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BIOCHEMICAL CHANGES AND ENDOCRINE RESPONSES IN PRE-COMPETITION TRAINING IN ELITE SWIMMERS

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ABSTRACT: The aim of this study was to describe biochemical changes and endocrine responses to low-volume pre-competition swimming training for elite swimmers. Twelve sprint swimmers (6 males and 6 females) participated in 3-week pre-competition training. Measures of velocity anaerobic threshold (VAT), creatine kinase (CK), blood urea (BU), haemoglobin (Hb) and testosterone/cortisol ratio (TC) were obtained before and after the 1st, 2nd and 3rd week of training. The training load decreased from 27.3 to 13.7 km per week within 3 weeks. The VAT tested the load with an increased training protocol of 200 m×4 freestyle swimming and initial loads were 85, 90, 95, and 100 percent of the individual load. There were changes in the values of VAT, CK, BU, Hb and TC ratio during the training, and the changes corresponded to the changes of the training stimuli in time. There were also differences between the male and female swimmers. The most significant finding in this study was that such training stimulated the enginery of the swimmers and helped the swimmers recover enginery and indicated improved velocity in the competition with the following adjusting exercise after pre-competition training.

KEY WORDS: swimming, pre-competition training, VAT, CK, BU, Hb, TC

INTRODUCTION

The swimming competition is an aim of sport training for swimming athletes, and the achievements in the swimming competition reflect the skills, techniques and exercise capacity of swimmers. Many swimmers have had bitter experiences such as severe fatigue in the body and mind after several months of hard training, and an inappropriate training plan before a swimming competition often leads to failure in the competition. It is important for elite swimmers to have appropriate training before a swimming competition in order to fully release their potential and succeed in the competition. This study monitored the velocity anaerobic threshold (VAT), creatine kinase (CK), blood urea (BU), haemoglobin (Hb), and testosterone/cortisol ratio (TC) of a group of swimmers in the training before a competition and analysed the change of the exercise capacity in elite swimmers in order to provide scientific evidence for an appropriate training plan before a competition. The VAT value reflected a swimmer's performance's capacity change, while values of CK and BU reflected the degree of body stimulation from training loads and volume. Hb and the TC helped to analyse changes of swimmer's body function.

MATERIALS AND METHODS

Subjects. Twelve swimming athletes of the national team in P.R. China volunteered for this study (age: 18-24 years) including six males (height 181.45 ± 8.36 cm, weight 75.42 ± 8.03 kg) and six females (height 174.25 ± 6.83 cm, weight 67.40 ± 4.78 kg). These athletes were elite swimmers, and their major discipline was 100 m or 200 m.

Experimental procedures

Three-week pre-competition training started 5 weeks before the competition. The purpose of having high volume exercise before the pre-competition training is to improve aerobic metabolism of the athletes and help them adapt to the pre-competition training

TABLE 1. SUBJECTS' AGE AND PHYSICAL CHARACTERISTICS

Variables	Male	Female
Age [years]	21.22 ± 2.67	20.71 ± 3.46
Height [cm]	181.45 ± 8.36	174.25 ± 6.83
Body mass [kg]	75.42 ± 8.03	67.40 ± 4.78

after adjustment and recovery for two weeks. The pre-competition training was characterized by a flexible training approach to reduce the total training load. The weekly distance achieved by swimmers was 27.3 km in the first week, 19.6 km in the second week, and 13.7 km in the third week. These loads were obviously lower than previous ones, which were 25-30 km per week. The key to pre-competition training was to control the training intensity, which was determined by the training level and enginery status of the swimmers. The total training loads were kept lower than those used to maintain the initial training efficiency so that the total training loads were decreased and the overall training efficiency was maintained. Based on the exercise capacity and sports ability of the swimmers in the pre-competition training, the appropriate training volume and intensity were determined. The training intensity refers to the intensity corresponding to the training loads of the first two weeks during the pre-competition training. Its indicator is key speed, which is 80-90% of the athlete's personal best speed. The training intensity was carefully controlled and adjusted so that appropriate training loads could be obtained which tried to avoid the loss of sports ability due to under-training or reduced performance and exhaustion due to overtraining. It indicated that the enginery was hardly able to recover when a large decrease of VAT, Hb and TC, and increase of CK and BU, happened in the pre-competition training. The 3rd week of training was the buffer period designed for enginery recovery and was characterized by decreased training intensity and volume. There was an interval of 7-10 days between the end of pre-competition and the final match for place adoption training and the trial match. All this training was recorded and analysed with physiological and biochemical parameters.

Test index and instruments

Laboratory tests were conducted prior to and during the 1st, 2nd and 3rd week of the pre-competition training. A YSI-1500 lactate analyser (US) and corresponding reagents were used to determine the blood lactate level (Bla) at various training loads. The serum T (testosterone) and C (cortisol) levels were measured with the ACCESS (US) and admeasure reagents (DPC). The CK, BU and Hb parameters were obtained with the REFLOTRON analyser (Germany) and admeasure reagents. This study was approved by the ethical committee of the local Sports Authority.

Methodology

During the 3-week training, performance tests were conducted on the 2nd and 3rd Saturday afternoons during the 200×4 m freestyle swimming and there was an increase in training intensity (85%, 90%, 95%, 100% of the best performance of the swimmers). The swimming speed was kept steady and the time interval between each training session was 3 min. The training load and performance were recorded. 2 min after each training session, a 20 μl blood sample was taken from each swimmer to obtain the blood lactate level (Bla) and compute the swimming speed when Bla reached 4 mmol/L. The velocity anaerobic threshold (VAT) was then calculated. A 3 ml blood sample was taken from a vein each Sunday morning (7:15-7:45 am) when the swimmers had no training and were on an empty stomach. Creatine kinase (CK), blood urea (BU) and haemoglobin (Hb) were then obtained with 32 μl of blood from the blood sample. The rest of the blood sample was refrigerated for 2 hours and centrifuged to obtain serum T and C levels. The testosterone/cortisol ratio (TC) was calculated afterwards.

$$TC = \frac{T}{C} \quad (1)$$

where, T is the serum testosterone concentration, and C is the cortisol testosterone.

SPSS (11.0) was used to perform the statistical analysis for the data of this study. Paired t-test and ANOVA analysis were used to examine the biochemical changes before and after the pre-competition training. The level of significance was set at 0.05 (0.01 indicating very significant difference).

RESULTS

The impact of the pre-competition training on VAT

As seen in Table 2, the values of mean ± standard deviation of VAT are lower in the 2nd-3rd week of the pre-competitive training phase when compared to the value before the pre-competitive phase. The one-way ANOVA result of the VAT ratio reveals a significant decrease in the 2nd and 3rd week of the pre-competition training. Post-hoc multiple comparison of VAT finds a significant difference between before training and the 2nd and 3rd week of the pre-competitive training phase ($p<0.01$).

The impact of the pre-competition training on CK, BU and Hb

After the 1st and 2nd week of the pre-competition training, the CK level was increased very significantly ($p<0.01$) for both male and female swimmers, as indicated by Tables 3 and 4. After the 3rd week of training, the CK level dropped for male and female swimmers, and was even lower than that before training ($p<0.05$). For the BU level, there was a significant increase ($p<0.01$) in the male swimmers after the 2nd-3rd week of training and a significant

TABLE 2. SWIMMING VELOCITY AT ANAEROBIC THRESHOLD IN PRE-COMPETITION TRAINING IN EXAMINED MALE AND FEMALE SWIMMERS

Subjects	before training phase (I)	14-day after phase (II)	21-day after phase (III)	One way ANOVA F Ratio	One way ANOVA Sig	Post hoc Test (Scheffe) Phases	Post hoc Test (Scheffe) Sig
Male swimmers [$m \cdot s^{-1}$]	1.636±0.022	1.590±0.016	1.606±0.021	7.47	$p<0.01$	I vs II & I vs III	$p<0.01$
Female swimmers [$m \cdot s^{-1}$]	1.533±0.024	1.493±0.022	1.504±0.017	6.45	$p<0.01$	I vs II & I vs III	$p<0.01$

Note: values are mean ± SD

TABLE 3. BIOCHEMICAL AND ENDOCRINOLOGICAL INDICES IN PRE-COMPETITION TRAINING IN EXAMINED MALE SWIMMERS (N=6)

Test time	CK [$U \cdot L^{-1}$]	BU [$mmol \cdot L^{-1}$]	Hb [$g \cdot L^{-1}$]	T [$ng \cdot dl^{-1}$]	C [$\mu g \cdot dl^{-1}$]	TC
Before training	119.2 ± 53.4	3.33 ± 0.49	157.2 ± 9.3	535.7 ± 104.3	18.23 ± 4.21	29.39 ± 8.71
Day 7	271.4 ± 101.6**	3.51 ± 0.37	153.5 ± 10.3	568.2 ± 85.6	21.46 ± 9.29*	26.54 ± 9.26
Day 14	313.7 ± 138.6**	5.75 ± 0.29**	155.4 ± 7.3	445.3 ± 95.5**	23.71 ± 3.58**	18.77 ± 7.71**
Day 21	102.5 ± 91.7*	4.71 ± 0.27**	155.0 ± 9.3	541.8 ± 107.7	19.60 ± 2.67	27.60 ± 8.18

Note: * - $p<0.05$, ** - $p<0.01$ compared with value before training; CK - creatine kinase, BU - blood urine, Hb - hemoglobin concentration, T - testosterone concentration, C - cortisol testosterone, TC - testosterone/cortisol ratio

TABLE 4. BIOCHEMICAL AND ENDOCRINOLOGICAL INDICES IN PRE-COMPETITION TRAINING IN EXAMINED FEMALE SWIMMERS (N=6)

Test time	CK [$U \cdot L^{-1}$]	BU [$mmol \cdot L^{-1}$]	Hb [$g \cdot L^{-1}$]	T [$ng \cdot dl^{-1}$]	C [$\mu g \cdot dl^{-1}$]	TC
Before training	89.7 ± 26.6	3.33 ± 0.34	141.1 ± 11.2	71.43 ± 8.69	20.54 ± 4.41	3.48 ± 0.47
Day 7	241.0 ± 104.4**	3.61 ± 0.28	144.4 ± 9.7	68.51 ± 8.70	23.44 ± 3.59*	2.93 ± 0.21*
Day 14	203.1 ± 116.5**	4.94 ± 0.31*	143.6 ± 13.3	54.36 ± 9.48*	25.31 ± 5.09**	2.15 ± 0.40**
Day 21	93.3 ± 37.7	3.84 ± 0.19	144.5 ± 8.7	56.62 ± 9.91*	21.26 ± 4.12	2.67 ± 0.33*

Note: * - $p<0.05$, ** - $p<0.01$ compared with value before training; CK - creatine kinase, BU - blood urine, Hb - hemoglobin concentration, T - testosterone concentration, C - cortisol testosterone, TC - testosterone/cortisol ratio

increase ($p<0.05$) in female swimmers after the 2nd week of training. There was an insignificant change in the Hb level in both the male and female swimmers.

The impact of pre-competition training on T, C and TC ratio

As shown in Tables 3 and 4, the C level was significantly increased for both male and female swimmers ($p<0.05$), while the TC was decreased ($p<0.01$) for both groups. In addition, the T level was significantly lower for both male swimmers ($p<0.01$) and female swimmers ($p<0.05$).

DISCUSSION

Change of VAT in the pre-competition swimming training.

The changes in the volume and intensity of pre-competition training and the corresponding psychological and physiological changes are the training stimuli that stimulate the internal environment of the swimmers. For speed endurance training, VAT can directly reflect the anaerobic work capacity of the anaerobic threshold (AT) [20]. Thus, the changes of VAT have drawn much attention in speed endurance training. During 1964-1986, Wasserman [19], Kuishen-Yang, and Junzhong-Pu et al. proposed the concepts of "inflexion of blood lactic acid", "anaerobic threshold", and "outshoot of blood lactic acid" based on the indices of "exchanges of breathing", "aerate of lung", "make of carbon dioxide", "blood lactic", "blood pyruvic acid" and "PH of blood" [7,10,19]. They pointed out that there was an acute increase in the concentration of blood lactate during sport or physical activity, and based on this, they further specified the anaerobic threshold, which occurs when the concentration of blood lactate reaches about 4 mmol/L [20]. The research of Koistionen et al. [8] indicated that the endurance of exercise capacity and the intensity of body oxygen supply are related [5,9,14]). Such a relationship provides the basis for further investigation on the changes in work capacity and energy metabolism for the athletes during the increased training [3]. The changes of VAT concentration in the pre-competition training can reveal the changes of exercise capacity of the swimmers and their endurance given that the training load is fixed and that the factors of swimming skills and mood changes are excluded (elite swimmers are relatively stable in their skills and mood).

Although the pre-competition training was designed to gradually reduce sport loads, one purpose of pre-competition training was to help the swimmers adapt to the training stimuli. Thus, it is inevitable that such training may cause fatigue. By changing the training volume and intensity to stimulate the body of the swimmers, and making the training stimuli similar to those in the swimming competition, the swimmers will be better prepared for the competition. If the intensity of such training is very low, it is hard to form a training stimulating environment for the body. On the other hand, training with too heavy loads may lead to overtraining and reduce performance. Therefore, it is important to explore appropriate training stimuli (volume and intensity) to help swimmers reach their full potential in the competition. Although the VAT level of the male swimmers after the 3rd week of training was lower than that of pre-training, it was higher than that after the 2nd week of training, which suggests a trend of increasing VAT level when the training volume dropped gradually. However, this trend is not obvious for female swimmers. Since there was a slight increase in the VAT level of female swimmers after the 1st week of training, the training plan was adjusted and the training volume was increased in the 2nd week of training, which led to a significant drop of their VAT level. The results of VAT indicate that compared with male swimmers, female swimmers are more adaptive to the training changes and might recover more easily. Our former study had a similar result [21,22]. Therefore, it is necessary to fully consider the difference between male and female swimmers and make different training plans.

Changes of CK, BU and Hb levels during the pre-competition training
Successful pre-competition training is one that provides appropriate training loads to athletes, and helps them recover from fatigue and reach their potential in the competition. The CK, BU and Hb concentration in the blood reflect the dynamic biochemical changes of the body. Creatine kinase (CK) is one of the key enzymes in the ATP-CP metabolism system and the changes of CK are the responses of muscle cells to the training loads [2]. Many researchers believe that CK is related not only to the duration, but also to the intensity of sport activity [2,6]. However, the CK level might be limited in reflecting the changes of exercise capacity of the swimmers because it only reveals the training stimuli of the recent 2-3 days. The significant increase in CK for the elite swimmers after the 1st and 2nd week of training indicates that the training stimuli break the balance of the original metabolism, anaerobic metabolism increases, the products of metabolism accumulate and the energy supply might not be sufficient, which causes an increase in the permeation of the cell membranes (with possible damage to the muscle cells) and enzyme release from the cells. Blood urea (BU) is an indicator of how well the economy adapts to the training loads, which is highly related to BU [13]. No BU change was found after the 1st week of training, while a BU increase was detected after the 2nd week, although the training volume was decreased in the 2nd week. This change in BU might be due to the training loads accumulated from the 1st week. The BU value of females decreased to the basic value after the 3rd week of training, while the value of males increased evidently compared with the one before pre-competition training. Based on the changes of BU values, the stimulus of training load had a greater effect on males than females. In addition, acute sport activity may cause red blood cells to temporarily have a lower energy supply and membrane oxidation may cause damage to red blood cells, which increases the concentration of epinephrine and thus the congested spleen may release haemolytic factors that further damage red blood cells. Therefore, the changes of Hb in the blood reflect the exercise capacity under training loads. In this study, there was no obvious change in the haemoglobin during the pre-competition training.

The different changes in the biochemical parameters indicate that CK is more sensitive to the changes in the training approach and scheme; there seems to be a relative delay in the changes of BU, although it is possible that the changes of BU might be earlier, which may be further investigated in the future. The increase of CK and BU during the pre-competition training reveals that the training volume has some impact on the exercise capacity , although the purpose of pre-competition training is to reduce the overall training volume. To achieve the goal of pre-competition training, it relies more on changing the training approach and scheme, but not on training intensity alone.

In order to help swimmers reach their full potential in a swimming competition, it is important to give them an appropriate training load and intensity with appropriate training stimuli during the pre-competition training. The high concentration of CK indicates that that swimmer may experience fatigue which might lead to overtraining symptom (severe fatigue, sudden drop in performance, mood disturbance, etc.) [1,17,18]. Similarly, the high level of BU reveals that protein catabolism becomes the dominant biochemical process in the body of the swimmer, which may have a negative impact on the body energy storage. The capability of a swimmer to win a competition depends on multiple factors including changes of exercise capacity , and weak local enginery may lead to reduced performance. Thus, sport researchers, coaches and swimmers need to watch out for high CK and BU levels and explore appropriate pre-competition training for swimming athletes. After the training of the 3rd week, the CK level of swimmers dropped significantly, which indicates that the body has adapted to the training stimuli. The CK index helps determine whether the body is in a good status for energy storage.

The significant drop of CK levels in the swimmers also indicates that CK is a sensitive index which reveals the biochemical changes and recovery of the body. This is consistent with other research results indicating that appropriate training can reduce muscle injury induced by sudden sport activity and reduce the CK level in the serum. After the recovery training of the 3rd week, the BU level dropped significantly in the female swimmers, which suggests that protein catabolism is reduced in the body and thus is good for enginery recovery. On the other hand, the BU level did not decrease in the male athletes, which means that the impact of the training stimuli is greater for the male swimmers than the female swimmers. From the changes of the BU index, one can see that recovery of the body is insufficient in the male swimmers, and therefore it is necessary to improve recovery after the pre-competition training.

Change of T, C and TC in pre-competition training period
Swimming requires strength and endurance to achieve high performance. Researchers have paid much attention to the analysis of assimilation hormone and catabolism hormone in assessing enginery. Testosterone (T) and cortisol (C) are two typical steroid hormones and their metabolism is in balance in normal physiological conditions [18]. When a person starts sport activity from a resting state, the concentrations of testosterone and cortisol usually increase simultaneously, which indicates the increase of both anabolism and catabolism in the body [4,15]. Under intense training of high volume, it is possible that the rate of catabolism is higher than that of anabolism. The increase of the cortisol level after the 1st week of training reflects the increase of catabolism as a response to the training stimuli. This result is different from that of Mcro et al. [12], but similar to the study of Vervoon et al. [16] on rowers. Thus, it is possible that such a result is related to whether the subjects in the sample are similar to each other and whether the athletes receive similar training stimuli. In addition, these effects could be different for athletes of different ethnicity or living in different regions [8,11,23]. The insignificant decrease for male swimmers in the TC vs. the significant decrease for female swimmers after the 1st week of training reveals the fundamental difference between male and female swimmers in the te-

stosterone concentration, because testosterone is a male hormone. The change in the TC is useful in assessing the impact of the training loads on male and female athletes, and more research may be needed to further explore it in the future. The significant decrease of the T level and TC and the significant increase of the C level in the swimmers after the 2nd week of training indicate that the enginery was decreased after training, which is consistent with what was observed in the changes of the VAT, CK and BU levels. Compared with the training after the 2nd week, the increase of the T level and the TC and the decrease of the C level after the 3rd week of training indicate that the recovery of enginery in the swimmers was consistent with what was revealed by the changes of the VAT, CK and BU indices. There are some differences in the recovery between the male and female swimmers after the 3rd week of training, because for the male swimmers, the T and C level and the TC were resumed to those of before the training, while for the female swimmers, their T level and TC were lower than those before the training (although higher than those after the 2nd week of training). This suggests that the recovery of the female swimmers is not as sufficient as that of the male swimmers during the recovery training. Therefore, it is necessary to help the female swimmers to fully recover before the competition.

In summary, this study monitored and analysed the biochemical changes and endocrine responses for a group of elite swimmers in the pre-competition training. Our results demonstrated that it is important to explore an appropriate pre-competition training plan (training volume and intensity, etc.) for swimming athletes and adjust the training loads/intensities timely according to the changes of their enginery in order to avoid overtraining and help the swimmers to reach their full potential in the swimming competition.

CONCLUSIONS

In conclusion, the biological indices in the study could reflect changes of exercise capacity y in swimmers during pre-competition training. The pre-competition training, producing training load stimuli and causing body fatigue, results in evident changes of these indicators. Recovery of most tested indictors were found in the last week of training. Further recovery and extra recovery of body function and enginery were to be expected during 7-10 day adjustment training and rest before competition. Therefore, this pre-competition training could help swimmers' body function reach a high level in the competition and improve their performance.

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