THE EFFECTS OF HYPERCAPNIC-HYPOXIC TRAINING PROGRAM ON HEMOGLOBIN CONCENTRATION AND MAXIMUM OXYGEN UPTAKE OF ELITE SWIMMERS

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Abstract:

The aim of this research was to establish the effects of the 8-week hypercapnic-hypoxic training program on hemoglobin concentration (Hb) and the maximum oxygen uptake (VO_{2max}) in swimmers. The research was conducted on a sample of 16 Croatian elite male swimmers (experimental group n=8, control group n=8). Both groups were subjected to the same swimming trainings and additional training sessions on a treadmill. The experimental group was subjected additionally to hypercapnic-hypoxic training program with enhanced muscular activity. The experiment lasted for eight weeks. The following variables were used: hemoglobin concentration (Hb) and maximum oxygen uptake (VO_{2max}). The ANOVA series application for the repeated measurements have shown significant Hb and VO_{2max} concentration differences related to the effect of both groups. The hypercapnic-hypoxic training method, which was applied to elite swimmers, has resulted in a 5.35% higher Hb concentration at the end of the program, which also caused a 10.79% increase in the VO_{2max}.

Key words: *hypercapnic-hypoxic training, hemoglobin concentration, maximum oxygen uptake, swimmers*

Introduction

The physiological reactions registered in elite free-divers could result in the improved sport performance in hypercapnic and hypoxic training. The previously conducted free-diver research has shown that hypercapnic and hypoxic training could be an effective alternative to the hypobaric and normobaric hypoxia in increasing the aerobic and/or anaerobic performance levels (Joulia, Steinberg, Wolff, Gavarry & Jammes, 2002; Joulia, et al., 2003; Prommer, et al., 2007; Schagatay, et al., 2007; De Brujin, et al., 2008; Richardson, et al., 2008; as cited in Lemaitre, Joulia & Chollet, 2010).

A practice in free-diving results in spleen contraction, which enhances the oxygen transfer, increases the erythrocyte count, hematocrit level and hemoglobin concentration (Schagaty, et al., 2005; Prommer, et al., 2007). Previously conducted research studies (Woorons, et al., 2005, 2007) have shown that the type of an intermittent hypercapnic-hypoxic training influences arterial desaturation, induces hypercapnia and thus enhances the buffer capacity. However, it has not yet been proven that the hypercapnic-hypoxic training program improves hematological parameters and aerobic performance. The research conducted by Woorons et al. (2005) and Millet, Roels, Schmitt, Woorons and Richaled (2010) indicate a necessity for further research in the area of hypoventilation in order to acquire additional knowledge and improve hypercapnic-hypoxic training methods.

During swimming, physiological activity is performed under alternate work conditions where a combination of anaerobic and aerobic condition prevails in relation to track length and swimming intensity (Sweetenham & Atkinson, 2003). The development of aerobic abilities is an important preparation factor for each swimmer regardless of the event he/she competes in. The more developed the aerobic ability, the more oxygen is to be exploited, which also results in speed sustenance during lengthy efforts (Kuterovac & Zoretić, 2009). A hypercapnic-hypoxic training program could also improve the buffer capacity of muscles (Joulia, et al., 2002; 2003, Julian, et al., 2004), which would reduce the post-hypercapnia blood acidosis. Furthermore, a delayed acidosis would also be beneficial for swimming performance and increase of work ability of both the skeletal and respiratory muscles through the mechanism of delaying their fatigue during extensive training. Therefore, the aim of this research was to determine the effects of a hypercapnic-hypoxic training program on hemoglobin concentration and maximum oxygen uptake in elite swimmers.

Methods

The research was conducted on a sample of 16 elite male junior and adult swimmers, who were 17 to 25 years of age. The sample included only those swimmers who were regularly practicing swimming for at least eight years, minimally six times a week for two hours and according to the Croatian Olympic Committee criteria had been awarded as I, II or III athletic category. The sample was stratified by the International Point Score (IPS scores) for 100 m front crawl stroke. By applying the block-randomization method, the test subjects were divided into two groups: the control group (CG; n=8) and the experimental group (EG; n=8).

All the subjects were in good health and had valid medical certificates for the participation in swimming competitions. The subjects were introduced to the experiment designs, possible health risks and measurement procedures. Each of them signed a consent form testifying that they were aware of the aim and the purpose of the measuring protocol, possible measurement risks and that they entered the experiment of their own accord.

All the measurements (the initial and the final one) were conducted at the Sports Diagnostic Centre of the Faculty of Kinesiology, University of Zagreb, and at the Medical and Biochemical Laboratory "Breyer". Two variables were used in order to describe the test subject sample and research goals: the hemoglobin concentration and the maximum oxygen uptake.

Experimental protocol. During the research the swimmers were subjected to the training program preparation stage for the winter competition cycle. During eight weeks, the subjects of the experimental group (EG) were subjected to both the swimming practice and to the hypercapnic-hypoxic training sessions (H-H) on a treadmill with the enhanced muscle activity. The load (strain) was determined based on the maximum heart rate (FS_{max}) when determining the maximum oxygen uptake (VO_{2max}) on a treadmill. The treadmill speed remained the same during the whole training program. Oxygen blood saturation (SaO_2), the carbon dioxide amount in the exhaled breath (CO_2) and heart rate (HR), which was 60% of the maximum HR, were constantly monitored. The hypercapnic-hypoxic training program was applied for eight weeks (the test subjects participated in at least 80% of training sessions), three times a week, 30 to 45 minutes. Each test subject has withheld breath individually, by a subjective feeling, for as long as possible. The condition is that each breath hold must be above the minimum values which describe hypercapnia, that is, the values of carbon dioxide in the exhaled breath had to be over 45 mmHg, which was controlled by a capnometer (Model C300, External Sidestream ETCO2 Module, Beijing National Medical Co). The time in seconds was measured for determining individual hypercapnic conditions for each test subject. The breaks between breath holds lasted as long as the full ventilation cycle (breath-in, withholding the breath + breath-out, breath-in – breath-out, breath-in + withholding the breath).

Besides the swimming training sessions the control group was subjected to additional aerobic training sessions on a treadmill with the intensity of 60% of the maximum HR. The program was conducted three times a week for eight weeks.

Results

Table 1 shows the basic descriptive parameters, the relative effect size measure between two arithmetic means in the initial and the final check-up and the central dispersion measures. The effect size of the obtained hypercapnic-hypoxic training differences between the initial and final measurements in all parameters was calculated with the Cohen d-index.

Based on the numerical parameters (Table 2) of the independent sample t-test (p<.05) it is noticeable that there was no statistically significant difference in the two measured variables in the initial measurement between the experimental and the control group.

The results of a series of ANOVA for the repeated measurements show that there were statistically

Table 1. Results of descriptive statistics for the experimental and control group in the initial and final measurement

Variable	Experimental group - Initial measurement	Experimental group - Final measurement	Cohen d	Control group - Initial measurement	Control group - Final measurement	Cohen d
	Mean±SD	Mean±SD		Mean±SD	Mean±SD	
Hb (g/L)	144.63±7.63	152.38±5.55	1.24	147.75±2.71	145.38±5.53	0.58
VO_{2max} (ml/kgxmin)	63.80±3.39	70.38±5.26	1.59	59.46±6.42	60.81±5.50	0.24

Legend: Mean - mean, SD - standard deviation, Cohen d - effect size used to indicate the standardized difference between two means, an effect size is a measure of the strength of a phenomenon. Hb - concentration of hemoglobin, VO_{2max} - oxygen uptake.

Table 2. Results of t-test for independent samples in the initial measurement

Variable	Experimental group - Initial measurement	Control group - Initial measurement	p
	Mean±SD	**Mean±SD**	
Hb (g/L)	144.63±7.63	147.75±2.71	0.12
VO_2 max (ml/kgxmin)	63.80±3.39	59.46±6.42	0.29

Legend: Mean - mean, SD - standard deviation, p – statistically significant at level p<.05, Hb - concentration of hemoglobin, VO_{2max} - oxygen uptake

significant differences in hemoglobin concentration and maximum oxygen uptake progression between the groups. The differences are shown separately for each variable in Figures 1 and 2 and Table 3.

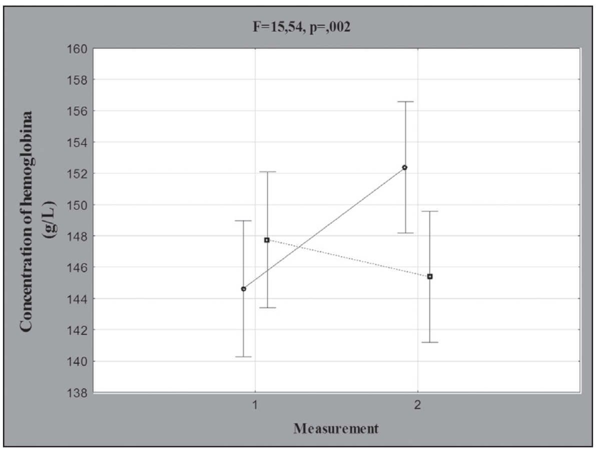
Figure 1 shows the results of the hemoglobin concentration variable (Hb). As shown, the exper-

Table 3. Results of repeated measures analyses of variance (ANOVAs) for each variable between the experimental and control group in the initial and final measurement

Variable	F	p
VO_{2max}	7.04	0.02
Hb	15.54	0.002

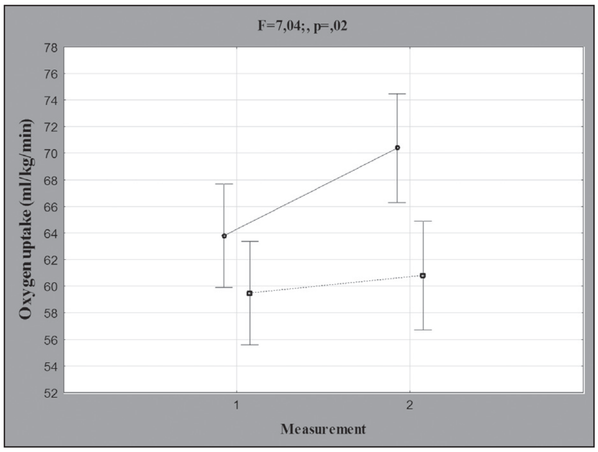
Legend: F - variance of the group means / mean of the within group variances, p - statistically significant at level p<.05, Hb - concentration of hemoglobin, VO_{2max} - oxygen uptake

imental and the control group are homogenous in the initial state (p=.12). In the final measurement the swimmers who were subjected to the hypercapnic-hypoxic training program scored better than the swimmers who were not subjected to the program. Based on the hemoglobin level value in the initial measurement (144.63±7.63 g/L), and in the



experimental group, control group, 1 – initial measurement, 2 – final measurement, **p** – statistically significant at the level of p<.05, **F** – variance of the group means / mean of the within group variances.

Figure 1. The differences between the experimental and control group in the initial and final measurement in the variable of hemoglobin.



experimental group, control group, 1 – initial measurement, 2 – final measurement, **p** – statistically significant at the level of p<.05, **F** – variance of the group means / mean of the within group variances.

Figure 2. The differences in progress between the experimental and control group in the initial and final measurement in the variable oxygen uptake (VO2max).

final measurement (152.38±5.55 g/L) it can be concluded that the hemoglobin level has increased for 5.35%.

Figure 2 shows the results in the maximum oxygen uptake variable (VO_{2max}). Based on the VO_{2max} initial EG measurement value (63.80±3.39 ml/kg/min) and the CG measurement value (59.46±6.42 ml/kg/min) it can be concluded that the EG value has improved for 10.31%, whereas the control group improved their VO_{2max} value by 2.27% sole by the aerobic training.

Discussion and conclusions

The results in Table 3 show that a statistically significant improvement occurred during the eight-week period in swimmers of the experimental group when compared to the improvement of the control group under the influence of the hypercapnic-hypoxic training program and training program conducted in the swimming club. The values of statistic error proportions show that the training process has resulted in statistically significant improvements of hemoglobin concentration and maximum oxygen uptake (Figures 1 and 2). The mean hemoglobin concentration values in the group of swimmers who were subjected to the hypercapnic-hypoxic training program with the enhanced muscle activity has increased for 6.71 g/L (Table 1) when compared to the control group (Table 1). Hemoglobin concentration along with the cardiovascular system capacity is a key factor of endurance because it enables oxygen transfer to muscle cells (Wachsmuth, et al., 2013). Therefore, the goal of all top-level athletes is to increase hemoglobin concentration with an adequate training method because, according to Saunders, Garvican-Lewis, Schmidt, & Gore, (2013), Wachsmuth, et al. (2013) as well as Zoretić and Kuterovac (2012), after the altitude training process the increase in the Hb concentration results eventually in the increase of the VO_{2max} and in a better sports performance. Hemoglobin is a buffer which can reduce the decrease of pH-blood values during the training process so that more lactate can be extracted from the working muscles, where pH is lower, to the blood, where pH is higher (Tossavainen, 2004). The buffering has an important role in acidosis postponing. A high buffer system in muscle cells can stabilize the cell pH and improve anaerobic ability or muscle hypoxia tolerance (Somero, 1986).

Increasing hemoglobin concentration, and thus the oxygen uptake, enables a swimmer to have large oxygen quantities available in the final moments of the race. The hypercapnic-hypoxic training method, which was applied with to elite Croatian swimmers increased the hemoglobin concentration by the end of the experiment for 5.35% and the VO_{2max} for 10.79%. A large effect of the hypercapnic-hypoxic training program has been also proven by Cohen d which is higher than 0.8 (Table 1). According to Wachsmuth et al. (2013), hemoglobin concentration has a significant effect on swimming performance, if the hemoglobin concentration increases 1% (11g/L), swimming performance can be improved by 1.8 IPS scores. The 1 g Hb changes are related to changes in VO_{2max} of circa 4 ml/min. The 6.5% hemoglobin concentration increase after the altitude training improved swimming performance for 11.7 IPS scores, which corresponds to a 0.4% of swimming speed increase (Schmidt & Prommer, 2010). Saunders et al. (2013) came to the conclusion that the 1% Hb mass increase after the altitude training eventually results in the 0.6-0.7% VO_{2max} increase. If the results obtained by the current research are put into relation, it can be concluded that the 1g/l Hb concentration increase after the H-H training lead to the 0.822 ml/kg/min VO_{2max} performance improvement of the Croatian elite swimmers, which means that if the Hb mass is increased for 1%, the VO_{2max} will proportionally be increased for 2.01%. Further research is required to prove that such training programs could influence swimming performance and a possible later onset of lactic acid accumulation due to buffer characteristics of hemoglobin and the oxygen uptake increases in muscles.

The findings and modern analytical approach have proven that the hypercapnic-hypoxic training program can be an alternative to the altitude training as far as the hemoglobin concentration is regarded, as well as the maximum oxygen uptake. The kinesiology-related aspect of this cognition should be of considerable value for understanding of normobaric hypercapnia and hypoxia adaptation in the function of improving athlete's (swimming) performance. This also opens the possibility of practical application of new information to competitive sport disciplines. From the physiological point of view, significance of this research should be recognized in valuable knowledge about the mechanism of physiological adaptation to hypercapnia and hypoxia and about the improvement of the muscle buffer capacity, the inadequacy of which is the primary cause of muscle fatigue.

References

Joulia, F., Steinberg, J.G., Faucher, M., Jamin, T., Ulmer, C., Kipson, N., & Jammes, Y. (2003). Breath-hold training of humans reduces oxidative stress and blood acidosis after static and dynamic apnea. *Respiratory Physiology & Neurobiology, 137*, 19-27.

Joulia, F., Steinberg, J.G., Wolff, F., Gavarry, O., & Jammes, Y. (2002). Reduced oxidative stress and blood lactic acidosis in trained breath-hold human divers. *Respiratory Physiology & Neurobiology, 133*, 121-130.

Julian, C.G., Gore, C.J., Wilber, R.L. Daniels, J.T., Fredericson, M., Stray-Gundersen, J., Hahn, A.G., Parisotto, R., & Levine, B.D. (2004). Intermittent normobaric hypoxia does not alter performance or erythropoietic markers in highly trained distance runners. *Journal of Applied Physiology, 96*, 1800-1807.

Kuterovac, P., & Zoretić, D. (2009). Energetska metabolička aktivnost tijekom plivanja. [Energy metabolic activity during swimming.] In Croatian. In I. Jukić, D. Milanović, C. Gregov & S. Šalaj (Eds.), *Zbornik radova 7. godišnje međunarodne konferencije Kondicijska priprema sportaša s glavnom temom „Trening izdržljivosti“*, Zagreb, 20.-21. veljače 2009. (pp. 72-76). Zagreb: Kineziološki fakultet Sveučilišta u Zagrebu.

Lemaîtrea, F., Joulia, F., & Chollet, D. (2010). Apnea: A new training method in sport? *Medical Hypotheses, 74*, 413-415.

Millet, P.G., Roels, B., Schmitt, L., Woorons, X., & Richaled, P. (2010). Combining hypoxic methods for peak performance. *Sports Medicine, 40*(1), 1-25.

Saunders, P.U., Garvican-Lewis, L.A., Schmidt, W.F., & Gore, C.J. (2013). Relationship between changes in hemoglobin mass and maximal oxygen uptake after hypoxic exposure. *British Journal of Sports Medicine, 47*(i26-i30), 1-6.

Schmidt, W., & Prommer, N. (2010). Impact of alterations in total hemoglobin mass on VO_2max. *Exercise and Sport Sciences Reviews, 38,* 68-75.

Somero, G.N. (1986). Protons, osmalytes and fitness of internal milieu for protein function. *American Journal of Physiology*, *251,*(2), R197-213.

Sweetenham, B., & Atkinson, J. (2003). *Championships swim training.* Champaign, IL: Human Kinetics.

Tossavainen, M. (2004). *Testing athletic performance in team and power sports*. Oulu: NewtestOy.

Wachsmuth, N.B., Volzke, C., Prommer, N., Schmidt-Trucksass, A., Frese, F., Spahl, O, Eastwood, A., Stray-Gundersen, J., & Schmidt, W. (2013). The effects of classic altitude training on hemoglobin mass in swimmers. *European Journal of Applied Physiology, 113*(5), 1199-121.

Woorons, X., Mollard, P., Pichon, A., Duvallent, A., Richalet, JP., & Lamberto, C. (2005). Prolonged expiration down to residual volume leads to severe arterial hypoxemia in athletes during submaximal exercise. *Respiratory Physiology* & *Neurobiology*, *158*(1), 75-82.

Woorons, X., Mollard, P., Pichon, A., Duvallent, A., Richalet, J.P. & Lamberto, C. (2007). Effects of a 4-week training with voluntary hypoventilation carried out at low pulmonary volumes. *Respiratory Physiology* & *Neurobiology*, *160*(2), 123-130.

Zoretić, D., & Kuterovac, P. (2012). Effect of 21 days of 'Living High – Training High' training period on sea-level swimming performance and hematological blood results in competitive swimmers. *Gazzetta Medica Italiana, 171*(3), 295-303.

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UČINCI HIPERKAPNIJSKO-HIPOKSIČNOG TRENINGA NA KONCENTRACIJU HEMOGLOBINA I MAKSIMALNI PRIMITAK KISIKA VRHUNSKIH PLIVAČA

Cilj istraživanja bio je utvrditi učinke hiperkapnijsko-hipoksičnog treninga na koncentraciju hemoglobina (Hb) i maksimalni primitak kisika (VO_{2max}) plivača. Istraživanje je provedeno na uzorku od 16 vrhunskih hrvatskih plivača muškoga spola (n=8 eksperimentalna grupa, n=8 kontrolna grupa). Obje grupe provodile su jednake plivačke treninge i dodatne treninge na pokretnoj traci. Eksperimentalna grupa provodila je hiperkapnijsko-hipoksični trening uz povećanu mišićnu aktivnost. Eksperiment je trajao osam tjedana. Korištene su sljedeće varijable: koncentracija hemoglobina (Hb) i maksimalni primitak kisika ($VO_{2max)}$. Rezultati primjene niza ANOVA za ponovljena mjerenja pokazali su da u koncentraciji Hb i VO_{2max} postoje statistički značajne razlike u učinku između grupa. Metodom hiperkapnijsko-hipoksičnog treninga, koju su primjenjivali vrhunski plivači, koncentracija Hb na kraju programa povećala se za 5,35%, a time i VO_{2max} za 10,79%.

Ključne riječi: *hiperkapnijsko-hipoksični trening, koncentracija hemoglobina, maksimalni primitak kisika, plivači*