared to low-altitude conditions. Comparative dynamics of changes in hemodynamic indicators in athletes of different qualifications after the camp at different altitudes above sea level is shown in Figure 2.

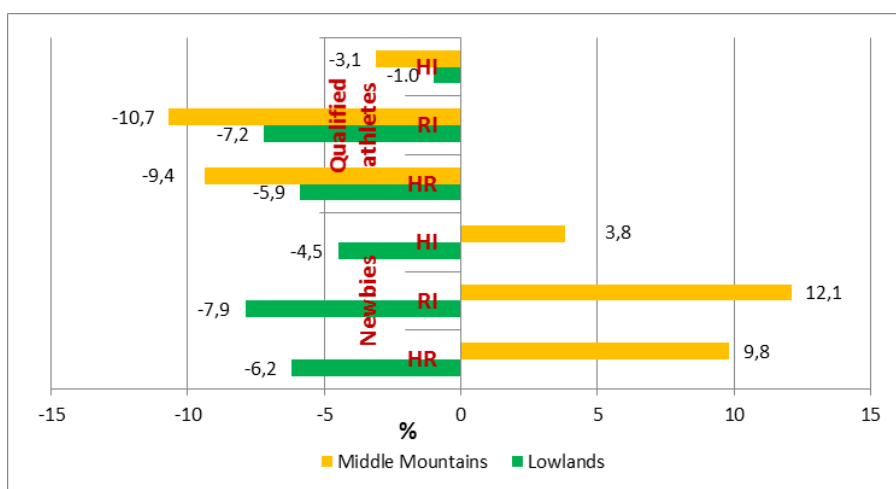


Fig. 2. Increase in central hemodynamic parameters after the training camp

After completing the camp, positive changes in central hemodynamics were observed in the athletes, except for beginner skiers who trained in mid-mountain conditions. A reduction in HR, along with decreases in the RI and HI, indicated increased aerobic capacity. These improvements reflect increased cardiorespiratory tolerance to physical activity. The most pronounced positive cardiovascular adaptations were observed in qualified athletes training at mid-mountain altitude compared to those training in low-altitude conditions.

Unfavorable dynamics of cardiovascular parameters were found in beginner skiers who trained in mid-mountain conditions. At the end of the camp, they noted an increase in resting heart rate, an increase in the values of the Robinson and Hildebrandt hemodynamic indices. This is a sign of the negative impact of training of unqualified athletes in mid-mountain conditions, which was carried out without sufficient prior preparation and acclimatization.

Dicussion

Achieving high athletic performance in sports where the main motor quality is endurance is possible only if the body develops the ability to withstand prolonged intense physical activity (Talsnes et al., 2024). The primary goal in cross-country skiing is to increase the level of functional reserves of the athlete's body. This allows for significant development of special endurance (Mishica et al., 2023; Bocharin et al., 2023). For this, first of all, it is necessary to improve the cardiorespiratory system (Guzii et al., 2021; Bocharin et al., 2022), which limits the performance of any physical activity. To increase the tolerance of the cardiorespiratory system to prolonged physical activity, athletes use a variety of basic and auxiliary means and methods of physical education and sports.

It is known from the scientific literature that training athletes at low partial pressure of oxygen, for example, in mountainous terrain, can significantly change the effect of physical activity on the functional systems of the body (Hauser et al., 2018; Hrozanova et al., 2021; Li et al., 2025). This is manifested in the functional mobilization of all physiological systems of the body. This improves the athlete's performance in competitions in terrain conditions close to sea level (Gutknecht et al., 2022; Bouten et al., 2023; Faiss et al., 2024). The genesis of the increase in the reserve capacity of the cardiovascular and respiratory systems under conditions of low partial pressure of oxygen is an increase in microcirculatory vasodilation. This leads to improved blood supply to tissues and organs and an increase in the content of muscle phosphocreatine, which is the source of muscle contraction (Faiss et al., 2024).

According to Y. Yu et al. (2022), it was reliably established that the lactate threshold velocity and upper body muscle mass increased significantly after training at moderate altitude. However, maximum oxygen uptake, hemoglobin, and the number of red blood cells did not increase significantly after the athletes returned to sea level. According to our data, no increase in body weight was found in athletes after 14 days of training camp. Perhaps this is due to the short duration of the training camp compared to the results presented by the authors, where the athletes trained for 4 weeks.

An important positive change in the cardiovascular system in endurance athletes is a slowdown in resting heart rate (Guzii et al., 2021; Bocharin et al., 2022). This phenomenon is explained by an increase in myocardial mass and expansion of the heart cavities, which leads to an increase in systolic blood ejection (Rudofker et al., 2025). Our experiment has established that after training camps in mid-mountain conditions, all athletes, with the exception of beginner skiers, have a positive vector of central hemodynamic indicators, which is characterized as an "athletic heart." According to our data, a decrease in resting pulse rate, normalization of systolic and diastolic blood pressure, a decrease in the Robinson index and Hildebrandt index are recorded. A tendency for a slowdown in the frequency of respiratory cycles at rest, an increase in the body's hypoxic resistance according to the Stange and Genchi respiratory tests have also been established. This is a sign of adaptation of the external respiration system to physical activity. In our experiment, the established increase in the tolerance of the cardiorespiratory system of athletes to physical activity led to an increase in their strength abilities. This is indicated by a reliable increase in the absolute values of dynamometry indicators of both hands and their strength index.

Positive changes in tests characterizing central hemodynamics are most pronounced in the group of qualified athletes who trained in mid-altitude conditions, compared to the results of the same athletes who trained in low-altitude conditions. Our results are consistent with the materials of other researchers who observed athletes training in conditions of low partial pressure while in the mountains or in simulated hypoxia conditions (Gutknecht et al., 2022; Brocherie et al., 2023; Bouten et al., 2023; Faiss et al., 2024). The authors note an increase in the functional capabilities of the cardiovascular and respiratory systems, which has a positive effect on the performance of athletes.

According to our observations, in the group of skiers who are starting sports activities and who trained in mid-altitude conditions, unfavorable dynamics of cardiovascular indicators were established. At the end of the training camp, they showed an increase in resting heart rate, instability of blood pressure, and an increase in the values of the Robinson and Hildebrandt hemodynamic indices. No significant increase in the values of hypoxic test indicators and strength indicators of the hand muscles was found. This indicates signs of a negative impact of training among novice athletes in mid-mountain conditions, which was carried out without sufficient prior preparation and acclimatization. Therefore, the use of low partial pressure of oxygen in mountainous terrain or when simulating hypoxia in novice athletes should be carried out with caution. For them, it is necessary to carry out preliminary gradual hypoxic preparation and acclimatization, which will allow the functional systems to tolerate mid-mountain conditions more favorably.

Conclusions

Analysis of the physiological indicators of the cardiovascular and respiratory systems in skiers of various qualifications allowed for the identification of their distinct responses to training loads at different altitudes above sea level.

In low-altitude conditions, training loads in low-skilled athletes trigger a high reactivity of the hemodynamic and respiratory systems, reflecting an active adaptation phase consistent with early development of the adaptation process. In contrast, highly skilled athletes exhibit decreased reactivity alongside greater functional fitness. Under mid-altitude conditions, skilled athletes—unlike their low-skilled counterparts—demonstrate a substantial increase in the functional reserves of the cardiovascular and respiratory systems, with clear signs of physiological adaptation to the workload. For novice athletes at mid-altitude, adaptation to oxygen deficiency is prolonged, requiring preliminary hypoxic training and acclimatization.

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