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ATHLETIC PERFORMANCE OF SWIMMERS AFTER ALTITUDE TRAINING (2,300 M ABOVE SEA LEVEL) IN VIEW OF THEIR BLOOD MORPHOLOGY CHANGES

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ABSTRACT: The aim of the study was to estimate changes in blood morphology caused by participation of record-seeking swimmers in a high altitude training camp at 2,300 m above sea level and to assess their performance during major competitions before and after the camp. Eight swimmers (two females and six males) - record-holders and medallists of the Polish National Championships, as well as finalists and medallists of the European and World Championships and the Olympic Games (including a two-time holder of the world record) - were recruited. During the 2006/2007 season the athletes attended a training camp organized according to the principle "live high and train high". The camp lasted 23 days and consisted of three micro-cycles of training, each of them with specific training objectives. Before and after participation in the training camp erythrocyte (red blood cells; RBC) count, haemoglobin (Hb) concentration and haematocrit (Hct) were estimated at a hospital laboratory. Scores amassed by the examined athletes during major competitions were presented after their transformation into points based on the FINA (International Swimming Federation) tables for years 2005-2008. The best results (time for a distance) achieved during competitions organized before and after participation in the camp were regarded as reference points. Additionally, liquid balance of the body was monitored during 30 selected training units (15 in the morning and 15 in the evening). The response of the examined swimmers from the Polish Olympic Team to the high altitude training (at 2,300 m above sea level) was represented by an almost three-fold increase in blood reticulocyte count during the first micro-cycle of training as well as by an elevated erythrocyte count (by 14.4%), and haemoglobin (by 13.5%) and haematocrit (by 14.8%) levels estimated after completion of the training, as compared to the results obtained before the camp. Six out of eight subjects improved their performance in major competitions organized after the training camp, and four of them broke their personal bests.

KEY WORDS: swimming, high altitude training, blood morphology, sport results

INTRODUCTION

The requirements of contemporary competitive sport compel athletes to ever more frequently participate in contests and to train in various climatic conditions. Indeed, it is a serious challenge for an athlete to compete at events organized in different parts of the world: they must acclimatize not only to changing time zones but also to considerable training and competition efforts exerted in difficult external conditions. A widely recognized method of elevating the level of adaptation of an organism to increased workloads is altitude training [6].

Currently, altitude training is known to effectively up-regulate the efficiency of basic functional systems of the organism, thereby enhancing the level of preparation of the athletes for competitions. However, many aspects of the impact of such training on changes in physical fitness are still poorly recognized and uncertain. One reason for this is obstacles (stemming, e.g., from difficulties in selection of large enough groups of examined and control subjects) in conducting the relevant studies in such specific conditions.

Investigations into the effectiveness of training at high altitude became very popular after the 1968 Olympic Games in Mexico City located at about 2,300 m above sea level. The results obtained at that time aroused interest in training in hypoxic conditions and stimulated further studies. Today we know that effects of high altitude training in endurance sports such as swimming translate into performance during competitions conducted at lower altitudes. This is due to physiological changes caused by altitude training. It has been established that this type of training stimulates production of erythrocytes (which are responsible for oxygen transport) triggered by the elevated erythropoietin level, increases haematocrit and circulating blood volume (so that larger amounts of oxygen can reach the tissues), and up-regulates maximal oxygen uptake and function of the lungs (resulting in faster gas exchange). Altitude training also contributes to elevation of the density of capillary vessels and triggers the activity of oxidative enzymes in the muscles [4,8].

High altitude training has become an important element of preparation of the top-class swimmers for major competitions. It is performed during training camps appropriately planned with respect to place (where and at what altitude), duration, frequency of exercising, and training content (the magnitude and structure of the training loads).

As highlighted by numerous authors [4, 5, 14, 16, 17], altitude training should last three to four weeks. The effect of such training shows already during the first twenty-four hours on return to sea level and usually remains unchanged for two to three weeks (depending on the individual response of an athlete).

Bułatowa and Płatonow [6] reported that after three-week phases of altitude training (as applied to athletes studied by these authors) the appearance and stabilization of adaptive responses were usually detected between the 30th and 36th days after return to lowlands.

These data suggest that the timing of the high altitude training should be closely coordinated with the upcoming contests so that the time of the competition coincides with the enhanced physical fitness of the athlete. After the return to lower altitude, training loads may be applied to maintain the adaptation of the organism (in terms of the energetic mechanisms) at the elevated level. Stabilization of the level of adaptation can be achieved by, among other things, induction of artificial hypoxia during the training, e.g., by swimming with held breath or with a breathing pipe [15].

In most athletes, prolongation of the adaptation of the organism in lowlands as well as shortening of the acclimatization time to the high altitude conditions can be attained through participation in further training camps. Thus, altitude training should take place as often as possible during the training season, since it contributes, among other things, to better adaptation of the organism to different external conditions [8].

In addition to the above, specific training principles should be selected. Depending on the altitude of the camp and the type of training the following three principles usually apply: "live high and train low," "live low and train high," and "live high and train high" [1]. The first principle is most frequently used by athletes from various endurance sports because it allows them to perform the training at the intensity attained at sea level. It also contributes to significant elevations of the circulating blood volume, mean erythrocyte volume, and haemoglobin mass (without increasing its concentration) [1, 9, 16, 17].

In athletes "living low and training high" (the second principle) increases in the number of mitochondria and the amount of myoglobin (which stores oxygen for use in cellular respiration) in the muscle cells were detected [3].

Training performed according to the third principle ("live high and train high") resulted in increased erythrocyte mass, reticulocyte count and haemoglobin concentration [3]. Swimmers from the Olympic Team examined in the present investigation trained according to this principle.

Currently, high altitude training is thought to be most effective when it is performed at the altitude of 2,000-2,300 m [8].

Platonow [11] emphasizes that selection of the optimal altitude for high altitude training should be based on the specifics of a particular sport. As an example, Platonow cites long-distance runners, whose performance depends on the power, the volume of the lungs, the economics of the work and the resistance of the energetic aerobic metabolism. Hence, these athletes can train at much higher altitudes compared to swimmers or rowers, whose results, according to that author, depend considerably on their speed and strength. Based on the results of the studies and according to his own experience, Platonow indicates that the altitude of 1,600-2,200 metres is most appropriate for the training of swimmers [6].

In addition to issues associated with rationally designed training, the importance of biological renewal and nutrition tailored to the effort made should be emphasized. Such measures are intended to restore, by a planned action, the total endurance capacity of an athlete.

Barszowski [2] reports that the readiness to withstand consecutive training loads is primarily limited by work-induced fatigue as well as by factors that restrict exertion of a successive effort. Protraction of an impaired effort capacity may disturb fulfilment of the planned subsequent tasks. Thus, supporting activities, such as removal of the redundant metabolites and restoration of the functional capacities of particular systems of the organism or parts thereof (e.g., by stimulation of regeneration of the muscles), are very important.

In addition to the proper physiotherapy (applied as part of the biological renewal process), an important role is played by appropriate diet. Łapucha [10], a dietician for the National Team of the Polish Swimming Federation, points to the fact that a well-designed diet provides an athlete with nutrients that help to postpone the appearance of fatigue. Such a diet also accelerates regeneration of the organism after strenuous exertion, stimulates the immune system, and prompts changes in the body mass and composition.

It is important that both before and during the high altitude training camp a well-designed diet be supplemented with iron (Fe), which should be added to the diet rather than used as an alternative. Indeed, increased iron consumption before moving to the higher altitude as well as while attending the camp may improve the effect of altitude training by stimulating the haematopoietic response [7].

Iron deficiency leads, among other things, to premature acidosis.

Because excretion of Fe with sweat is increased during intense effort, concentration of this element in the organism should be balanced by appropriate pharmaceutical supplementation [13].

An important, or even essential, role in swimming, irrespective of the distance, is played by the athlete's endurance, relying on his or her physical capacity. In races longer than 100 metres, it is aerobic metabolism that predominates in providing the muscles with energy needed for contractions. Hence, to improve physical fitness of the organism it is necessary to start the training early enough before a major competition so that the mean erythrocyte volume and haemoglobin mass (both responsible for oxygen transport) as well as the number of mitochondria and the amount of myoglobin in the muscles are elevated in a timely fashion.

The aim of the present study was to determine the effects of participation in a high altitude training camp at 2300 m above sea level on changes in blood morphology (reticulocytes, erythrocytes, haemoglobin, haematocrit) and performance of swimmers during major competitions organized before and after the camp.

In order to carry out such an analysis of changes in blood morphology, a blood count was performed and answers to the following questions were sought:

1. What morphological changes are evoked in the examined swimmers by the high altitude training?
2. Do the swimmers perform better in major contests after completion of the training than before attending the camp?
3. Is high altitude training (at 2,300 m above sea level) appropriate for swimmers from the Olympic Team who have had no previous experience in such training?

MATERIALS AND METHODS

After obtaining the appropriate approval from the Senate Research Ethics Committee of the Józef Piłsudski University School of Physical Education in Warsaw, eight swimmers (two females and six males) were recruited to participate in the study. The athletes, who were record holders and medallists of the Polish National Championships, finalists and medallists of the European and World Championships and the Olympic Games (including a two-time holder of the world record), were members of the Olympic Team of the Polish Swimming Federation. The swimmers attended the high altitude training camp in Sierra Nevada in Spain set at about 2,300 m above sea level. Mean age, height, body mass, and training experience of the examined subjects equalled 21.3±1.7 years, 185.5±3.3 cm, 79.8±4.3 kg, and 12±2.7 years, respectively. The athletes lived and trained at the same altitude according to the principle "live high and train high".

The training camp lasted 23 days and consisted of three micro-cycles. The first micro-cycle (8-15 July) consisted of 12 training units. Intensity of the workload in this micro-cycle was low and its main goal was to acclimatize the athletes to new outdoor conditions. The aim of the second ('hit') micro-cycle (16-22 July), which also consisted of 12 training units, was to induce the adaptive response as a result of increasing training loads. For this purpose, an elevated volume of anaerobic exercises was planned. The impeded gas exchange resulting from the low partial oxygen pressure in the air (training at the altitude of 2,300 metres) constituted an additional stimulus. The aim of the third (lead-in?) micro-cycle (23-30 July) consisting of 14 training units was to finally prepare the swimmers for competition. This cycle was characterised by a decreased workload without lowering of the intensity of training so as to make the athletes ready for the upcoming contests (2-5 August – French Open Championships, and 21-24 August – Grand Prix of Japan).

Before and after participation in the training camp estimations of the erythrocyte (red blood cells; RBC), haemoglobin (Hb) and haematocrit (Hct) levels were performed.

TABLE 1. CHANGES IN BLOOD MORPHOLOGY INDICES AFTER THE ALTITUDE TRAINING RELATIVE TO THE RESULTS OBTAINED BEFORE THE CAMP

	Before training	After training	Average increase (%)
Erythrocytes [mill./mm^3]	4.69 ± 0.4	5.37 ^{a} ± 0.3	14.4
Haemoglobin [g/dl]	14.8 ± 0.9	16.8 ^{a} ± 0.9	13.5
Haematocrit [%]	42.8 ± 2.2	49.1 ^{a} ± 2.5	14.8

Scores amassed by the examined swimmers in major contests were transformed into points according to the FINA (International Swimming Federation) tables set for the years 2005-2008. The best scores (the shortest time for a distance) achieved during the competitions organized before and after the training camp were regarded as the reference points.

During 30 selected training sessions (15 in the morning and 15 in the evening) liquid balance (i.e., the amounts of liquids consumed vs. excreted by a swimmer) was also monitored to determine the level of dehydration in a subject. To this end, the following parameters were registered in the examined swimmers during the training period: body mass before and after the training, and the amounts of consumed isotonic drinks and excreted urine. Two weeks before leaving for the camp as well as during the training subjects 1 and 2 took once daily (before breakfast) a tablet of Tardyferon containing 80 mg of Fe.

RESULTS

During altitude training the number of immature erythrocytes (reticulocytes) in the blood reflects the rate of the haematopoietic response to the training. In the examined swimmers the largest mean fraction of circulating reticulocytes equal to 23.6‰ was detected after the first week of the training camp, i.e., after the first micro-cycle (Fig. 1). In the consecutive weeks of the training this fraction decreased (owing to maturation and differentiation of reticulocytes to erythrocytes), but still exceeded the values recorded before the training camp. After the first, second, and third micro-cycles the reticulocyte counts increased by 295.3%, 67.2%, and 43.8%, respectively.

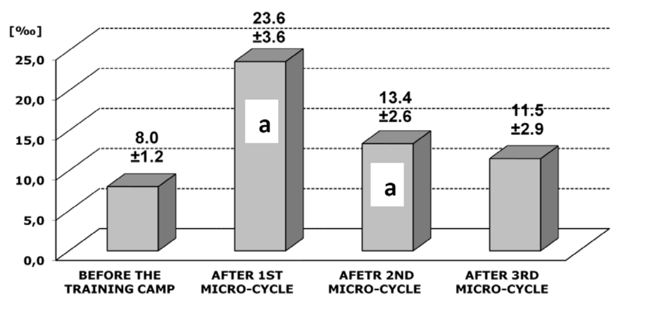

FIG. 1. CHANGES IN MEAN RETICULOCYTE FRACTIONS IN THE EXAMINED SWIMMERS AFTER CONSECUTIVE MICRO-CYCLES OF HIGH ALTITUDE TRAINING

Note: a – indicates statistically significant difference between mean value obtained after the 1st, 2nd, or 3rd micro-cycle and before the training; $p<0.05$

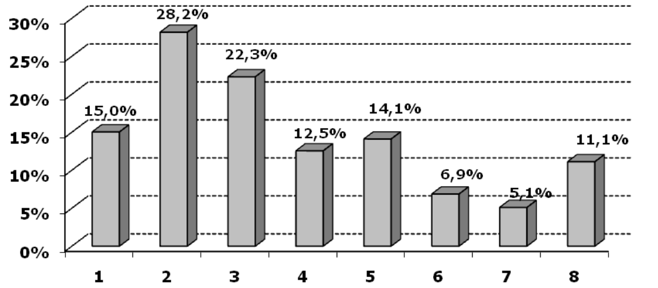

FIG. 2. INCREASES (IN PERCENTAGES) IN ERYTHROCYTE COUNTS IN THE EXAMINED SWIMMERS AFTER THE HIGH ALTITUDE TRAINING RELATIVE TO THE VALUES OBTAINED BEFORE THE TRAINING

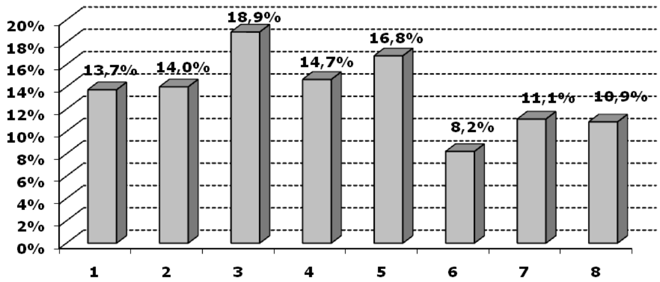

FIG. 3. INCREASES (IN PERCENTAGES) IN HAEMOGLOBIN LEVELS IN THE EXAMINED SWIMMERS AFTER THE HIGH ALTITUDE TRAINING CAMP RELATIVE TO THE VALUES DETECTED BEFORE THE CAMP

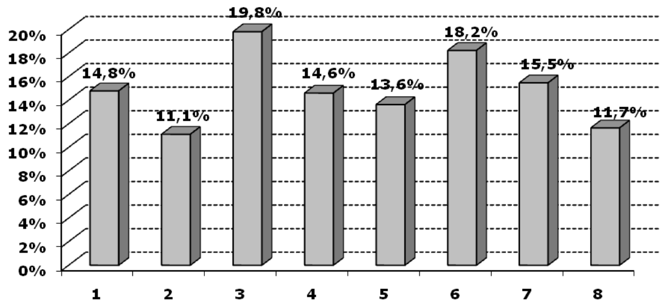

FIG. 4. INCREASES (IN PERCENTAGES) IN HAEMATOCRIT VALUES IN THE EXAMINED SWIMMERS AFTER THE HIGH ALTITUDE TRAINING CAMP RELATIVE TO THE VALUES OBTAINED BEFORE THE CAMP

Mean fractions of reticulocytes detected after the first and the second micro-cycle of training were significantly increased as compared to those found before the camp (Fig. 1).

Before attending the training camp in Sierra Nevada (at the altitude of 2,300 m), mean erythrocyte (RBC, responsible for the transport of oxygen and carbon dioxide) count was 4.69±0.4 mill./mm^3. After completion of the camp this count was increased by about 14.4% in all the examined swimmers (Table 1).

As indicated in figure 2, the highest (28.2%) and lowest (5.1%) increases in RBC counts after the altitude training were detected in swimmers 2 and 7, respectively.

Estimations of the level of haemoglobin (the iron-containing protein in erythrocytes that carries oxygen from the lungs to the tissues) demonstrated that the high altitude training enhanced production of this protein (Fig. 3); mean increase in the haemoglobin level was 13.5% (individual changes are shown in figure 3).

Haematocrit, defined as the percentage of total blood volume that consists of erythrocytes, was in all the examined athletes higher by 11.1% to 19.8% after completion of the high altitude training than before the training (Fig. 4).

Mean haematocrit values before and after the training camp were 42.8% and 49.1%, respectively (mean increase by about 14.8%).

During the training camp liquid balance was monitored over 30 selected training units (15 in the morning and 15 in the evening). The subjects demonstrated a negative liquid balance in, on average, 19.1±9.3 cases, and a positive liquid balance in, on average, 10.9±9.3 cases out of all the monitored units. When individual results of the measurements were analysed (Fig. 5), six swimmers demonstrated a negative liquid balance during most of the monitored training sessions. For example, in swimmer 1 the negative balance ranged from -0.1 to -1.2 L. In swimmer 3 a negative liquid balance was detected in 52% of the monitored training sessions; in view of the fact that these were sprint training sessions, such findings were especially unsatisfactory since they could adversely affect the quality of performance.

A positive liquid balance was registered in only two swimmers (subjects 2 [86.7%] and 4 [73.3%]). These athletes drank about 1.5 L of liquids during the training sessions, which appeared to be the optimal liquid intake for them.

Scores amassed by the athletes in major competitions organized before and after the altitude training are shown in figure 6. The subjects had an interim after the National Championships followed by a preparatory period during which they attended the training camp in Sierra Nevada getting ready for the Grand Prix of Japan. The scores achieved before the camp and calculated according to the FINA table equalled, on average, 930.6±42.5 pts. During competitions organized after completion of the training camp (the French Championships and Grand Prix of Japan) six swimmers improved their performance compared to that exhibited during competitions before the training camp, and four of them even broke their personal bests. Mean score presented in the FINA classification was 966.8 pts. (mean increase by about 3.1%).

As for individual results, swimmer 1, for example, achieved her best score of 1017 pts. in the 400-m freestyle race during the World Championships in Melbourne organized before the training camp, while after the camp she amassed the same number of points in the 200-m butterfly race completed in 2:05.92 (the third best result in the history of swimming).

Another example is the result of subject 2, who achieved the highest score (978 pts.) during the World Championships in Melbourne (before the training camp) in the 200-m butterfly race completed in 1:55.87. During the Grand Prix of Japan (organized 23 days after the camp) this swimmer amassed 1005 pts. in the same race, improving on his personal best by about 2.8%.

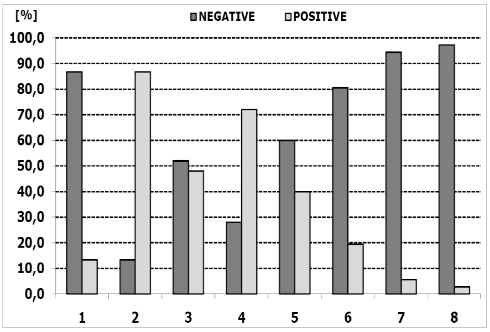

FIG. 5. LIQUID BALANCE IN 30 TRAINING UNITS PERFORMED BY THE EXAMINED SWIMMERS DURING THE HIGH ALTITUDE TRAINING CAMP

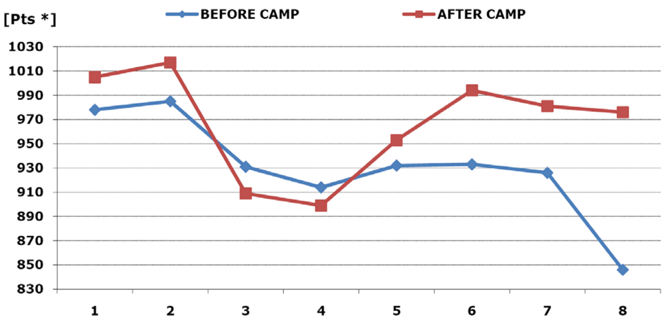

FIG. 6. SCORES AMASSED BY THE EXAMINED SWIMMERS DURING MAJOR COMPETITIONS BEFORE AND AFTER THE HIGH ALTITUDE TRAINING CAMP
Note: * Calculated according to the FINA Table for years 2005-2008

DISCUSSION

Altitude training has become a crucial element in the preparation of elite Polish swimmers for major competitions. The impact of the high altitude environment on athletes depends on numerous factors, of which the most desirable and encouraging to do the training at altitude is a lowered partial oxygen pressure in the air. This, along with other factors, such as changes in ambient temperature and humidity or increased ionization of the air, poses a real challenge for the athletes.

Notably, five out of the eight examined subjects attended the high altitude training camp for the first time. Evaluation of the effects of altitude training on the best Polish swimmers was a new experience. Introducing a new kind of training during the preparatory period directly preceding the competitive season, the coach of the Olympic Team was aware of the beneficial effects of high altitude training on the aerobic capacity of swimmers, but he could not be sure whether such an 'experiment' would result in better performance of the athletes during major competitions organized after the camp.

The training in Sierra Nevada met the expectations in that six subjects improved their scores by, on average, 4% during major competitions following the camp, as compared to the scores achieved before the camp (during the World Championships and the National Championships). After transformation of the scores into FINA points, these subjects amassed, on average, 966.8±43.3 pts.

In terms of individual results, the largest increase in scores achieved after completion of the training camp was observed in swimmer 6, who covered the distance of 1500 m in 14:50.72 (994 pts.), improving his result from the period preceding the training camp by about 6.5%.

During altitude training the stimulated function of the bone marrow increases the number of circulating reticulocytes, which drops again after adaptation of the organism to the new conditions [6]. This phenomenon has been confirmed in swimmers investigated in the present study, in whom an approximately three-fold rise in the reticulocyte count was detected in the first week of the camp compared to the number counted before the high altitude training. Also, significant differences ($p<0.05$) were registered between the counts recorded before the camp and those estimated after the second and third micro-cycles of the training.

In determining the effects of altitude training, a period of time long enough to allow for the development of a steady adaptation level should be taken into account. Wilmore and Costill [18] report that elevations of the erythrocyte count and haemoglobin concentration in the blood occur within the first hours spent at altitude.

After completion of the training camp the erythrocyte volume and haemoglobin concentration increased by about 14.4% and 13.5%, respectively. The up-regulated production of red blood cells (5.37±0.3) resulted in the elevation of the haematocrit value in the examined subjects by about 14.8%.

During exercising in a very warm and humid environment (i.e., in conditions characteristic for a swimming pool) the organism intensely eliminates excess heat through perspiration (the most effective way of losing heat). It is assumed that about 80% of the heat generated in the athlete's organism is perspired. During training an athlete may lose even more than two litres of water per hour, which impairs the water balance of the organism and consequently leads to dehydration [13]. In order to keep this balance in check a steady water volume and electrolyte content (especially of sodium chloride and potassium chloride) of the organism must be preserved [19]. Wojcieszak and Golec [19] emphasize that a negative liquid balance may have detrimental effects on physical fitness, fatigability, and the capacity to concentrate. During most of the training sessions (in 19.1±9.3 out of the 30 monitored training units) the examined subjects presented a negative liquid balance which could affect their comfort and disposition, fatigue level, and quality of the training performance.

No significant differences were detected in the present study between female ($n=2$) and male ($n=6$) swimmers with respect to the examined blood morphology parameters, this observation confirming the earlier findings of Pyne et al. [12], who were not able to demonstrate any gender differences in responses to altitude training.

CONCLUSIONS

Based on the obtained results the following conclusions can be drawn:

1. The examined swimmers measurably responded to the applied altitude training (2,300 m above sea level), as evidenced by

the almost three-fold increase in blood reticulocytes after the first micro-cycle of the training as well as by the substantially elevated erythrocyte count (by 14.4%), and haemoglobin (by 13.5%) and haematocrit (by 14.8%) levels compared to the results obtained before the camp.

2. Six out of the eight examined swimmers from the Olympic Team improved their performance during major competitions organized after the altitude camp, and four of them broke their personal bests. Mean level of the amassed scores expressed in FINA points was 966.8 pts (average increase by 3.1%).
3. In view of the significantly improved blood morphology parameters and performance during major competitions organized after the high altitude training camp, altitude training of the examined swimmers from the Olympic Team seems to be well grounded.
4. The obtained results support the concept of training involving participation of athletes in high altitude (2,300 m above sea level) training camps.

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