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Physiological adaptation of race walkers' cardiovascular system to medium mountain conditions

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Abstract

Background. Hypobaric hypoxia causes complex structural and functional changes that can manifest themselves in different ways depending on the individual level of adaptability. Studying these reactions allows for the optimization of training loads of highly skilled athletes.

Material and methods. The study examined 15 highly skilled race walkers during a 14-day training camp in medium mountain conditions (1,600 m above sea level). Heart rate, systolic and diastolic blood pressure were measured daily in a state of functional rest.

Results. Unstable heart rate indicators were observed during the first 4-5 days of remaining in medium mountain conditions. Some athletes showed a decrease and stabilization of heart rate starting from the 5th-6th day, which indicated effective acclimatization. Blood pressure indicators remained relatively stable in most participants.

Conclusions. A relatively high reactivity of heart rate values at the beginning of acclimatization was revealed. The 4-5-day period was defined as the period of mobilization of adaptation processes, which requires a decrease in training loads during this period. In general, we consider it advisable for athletes to stay longer (more than 14 days) in mid-mountain conditions. At the same time, highly adaptive individuals can begin more intensive training after 5-6 days of stay.

Keywords: medium mountain conditions, professional sports, physiological adaptation, cardiovascular system, heart rate

Introduction

Adaptation of the cardiovascular system to physical exertion is a key aspect of athlete training, as the efficiency of the cardiovascular system directly affects physical performance and the body's ability to withstand high physical exertion. For race walkers engaged in long-term and monotonous physical activity, adaptation to medium mountain conditions is an important part of training that allows them to increase their endurance and reduce the risk of injury.

Training in medium mountain conditions is an effective tool in preparing athletes due to the phenomenon of hypobaric hypoxia. The main goal of such training is to force the body to work in conditions of oxygen deficiency. This triggers a cascade of compensatory reactions, including stimulation of erythropoiesis, an increase in hemoglobin levels, which directly improves the ability of blood to transport oxygen to muscles, and economization of functions, as the body uses available oxygen more efficiently by improving mitochondrial function and increasing capillary density in muscles [1,2]. The result of these changes is improved aerobic capacity during competitions under normal conditions (at sea level) as well as at moderate or high altitudes [3].

During the Olympic Games in Mexico City (1968), located at an altitude of 2,240 meters above sea level, a decrease in the performance of Olympic athletes was observed [1]. It became clear that athletes needed to acclimatize for a certain period of time. This time should be sufficient for them to adapt to the changed conditions but must not be too long due to the danger of exhausting the body's adaptive reserves. Today, training at moderate altitudes as part of competition preparation is used in various sports. In particular, it has been established that in the training of professional athletes who specialize in sports aimed at developing endurance, training in mountain conditions plays a significant role in the formation of physical qualities [4].

From the point of view of physiological adaptation, the influence of moderate altitudes with their inherent set of conditions (mainly a decrease in the partial pressure of oxygen and carbon dioxide, a decrease in air temperature, and an increase in solar radiation) is phased and causes a series of sequential adaptive changes in the human body. The duration and severity of such changes largely depend on the genotypic and phenotypic adaptability of a particular person's body, as well as on the duration of stay at moderate altitudes. Therefore, although training at moderate altitudes is quite effective, it requires special attention and individualized training programs for athletes [2,5]. In particular, as a result of analysis [3], a two-week period is determined as one that leads to satisfactory adaptation to high altitude conditions.

Desaturation occurring at moderate altitudes not only during exercise but also at rest [2] is compensated for by both hyperventilation and hemoconcentration [3] and changes in vascular permeability. The mentioned reactions develop during the first days of exposure to extreme conditions.

Adaptive changes occur in the autonomic nervous system, manifested by an increase in heart rate (HR) and cardiac output during the first days after exposure to hypoxia. This improves oxygen transport to body tissues and limits myocardial overload under conditions of increased metabolic demands [6].

The following changes in HR during acclimatization have been described [7]: a gradual decrease in mean HR values while the minimum HR initially increases followed by a decrease. The authors concluded that acclimatization to altitudes of 1,360 m above sea level affects the autonomic nervous system, heart rate, and sleep parameters in healthy adults.

Blood pressure undergoes mainly moderate and transient changes at moderate altitudes. A slight temporary increase in systemic blood pressure is possible at the initial stage of staying at altitude. Cardiac output normalizes and systemic blood pressure, as a rule, stabilizes without a persistent increase during acclimatization. At the same time, there is a constant increase in pulmonary artery pressure, especially during physical exertion while the filling pressure of the heart remains unchanged. Thus, according to the data [8], moderate altitudes are characterized by the absence of long-term significant changes in blood pressure with the presence of adaptive changes in pulmonary hemodynamics.

Aim of the work

The aim of the study to investigate the adaptive reactions of the cardiovascular system of highly qualified athletes to training in medium mountain conditions and to develop recommendations for optimizing training for highly qualified athletes.

Material and methods

The study was conducted at the training camp of the Ukrainian national race walking team in the Tien Shan (Kyrgyzstan) at an altitude of 1,600 m. The reactions of the cardiovascular system of highly qualified athletes (race walking) to training at moderate altitudes (1,600 m above sea level) were studied for 14 days. The study involved 15 athletes, including 2 Honored Masters of Sports of Ukraine, 11 Masters of Sports of Ukraine of international class, and 2 Masters of Sports of Ukraine (according to the Ukrainian sports classification); winners of the World Team Cup in Race Walking (Taicang – 2014), winners of the European Team Cup in Race Walking (Podebrady – 2017, Alytus – 2019), winners of the World Universiade in the team (Gwangju – 2015, Taibet – 2017), and prize-winners – Rome, 2019; prize-winners of the World Team Race Walking Championship (Rome –2016, Taichung – 2018), prize-winners of the European Team Race Walking Championship (Podebrady – 2025).

The morning measurements of HR, systolic (SP), and diastolic (DP) blood pressure were performed in a state of functional rest during this period. Determination of morning resting HR and HR variability indicators allows for non-invasive assessment of an athlete's individual response to stress factors, in particular the effect of altitude [9].

HR (bpm) was measured by palpation for 1 min in the supine position at functional rest.

Blood pressure was measured using a mechanical tonometer using the Korotkoff method (mmHg) in the supine position at functional rest.

The median (25th and 75th percentiles) as well as the minimum and maximum values characterizing the spread of data and individual reactions of athletes were analyzed. Pearson correlation analysis in Microsoft Excel was performed to establish the relationship between heart rate, blood pressure, and duration of stay in conditions of reduced atmospheric pressure (medium mountains).

The level of statistical significance was set at α=0.05. Differences were considered statistically significant when $p<0.05$ [10,11]. The statistical significance of the correlation coefficient was determined using the t-test according to the formula:

$$t = \frac{r}{\sqrt{\frac{1 - r^2}{n - 2}}}$$

where r is the correlation coefficient, and n is the degrees of freedom.

The exact *p*-value was calculated based on the two-tailed Student's t-distribution [10,11].

Results

Analysis of HR dynamics

We analyzed the dynamics of HR over 14 days to assess the speed and quality of acclimatization. We tried to identify the periods of greatest functional stress and determine the individual sensitivity of athletes to the hypobaric environment. We used such statistical indicators as the median, 1, 3 percentiles, minimum and maximum values. We found that the median HR indicators are characterized by a general tendency to decrease, starting from the fifth day of stay in conditions of reduced pressure. At the same time, the first 4-5 days are characterized by higher HR values and fluctuations, which may indicate an active adaptive process and activation of the sympatho-adrenal system. It is worth paying attention to the maximum values, which differ significantly (unlike the minimum values) from the median (Table 1), while the highest HR values were recorded in athletes of lower qualification, which may indicate lower adaptability of the cardiovascular system in these individuals at the initial stage of acclimatization.

Table 1. HR indicators, beats/min (n=15)

HR indicators	1 day	2 day	3 day	4 day	5 day	6 day	7 day	8 day	9 day	10 day	11 day	12 day	13 day	14 day
Min	48	48	43	42	46	46	46	44	44	45	45	45	44	44
1 quartile	50	49	48	50	48	48	48	48	48	48	46	47	47	45
median	54	53	52	54	50	50	49	49	49	48	48	48	48	48
3 quartile	56	60	58	59	60	59	59	60	59	55	56	55	59	55
Max	62	60	60	62	68	63	63	68	68	66	70	65	65	68

Pearson correlation analysis revealed inverse correlations between group average HR and duration of exposure to low atmospheric pressure (r=-0.77; $p \leq 0.001$; n=14). We also conducted a Pearson correlation analysis of individual HR values and duration of stay in the medium mountains. We found a statistically significant decrease in HR with increasing duration of stay in 6 subjects (40% of the total sample) (r=-0.68, $p=0.0073$; r=-0.69, $p=0.068$; r=-0.78, $p=0.001$; r=-0.71, $p=0.005$; r=-0.91, $p \leq 0.001$; r=-0.74, $p=0.003$). In one athlete (subject no. 5), the opposite trend was observed (r=0.75; $p=0.002$) (Figure 1).

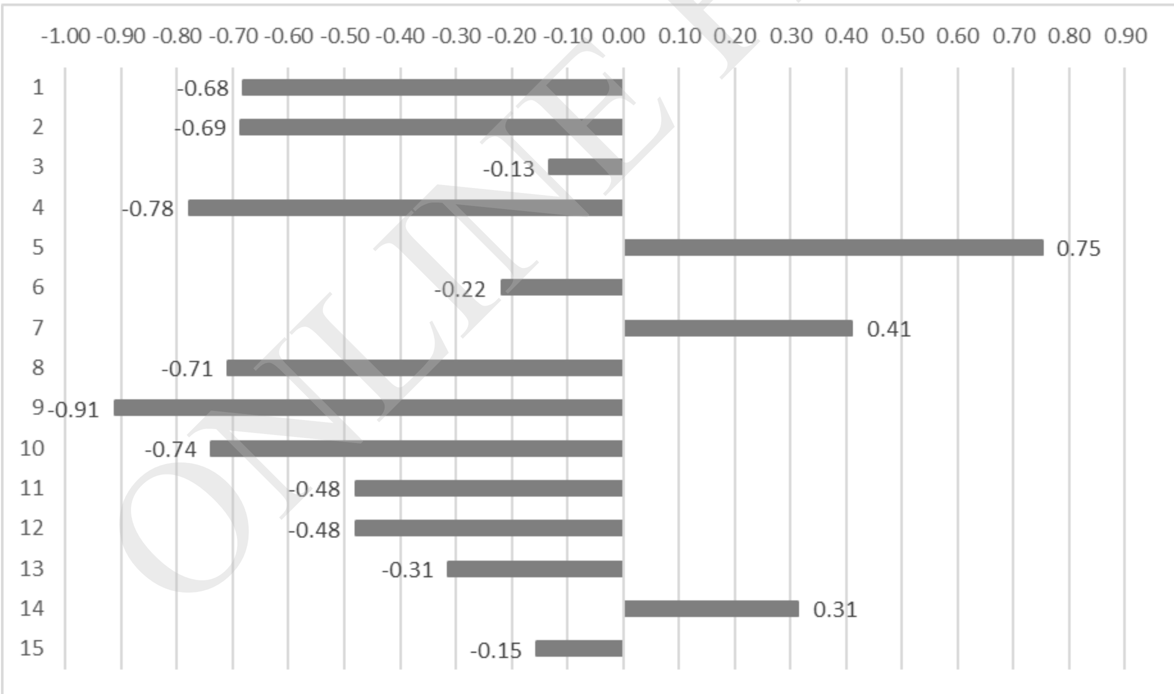

Figure 1. Correlation coefficients of HR and duration of stay in conditions of reduced atmospheric pressure

If we divide the participants into two groups according to the dynamics of the HR in such a way that one group includes individuals with a significant decrease in HR with an increase in the duration of stay in conditions of low atmospheric pressure (the highly adaptive group), and the second group includes all the others (the low adaptive group), then the dynamics of the HR will look as follows (Figure 2).

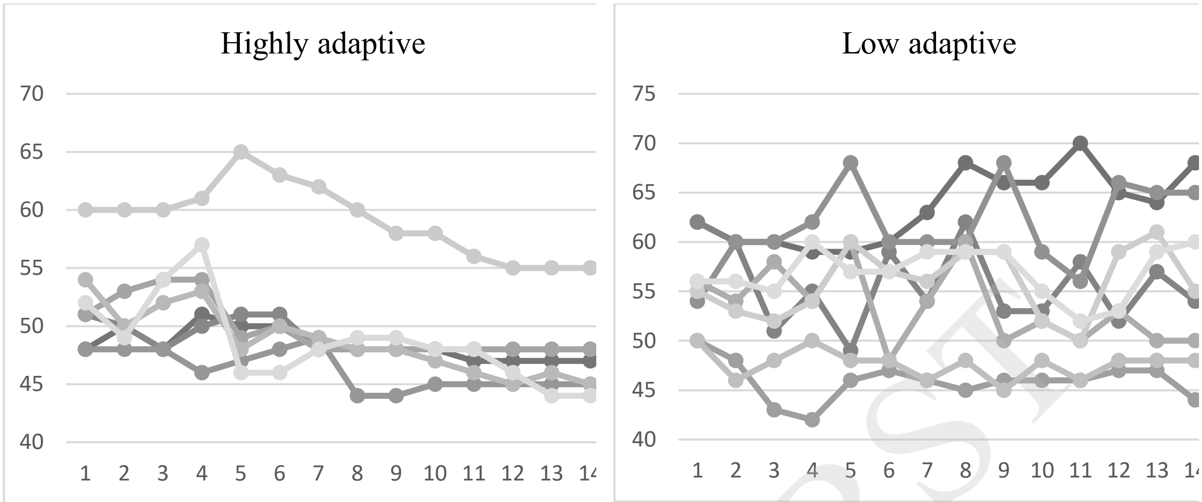

Figure 2. Dynamics of individual HR indices in the two studied group

The participants in both groups are characterized by significant fluctuations in HR during the first 4-5 days of exposure to reduced atmospheric pressure. However, in the "highly adaptive" group, the indices stabilize starting from the 5-6th day and remain so (with a tendency to decrease) for the rest of the time. In contrast, in the "low adaptive" group, the unstable dynamics of the first days is characteristic of the remaining days (Figure 2).

Analysis of blood pressure dynamics

SP shows minor fluctuations within 5 mm Hg in median values throughout the observation period. Minimum and maximum values fluctuate in a slightly larger range but still remain quite stable throughout all 14 days (Table 2).

Table 2. SP indices, mm Hg (n=15)

SP indices	1 day	2 day	3 day	4 day	5 day	6 day	7 day	8 day	9 day	10 day	11 day	12 day	13 day	14 day
Min	90	90	100	95	100	100	100	100	105	105	95	95	100	100
1 quartile	100	100	105	100	100	100	105	105	105	105	110	110	110	105
median	110	110	110	108	110	110	110	105	110	110	110	110	110	110
3 quartile	110	110	120	110	115	115	115	110	115	115	110	110	110	110
Max	130	120	120	120	120	120	120	120	120	120	120	120	120	118

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The analysis revealed that the average group indices of systolic pressure (SP) directly correlate with the duration of stay in the medium mountains (r=0.55; $p \leq 0.042$; n=14). Three participants were identified whose individual SP indices rose with increasing duration of stay in the medium mountain terrain (r=0.95, $p \leq 0.001$; r=0.73, p=0.003; r=0.68, p=0.008) (Figure 3). Two of them, subjects no. 8 and no. 10, had a significant decrease in HR (Figure 1).

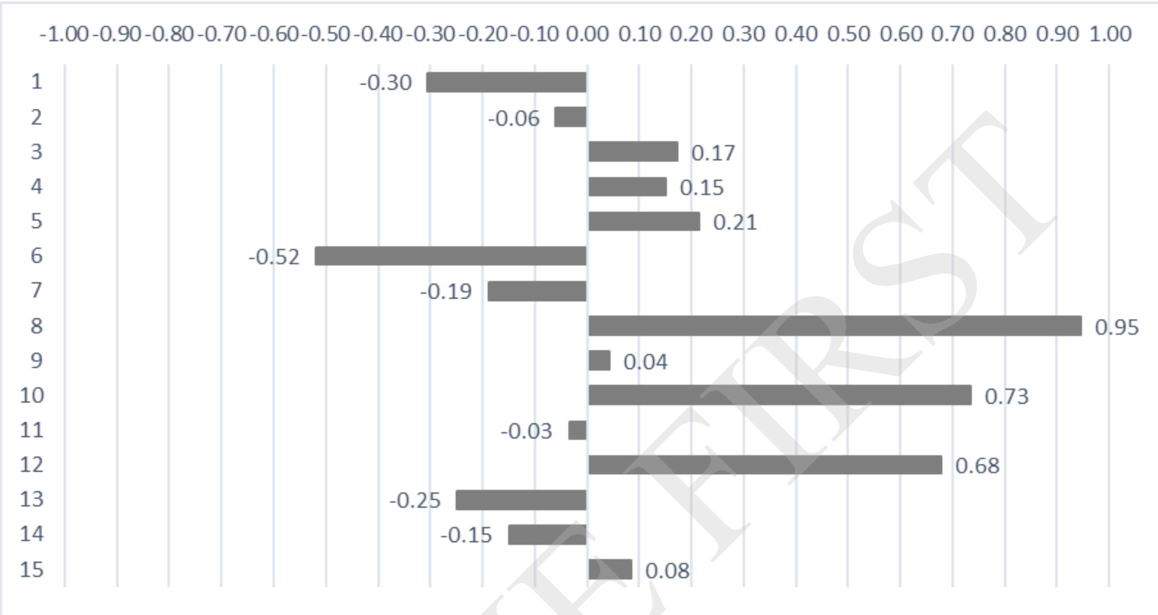

Figure 3. Correlation coefficients of SP and duration of stay in conditions of reduced atmospheric pressure

The median diastolic pressure (DP) remained constant throughout the period (70 mm Hg). There was a greater deviation from the median of the maximum values compared to the similar SP indices (Table 3).

Table 3. DP indices, mm Hg (n=15)

DP indices	1 day	2 day	3 day	4 day	5 day	6 day	7 day	8 day	9 day	10 day	11 day	12 day	13 day	14 day
Min	60	60	60	60	60	60	65	60	65	70	65	70	68	67
1 quartile	65	60	65	60	70	70	70	70	70	70	70	70	70	70
median	70	70	70	70	70	70	70	70	70	70	70	70	70	70
3 quartile	80	75	80	75	80	70	80	75	70	80	80	75	75	70
Max	85	80	80	80	80	90	80	80	80	90	85	80	80	80

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The average group indices of DP did not correlate with the duration of stay in the medium mountains (r=0.45; *p*=0.106; n=14). Correlation analysis of individual indices of DP were revealed in three participants when direct correlations were observed (r=0.74, *p*≤0.003; r=0.85, *p*≤0.001; r=0.74, *p*=0.003). On the contrary, subject no. 11 experienced a significant decrease in DP indices with an increase in the duration of stay in conditions of reduced atmospheric pressure (r=-0.64, *p*=0.014) (Figure 4).

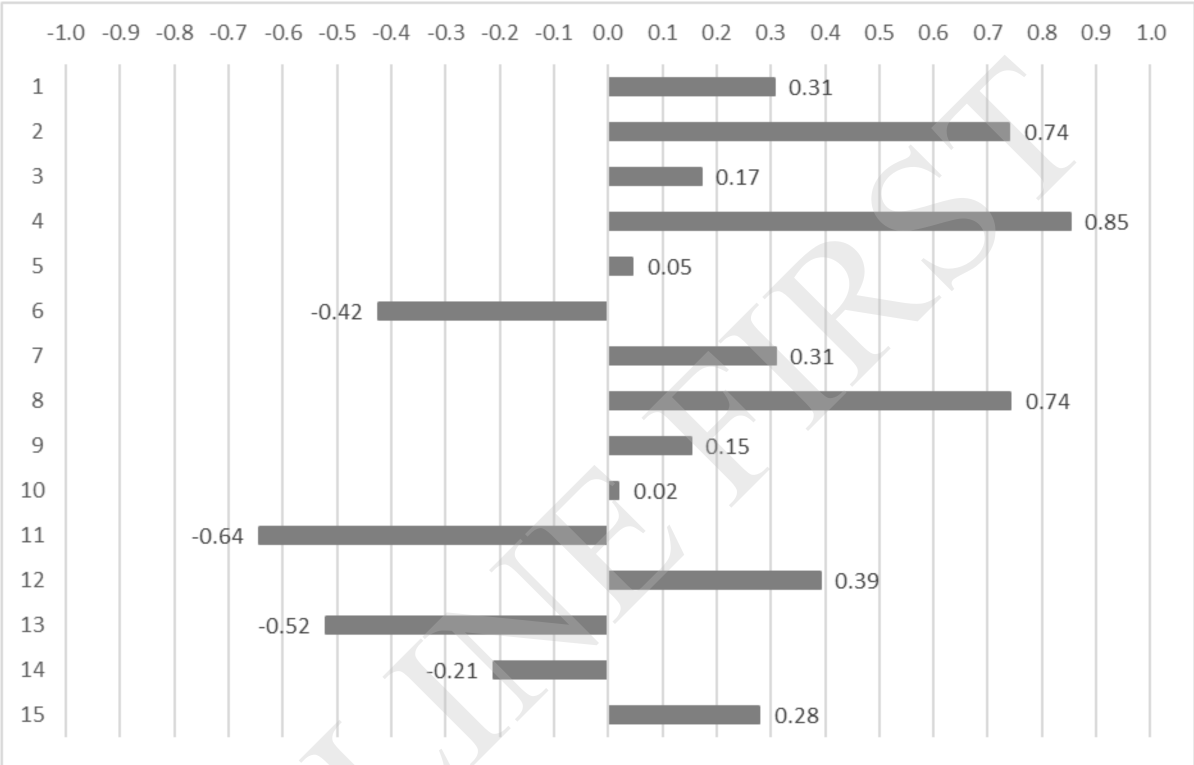

Figure 4. Correlation coefficients of DP and duration of stay in conditions of reduced atmospheric pressure

Discussion

Particularly pronounced changes were observed in HR indicators during the 14 days of the study. In the first 4-5 days, HR indices were higher than in the rest of the days in most participants. A characteristic feature of this period was the instability (fluctuations) of HR observed in all the athletes. Such HR dynamics during the stay in the medium mountains in combination with the training process indicates the active mobilization of adaptive mechanisms at the initial stage of exposure to the complex difficult conditions of the medium mountains in combination with the training process.

Starting from the 6th day, a significant portion of the participants observed a gradual decrease and stabilization of heart rate, which indicates a decrease in the role of the sympatho-adrenal system and the formation of adaptive changes that allow the cardiovascular system and the body as a whole to use oxygen more effectively. We believe that a decrease in HR at the second stage indicates effective acclimatization and characterizes the participant as highly adaptive. Since sport walking is characterized by long and monotonous loads, an increased resistance to hypoxia will potentially positively affect sports results. Improvement of the system of oxidation-reduction regulation processes and more efficient use of oxygen as a result of this enabling the body adapt to reduced atmospheric pressure are equally effective during prolonged muscular work.

It should be noted that some participants' stabilization and reduction of HR did not occur on days 6-14, and in some participants, it even increased (subjects no. 5, 7, 14, 15). In our opinion, this portion of athletes adapts more slowly, and the immediate sympatho-adrenal reaction is longer and therefore more energy-consuming. Thus, they need constant monitoring of the state of the cardiovascular system and gradual, stepwise loads with sufficient recovery periods. It is worth noting that during the period of active acclimatization (the first 4-5 days), training loads with low intensity (focus more on practicing the technique) should be performed by all participants, regardless of whether they are highly adaptive or not. This is supported by data [12], which recommend the use of strategies such as gradual ascent, maintaining stable breathing rhythms, and incorporating recovery training before and after ascent to high altitude, which can help mitigate autonomic disturbances and promote early acclimatization.

Throughout the entire study period, SP was quite stable in most subjects. Only one athlete, and only on the first day, showed an increase in SP in combination with a relatively high DP and HR compared to other study participants. Overall, the median remained stable and the maximum and minimum indices deviated slightly. The results of the correlation analysis indicated a significant increase in SP only in three subjects, while two of them had a simultaneous significant decrease in HR, which probably indicates the prevalence of vascular reactions in their adaptation process. Studies [13] show that the adaptation of the body to conditions of reduced atmospheric pressure is characterized by an increase not only in HR but also in blood pressure, which is associated with an increase in cardiac output. Activation of the sympathetic nervous system and the renin-angiotensin system leads to increased vasoconstriction and an increase in blood pressure [13]. We did not find confirmation of this conclusion, which is probably due to the overall high level of adaptation of the participants in our study, since they are highly qualified athletes.

Similar dynamics were observed in DP indices, the median of which remained constant throughout the study period. The minimum and first quartile indices of DP deviated within 10 mm Hg. Larger deviations of the DP maximum indices were observed on days 1, 6, 10, and 11.

The drop in the partial pressure of oxygen in the inhaled air creates a state of hypobaric hypoxia [14]. Accordingly, less oxygen reaches the working muscles, which in turn leads to a drop in saturation. Under conditions of hypoxia, vascular growth factor is activated, which promotes the development of the capillary network and, as a result, improves the blood supply to the muscles, not only in conditions of being at high altitudes but also during training/competition under normal conditions [1]. Such structural and functional changes do not occur quickly but require some time, unlike functional changes that occur immediately and work on already existing support mechanisms. Since professional athletes are relatively resistant to desaturation, their acclimatization to moderate altitudes occurs without significant shifts in physiological indicators.

Since the study was limited to 14 days, and some participants did not achieve satisfactory adaptation during this period of time, we consider it advisable to conduct similar studies over a longer period of time.

Conclusions

1. The assumption of a high level of plasticity of athletes' adaptation processes in medium-mountain conditions was confirmed.
2. A relatively high reactivity of HR values at the beginning of acclimatization was revealed. A 4-5-day period was determined as the period of mobilization of adaptation processes, which requires a decrease in training loads during this period.
3. Different reactions of athletes of a high level of qualification to medium-mountain conditions were revealed. Individuals of a highly adaptive type can start more intensive training from the 5-6th day of stay; low-adaptive athletes require more time for acclimatization, more moderate loads, and longer periods for recovery.
4. In general, we consider it advisable for athletes to stay longer (more than 14 days) in mid-mountain conditions.

Disclosures and acknowledgements

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The study was conducted in humans. The participants were fully informed about the purpose and protocol of the study and provided informed consent. The study was conducted anonymously, and participants' identities were not disclosed in accordance with the Declaration of Helsinki. The study was approved by the Bioethics Committee of Lesya Ukrainka Volyn National University (Protocol No. 1 of January 10, 2025).

Artificial intelligence was not used in the creation of the manuscript.

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