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RESEARCH

Research on the Physiological Monitoring and Evaluation of Pre-Competition Altitude Training for Zhejiang Elite Swimmers

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Purpose: The aims of this study were to analyze the physical functions of swimmers and the effects of altitude training through the blood physiological and biochemical tests during the altitude training and comparing individual lactate threshold testing before and after the altitude training, respectively.
Methods: Eight elite swimmers took a 26-day altitude training session. The individual lactate threshold test was carried out by the Swedish Monak839E power cycle progressive loading method before and after the training. During the altitude training period, 5 ml of blood of the subjects' elbow vein was extracted and tested on an empty stomach and in a quiet state every Monday morning.
Results: There is no obvious difference in the hemoglobin between the plain and plateau when swimmers first reached. In the second week, the hemoglobin value showed a significant downward trend both in males and in females. The hemoglobin value in the third week has increased significantly and is higher than the level when swimmers first entered the plateau. During altitude training, the serum testosterone value of males and females showed different trends. Compared with the first week, the second and third weeks have a significant weekly upward trend. From the changes of creatine kinase in male swimmers, the highest value of creatine kinase was 731 U/L in the first week and fluctuated within the normal range in the following two weeks. The creatine kinase of female swimmers fluctuated within the normal range of three weeks. There is no obvious change in individual lactate threshold before and after altitude training for both male and female swimmers.
Conclusions: The altitude training has generally improved the swimmers' training ability, however, based on factors such as training years and gender, individualized training programs need to be targeted according to each swimmer's situation, to achieve better performance.

Keywords: Swimming; Altitude training; Physical function; Lactate threshold

Introduction

In recent years, the overall athletic performance of Chinese swimming events has been continuously increasing, especially in Zhejiang Province. A large number of outstanding swimmers such as Yang Sun, Shiwen Ye, Yuanhui Fu, Jiayu Xu, Shun Wang have achieved pride in domestic and international competitions.

The excellent swimming performance is inseparable from the accurate grasp of altitude training by senior coaches in the Zhejiang swim team over the years. Altitude training has been of great popularity to coaches and researchers working with swimmers (Robach et al. 2006, Robertson et al. 2010, Roels et al. 2006). In order to induce favorable physiological adaptation to improve subsequent training and competition performance, mid-season altitude training has become a common practice in sports training (Gough et al. 2012). Classical altitude training includes athletes living and training at medium altitude (2,000–3,000 meters), typically for 3–4 weeks. Friedman et al. (Friedmann et al. 2005, Friedmann 2008) reported that in the absence of other time points for comparison, swimming performance improved by 2% after 10 days of classic altitude training. Despite limited recorded evidence on performance improvements from altitude training in elite swimmers, several leading swimming nations use this method for competition. In

the erythropoietin pathway, the increased release of erythropoietin at high altitudes increases the blood's oxygen-carrying capacity and may enhance the maximum oxygen uptake (Levine and Stray-Gundersen 1997). Altitude training improves the aerobic metabolism and anti-hypoxic ability of swimmers, and at the same time can migrate to specific abilities, thereby improving swimming performance (Bailey and Davies 1997, Truijens et al. 2003).

Therefore, the main purposes of this study were to evaluate the rationality and scientificity of the coach-prescribed training method and the suitability of training load and training effect through the blood physiological and biochemical indicators during altitude training, individual lactic acid threshold tests before and after altitude training, etc. This is to provide the experimental basis for accumulating experience in altitude training and to provide reference materials for the successful altitude training of the Zhejiang swimming team before the competition.

Methods

Eight qualified elite athletes were preparing for the National Games in Tianjin. During the altitude training before the National Games, every Monday morning from 7:00 to 7:30, 5 ml of blood of the cubital vein of the subjects was extracted on an empty stomach and in a quiet state. The following indicators were used for the tests of blood routine, hemoglobin (Hb), testosterone (T), cortisol (C), creatine kinase (CK), blood urea (BUN), white blood cell (WBC), red blood cell (RBC).

Before and after altitude training, this study adopted the German Cortex MM3B sport's cardiopulmonary function tester and the matching Swedish MONAK839E power bicycle for testing. Individual lactic acid threshold test was conducted with a German EKF desktop lactic acid meter. After each level of load, blood was collected for 3, 6, 9, 12 minutes during exercise and immediately after exercise, and the lactic acid value in blood during exercise was measured. The blood samples were taken immediately after exercise in the recovery period of 1, 3, 5, 7, and 10 minutes to test the blood lactic acid value after exercise. The maximum value of blood lactic acid in each athlete was the peak value of lactic acid.

Results

Hemoglobin

There is no obvious difference in the hemoglobin between the plain and plateau when swimmers first reached (male: 156.2 ± 7.01, female:135.7 ± 8.75 g/L) (**Tables 1–2**, **Figure 1**). In the second week, the hemoglobin value showed a significant downward trend both in males and in females (male: 154.03 + 5.67, female: 134.23 + 9.66 g/L) ($p < 0.05$). The hemoglobin value in the third week has increased significantly (male: 157.17 + 3.7, female: 141.93 + 10.06 g/L), and is higher than the level when swimmers first entered the plateau.

Table 1: The main physiological and biochemical index test results During altitude training.

Index	Gender	Total	Min	Max	Ave	Sd
CK (U/L)	M	4	104	731	278.11	221.33
	F	4	69	371	183.22	107.84
Urea nitrogen (mmol/L)	M	4	5.17	7.24	6.47	0.83
	F	4	3.89	7.93	6.46	1.56
Testosterone (ng/dl)	M	4	311	615	474.33	97.06
	F	4	10	57	33.67	17.25
Cortisol (ug/dl)	M	4	12.3	22.3	18.47	3.14
	F	4	18.2	23.8	20.84	2.03
White blood cells ($*10^9$/L)	M	4	4.4	7.3	6.44	0.91
	F	4	4.6	7.9	6.4	1.06
Red blood cells ($*10^{12}/mm^3$)	M	4	5.01	5.42	5.25	0.19
	F	4	4.24	5.2	4.58	0.28
Hemoglobin (g/L)	M	4	144.3	159.4	153.89	5.2
	F	4	121.1	153.5	136.19	9.66

Table 2: The list of blood physiological and biochemical significance analysis of athletes during altitude training.

Index	First week	Second week	Third week
CK(U/L)	409.83 ± 205.17	167.83 ± 47.53*	114.33 ± 35.18**
UN(mmol/L)	7.35 ± 0.39	6.69 ± 1	5.37 ± 1.18
Testosterone(ng/dl) M	479.67 ± 76.25	492.33 ± 83.6*	451 ± 153.41
Testosterone(ng/dl) F	29.33 ± 21.83	32 ± 23.26*	39.67 ± 9.29**
Cortisol(ug/dl)	18.9 ± 1.95	19.37 ± 1.92*	20.7 ± 4.23**
RBC(*10^9/L)	7.13 ± 0.56	5.67 ± 1.13	6.52 ± 0.49
Hemoglobin(g/L)	145.95 ± 13.28	144.13 ± 13	149.55 ± 10.75**

Note: * $p < 0.05$, the significant differences while compared to the first week; ** $p < 0.01$, the more significant differences while compared to the first week.

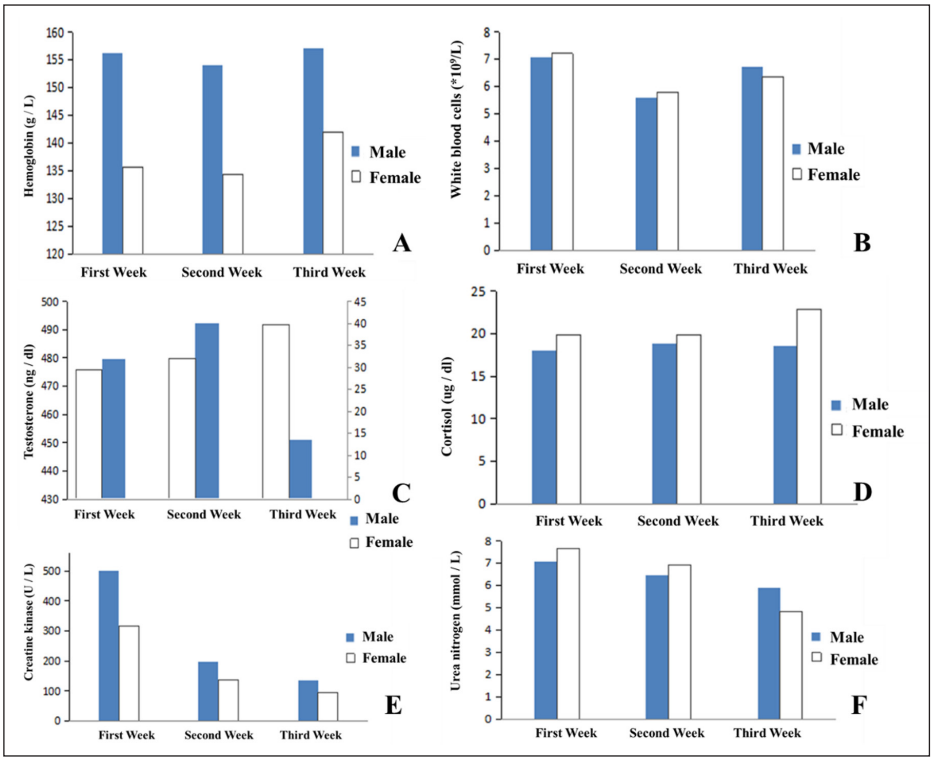

Figure 1: Changes of main functional indexes monitored systematically during altitude training.

Blood testosterone

During altitude training, the average blood testosterone was 474.33 ± 97.06 ng/dL in male swimmers and 33.67 ± 17.25 ng/dL in female swimmers (**Tables 1–2**, **Figure 1**). The serum testosterone value of males and females showed different trends. The value of males were 479.67 ± 76.25, 492.33 ± 83.61, and 451 ± 153.41 ng/dL from Monday morning of three weeks, respectively. The value of females were 29.33 ± 21.83, 32 ± 23.26, and 39.67 ± 9.29 ng/dL of three weeks, respectively. Compared with the first week, the second and third weeks have a significant weekly upward trend ($p < 0.05$, $p < 0.01$).

Creatine kinase

From the changes of creatine kinase in male swimmers, the highest value of creatine kinase was 731 U/L in the first week and fluctuated within the normal range in the following two weeks (**Tables 1–2**, **Figure 1**). The creatine kinase of female swimmers fluctuated within the normal range of three weeks.

There is no obvious change in individual lactate threshold before and after altitude training for both male and female swimmers (**Table 3**, **Figures 2–3**). Most of the blood lactic acid peaks appeared within 1–3 minutes of the recovery period, and the average value had increased from 8.96 ± 1.86 mmol/L to

Table 3: Comparison of individual lactic acid threshold curve of swimmers before and after altitude training.

Index	Category	Before	After
Individual lactic acid threshold	All	3.49 ± 0.45	4.04 ± 0.65
(mmol/L)	M	3.33 ± 0.28	4.04 ± 0.82
	F	3.65 ± 0.58	4.05 ± 0.56
Lactic acid peak	All	8.96 ± 1.86	9.99 ± 1.47
(mmol/L)	M	8 ± 2.22	10.91 ± 1.43
	F	9.92 ± 0.79	9.07 ± 0.88

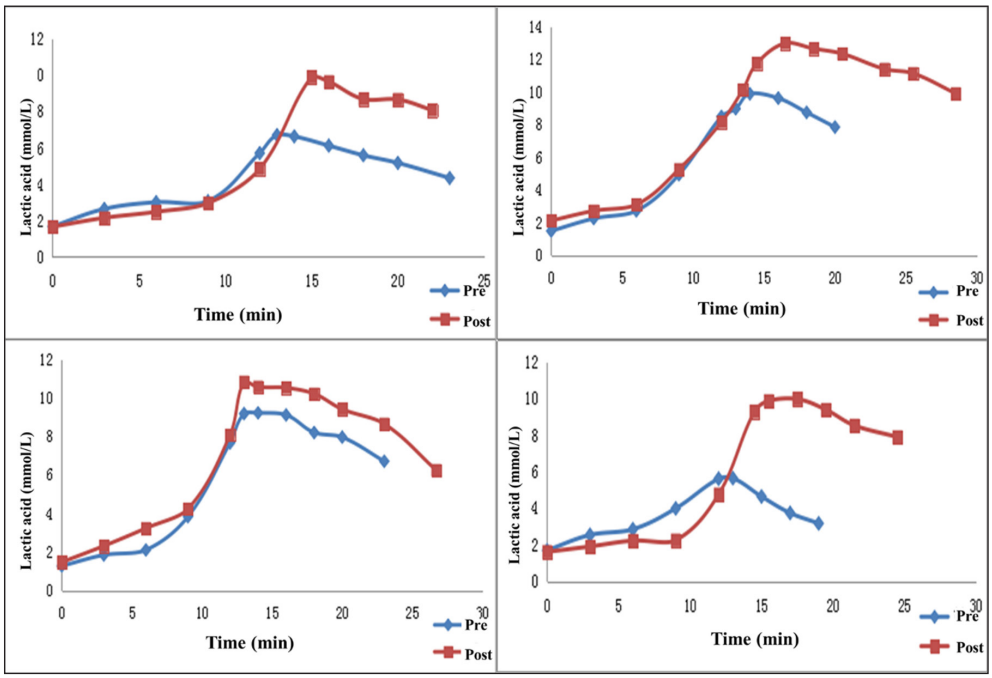

Figure 2: Changes of lactic acid in male swimmers before and after altitude training.

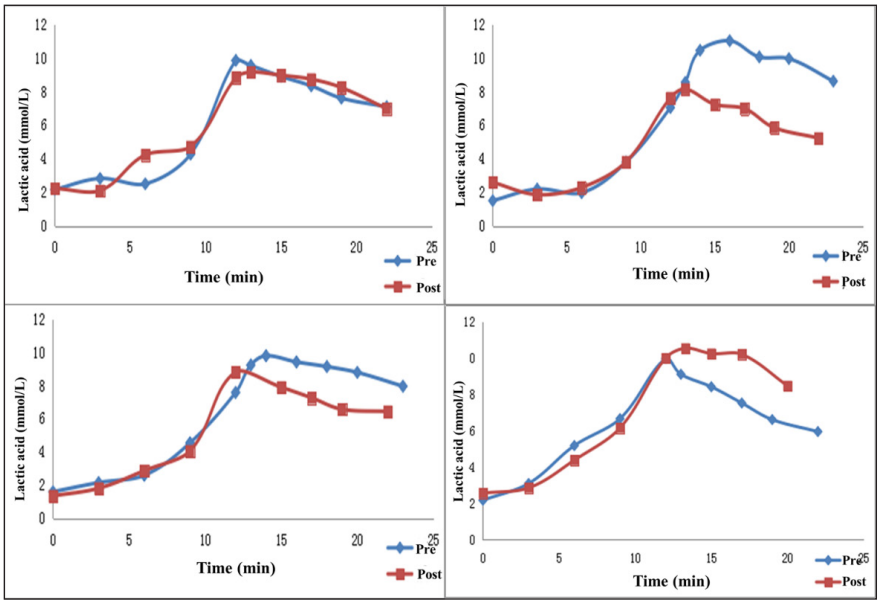

Figure 3: Changes of lactic acid in female swimmers before and after altitude training.

9.99 ± 1.47 mmol/L. The average value of blood lactic acid in male increased from 8 ± 2.22 mmol/L to 10.91 ± 1.43 mmol/L, while that in female decreased from 9.92 ± 0.79 mmol/L to 9.07 ± 0.88 mmol/L.

Discussion

Blood indexes during altitude training

The content of hemoglobin (Hgb) has a great influence on the athletic ability of athletes, especially for the special quality of endurance athletes. The measurement of Hgb is helpful to understand the nutritional status of athletes, their adaptation to load, and the level of body function. There are many reports on the changes of hemoglobin and red blood cells during altitude training in the world (Wachsmuth et al. 2013, Rodríguez et al, 2015). The Hgb of most athletes will increase after altitude training, but there are still a few declines or unchanged phenomena. The results of our study showed that most of the swimmers during altitude training, in addition to hypoxia stimulating red blood cell production response, the body also gradually adapted to the training load, and the hemoglobin value had increased, indicating that the research object was more suitable for altitude training. The fluctuation of hemoglobin and erythrocyte levels during altitude training is not only affected by the changes of erythrocyte production stimulated by plateau hypoxia but also affected by factors such as altitude dehydration, training volume, duration, training intensity, etc. (Feng & Zhang, 2007).

The change of serum creatine kinase concentration can be used as an important and sensitive biochemical index for evaluating muscles to withstand stimulation, understanding whether athletes adapt to training load, and evaluating recovery from fatigue and injury. Changes in serum creatine kinase concentration can be used as an important and sensitive biochemical indicator for evaluating muscles to withstand stimulation, understanding whether athletes adapt to training load, and evaluating recovery from fatigue and injury. Regular detection of serum creatine kinase concentration and the change of serum creatine kinase concentration can be used as a microcosmic basis for adjusting training load intensity throughout the training process, which can enable coaches to know the athletes' adaptation level to training load and their functional state, to ensure scientific training. The results of this study showed that the creatine kinase of male swimmers was significantly higher than the normal range of the first week, indicating sensitivity to altitude training. In general, the concentration of creatine kinase was mostly lower than 300U/L, and swimmers had no fatigue accumulation, which is related to sports events. Swimming is mainly done in water, or some running and strength training on land. Swimming is an event that is not directly confronted by the body. Therefore, the creatine kinase level of swimmers is much lower than that of some confrontation events (Lu et al., 2005).

During normal physiological activities, the production and excretion of urea are in a balanced state, so that the concentration of blood urea remains relatively stable. During long-term endurance exercise, the catabolism of amino acids is strengthened, and the production of ammonia increases. Most of the ammonia is converted to urea by liver cells. This area will gradually accumulate in the blood. The longer the exercise time, the more it accumulates. The results of this study showed that the blood urea value of swimmers fluctuated with the different volumes of weekly exercise. However, the weekly variation range was not large, all of which were within the normal range of the quiet value, indicating that the swimmers were more adaptable to the exercise load during this altitude training.

There are inconsistent reports on whether altitude training promotes or inhibits testosterone secretion in athletes. In general, the effect of altitude training on serum testosterone showed a downward trend. If an athlete's serum testosterone level below the lower end of the normal range, it can lead to decreased somatic function. In addition, when the athletes' serum cortisol level exceeds a certain range, it will inhibit the production of testosterone, reduce the body's immune ability, and make the athletes unable to adapt to the training load. The results of this study showed that the serum testosterone of males was lower than the average value of national team swimmers, which is related to the fact that the swimmers in this study were younger, had shorter training years, and had not yet fully developed.

In the third week, the blood testosterone of males showed the lowest value of this altitude training, while the blood testosterone of females showed a weekly upward trend. This also further indicates that this training program is more suitable for male swimmers with shorter training years. The body has a certain degree of fatigue accumulation, but the decline is within a reasonable range. However, for female athletes, the stimulation depth of training is not enough, and it is necessary to further tap the potential of female swimmers to improve the effect of altitude training.

Individual lactic acid threshold curve before and after altitude training

The individual lactate lactic threshold was measured by the method of blood lactate lactic dynamics adopted by Stegmann in 1981, which determines the individual lactic acid threshold according to the law of elimination of blood lactic acid during and after exercise with increasing load. In the process of exercise, the muscle intensity gradually increases, the ratio of glycolysis work increases, the generation rate of lactic acid exceeds the clearance rate and begins to accumulate rapidly. The inflection point formed into the dynamic curve of blood lactic acid is a linear deviation that rises sharply from a transition period with the increase in exercise intensity.

The results of this study showed that there is no obvious change for both male and female swimmers in the value of individual lactic acid threshold before and after altitude training. In this regard, it may be due to the altitude training only adopted the pattern of three and a half weeks, and the training time is slightly shorter. Secondly, as the professional swimmers, with the extension of training years, the 'plastic space' gradually decreases with the aerobic capacity. Therefore, swimmers should pay attention to the completion of each training content in aerobic training to ensure the quality and quantity of the completion of the coach's training purposes, fully stimulate the functional ability of themselves, and achieve the improvement of the personal lactate threshold (Li et al., 2003) (Dubouchaud et al. 2000).

Through the measurement of the peak value of blood lactic acid to show the body's anaerobic metabolism and the ability of lactic acid tolerance, to analyze the phased training effect of athletes. The results of this study showed that most of the peak blood lactate appeared within 1–3 minutes of the recovery period, and the average value increased from 8.96 ± 1.86 mmol/L to 9.99 ± 1.47 mmol/L. There was a significant difference in the peak blood lactate value of males before and after the altitude training, as the average blood lactate peak value of males increased from 8 ± 2.22 mmol/L to 10.91 ± 1.43 mmol/L. Meanwhile, the average peak value of females' blood lactic acid decreased from 9.92 ± 0.79 mmol/L to 9.07 ± 0.88 mmol/L, which was mainly caused by a certain swimmer. This inevitably requires us to analyze the training situation and physical functions of the swimmers in this player in this altitude training, to avoid similar situations in the future.

Conclusion

The altitude training has generally improved the swimmers' training ability, however, based on factors such as training years and gender, individualized training programs need to be targeted according to each swimmer's situation, to achieve better performance.

Competing Interests

The author has no competing interests to declare.

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