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Effect of simulated altitude training on blood components and performance in elite speed skaters

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ABSTRACT

The study aimed to evaluate the effect of a simulated altitude training on blood components and aerobic and anaerobic performance in elite speed skaters. Six elite speed skaters participate in this study and performed before (day 1; pre-test) and after (day 26; post-test) a two weeks simulated altitude (2.500 m) training period an incremental exercise test on a cycle ergometer to determinate maximal oxygen uptake ($VO_{2max.}$) and a Wingate test to determine peak (PP) and mean (MP) power. In addition, blood samples were obtained at day 1, day 15 and day 26. Erythrocytes and hemoglobin concentrations increased respectively from 3.4 and 6.1% ($p<.05$) between pre- and post-test. An increase in VO_{2max} of 16.7% ($p<.05$) between pre- and post-test was found while PP and MP did not change. This study shows that two weeks simulated altitude training significantly increases erythrocytes and hemoglobin concentrations, and that these haematological changes might be responsible for the rise in VO_{2max}.

Keywords: Altitude training, Hypobaric chamber, Haematopoiesis, Aerobic performance, Anaerobic performance.

INTRODUCTION

In the last decades, news world records in distance events have been constantly established and one of the responsible factors therefore is perceived to be altitude training. Using altitude training as an ergogenic aid to improve sea-level performance remains very popular by elite athletes. Many coaches believe that altitude works for everybody and choose to include altitude to their training program.[1] Altitude training is based on the belief that this practice increases the natural physiological processes that generate physical power and develops changes and adaptations similar to those caused by endurance training.[2] Immediately after arrival to altitude, physiological adaptations occur within 4 hours of hypoxia and will last many weeks if exposure continues.[1] These adaptations represent what it's called altitude acclimatization and concern respiratory, cardiovascular and metabolic responses.

The haematological response represents probably the most important adaptation to altitude training that improves sea level performance.[1,3,4] On the day of arrival at altitude, plasma volume decreases progressively and an increase of erythrocytes production is observed at altitude due to an augmentation of erythropoietin level.[3,4-7] Consequently, these physiological adaptations make many coaches believe that altitude acclimatization or altitude training could be benefit to all athletes and should enhance their performance at sea level. Over the last years, studies have shown controversial results and haven't evaluated clearly the potentiating effects of altitude training: the benefit of this practice stays equivocal. Some researches have shown an ergogenic effect on endurance performance, due particularly to an increase of the maximal oxygen uptake (VO_{2max}), or on submaximal and maximal performance after altitude acclimatization, or altitude training while others were unable to support this claim.[5,6,8-11]

As scientific evidence on the positive effect of altitude training on sport performance remains doubtful, and with regard to the financial burden of altitude training, scientific scientist and coaches have been exploring the possibility to use a hypobaric chamber as a substitute to simulate altitude conditions. Staying at sea level, athletes can train in hypoxia, choose easily the right atmospheric pressure and benefit then from the physiological adaptations. Whether

simulated altitude training is effective in elite speed skaters remains unknown. Then, the purpose of this study is to determinate the effect of simulated altitude training on blood components and aerobic and anaerobic performance in elite speed skaters.

MATERIALS AND METHODS

Six elite speed skaters, members of the Dutch national team, all men and highly trained, born and living at sea level, gave their verbal consent to participate in this study. All subjects were informed on the experimental procedures and were asked to maintain their normal diet and to abstain from any medicine during the period of the study. Body mass, height and body fat percentage (4 skinfolds thickness, Womersley and Durnin) were measured before and after the training period. Before the start of the study, subjects followed similar training programs and were made familiar with the testing and training protocols and with the hypobaric chamber (cycle ergometer, skate bench).

Table 1. Subjects' characteristics

	N	Age, years	Height, cm	Body mass, kg	Body fat, %
Before HCT	6 (M)	21.00 ± 1.00	182.08 ± 3.25	75.67 ± 4.00	9.48 ± 0.63
After HCT	4 (M)	20.75 ± 1.25	180.75 ± 3.13	75.75 ± 3.38	9.39 ±0.72

Values are means ±SD; HCT, hypobaric chamber training; N, number of subjects; M, male.

Over a two weeks period, all subjects trained on an electrical cycle ergometer (Spintrainer, TechnoGym®, Italy) and on a self-made skate bench in a hypobaric chamber. The simulated pressure was set at 550 mmHg which is the atmospheric pressure measured at 2,500 m, corresponding to an optimal altitude for great physiological changes [2,14,16]. The hypobaric chamber was 12.5 meters in length and 3.0 meters in diameter. The temperature in the hypobaric chamber was held at 21 ± 4 ºC and humidity at 45 ± 10%. The first week, the subjects trained at simulated altitude from Tuesday to Friday mornings and during the second week from Monday to Friday mornings. In the afternoons, they remain their normal training program at normoxia. During the 20 minutes needed to achieve depressurisation to 550 mmHg, the subjects warmed-up and their total daily training program were elucidated. The atmospheric pressure in the hypobaric chamber was maintained for about 90 minutes during which the subjects trained in hypoxia. Subjects were coached during the whole training. Each training session at simulated altitude started at 8:30 a.m. and lasted between 75 and 90 minutes. During the first week (4 sessions), the subjects followed two aerobic endurance sessions within intermittent exercises on skate bench, one anaerobic power-endurance session and one recovery training. In the second week, they performed three aerobic endurance training within intermittent exercises on skate bench and two anaerobic power-endurance training. At the end of the training session in hypoxia, the subjects recovered for 20 minutes needed to return to sea level atmospheric pressure.

Venous blood samples were taken from the antecubital vein just before the first training session in the hypobaric chamber (*day 1*), after the last training session (*day 15*) and ten days later (*day 26*). The EDTA data were analysed for leukocytes, erythrocytes (Er), hemoglobin (Hb), hematocrit (Ht), mean cell volume (MCV), mean cell hemoglobin (MCH), mean cell hemoglobin concentration (MCHC), thrombocytes, neutra granulocytes, lymphocytes, reticulocytes (Rt) and immature reticulocytes fraction (IRF). The blood serum was analysed for iron, urea, creatinine, ASAT, creatine kinase, ferritin, testosterone and cortisol.

All subjects performed a standardised incremental exercise test on a cycle ergometer (LODE Excalibur, Lode, The Netherlands) at sea level before (*day 1*) and after (*day 26*) simulated altitude training for the determination of maximal oxygen uptake (VO_{2max}). The subjects adjust their handle bar position and seat height so that his legs are fully extended at the bottom of the pedalling cycle (this was recorded and maintain in all exercises). The exercise test started at 1 and 2 watt per kg body mass during 5 minutes, and then gradually increased by 0.33 watt per kg body mass every minute. Several cardiopulmonary variables were measured as maximal expired carbon dioxide (VCO_{2max}), maximal ventilation (V_{Emax}) and breathing frequency (Bf), using an open-circuit gas analyser (Oxycom Champion V 3.1, Jeager, Germany). The subjects freely chose pedal rate. Heart rate (HR) and ECG during the test were continuously recorded by a Quinton (Q5000, Lode, The Netherlands). The maximal aerobic power (VO_{2max}) was the highest VO_2 obtained during the concluding periods of exercise test. Subjects achieve on average a total test time ranging from 18 to 20 minutes.

All subjects performed the most used anaerobic performance test described first in 1974: the 30 Seconds Wingate Test [5,24]. The Wingate Test requires pedalling or arm cranking on a cycle- of arm ergometer for 30 seconds at maximal speed and against a constant force. After a warming-up of 5 minutes, the subject pedalled for 30 seconds at maximal speed against a constant force. This force was set at 0.075 kp per kg body mass. Three performance indicators are measured: *mean power* (MP), defined as the mean work output over the 30 seconds; *peak power* (PP),

defined as the highest power output; and *Fatigue index* (FI), defined as the difference between the peak power and the lowest power output divided by peak power.

All laboratory exercise tests were performed at normobaric normoxia, all subjects living at sea level. To prevent an iron content failure, all subjects received an iron supplement of 525 mg per day (ferogradumet®) during the whole simulated altitude-training period. In the first week of training period, there were two withdrawals due to illness. This study was performed in accordance with the Helsinki Declaration (1964) and was approved by the technical and medical staff of the Dutch National Skate Federation (KNSB).

Descriptive analyses (mean, standard deviation) were performed for all relevant outcome measures. To examine the statistical evolution of haematological components, cardiopulmonary variables, VO_{2max}, PP, MP and FI, T-paired tests were performed with the scores of the subjects who completed both pre- and post-test. The level of statistical significance was set at $p<.05$.

RESULTS

Changes in blood components resulting from the simulated altitude training are presented in table 2, showing that erythrocytes concentration increased from 5.03 at day 1 to 5.20 /pl at day 26 ($p<.05$), the hemoglobin content from 9.33 at day 1 to 9.90 mmol.l^{-1} at day 26 ($p< 0.05$) and MCHC concentration from 20.48 at day 1 to 20.98 mmol.l^{-1} at day 26. This represents an increase at post-test 2 of respectively 3.4, 6.1 and 2.4% ($p<.05$). Table 2 shows also that urea and creatinine increase between day 1 and day 15 respectively from 5.65 and 95 to 6.45 mmol.l^{-1} and 115 µmol.l^{-1} ($p<0.05$). The testosterone concentration raised between day 15 and day 26 from 17.43 to 22.58 nmol.l^{-1} ($p<0.05$).

Table 3 shows a significant ($p<0.05$) increase in VO_{2max} and VCO_{2max}: VO_{2max} from 4.36 to 5.09 l.min^{-1} and VCO_{2max} from 5.34 to 6.04 l.min^{-1}. Table 3 shows no changes in PP (from 20.10 to 20.93 watt.kg^{-1}) and in MP (from 11.93 to 11.85 watt.kg^{-1}).

Table 2. Effect of simulated altitude training in a hypobaric chamber for 2 weeks on serum and EDTA haematologic data (mean ± standard deviation) in elite speed skaters (N = 4).

Parameter	Pre-test at *day 1*	*Post-test 1 at* ' 15	*Post-test 2 at* ' 26
Iron (µmol.l^{-1})	17.58 ± 2.38	23.88 ± 6.31	23.08 ± 4.38
Urea (mmol.l^{-1})	5.65 ± 0.30	6.45 ± 0.45	5.15 # ± 0.75
Creatinine (µmol.l^{-1})	95.00 ± 5.50	115.00 ± 4.50	96.50 # ± 6.50
ASAT (U.l^{-1})	11.50 ± 1.75	13.25 ± 2.25	11.75 # ± 2.25
Creatine kinase (U.l^{-1})	60.00 ± 7.00	59.75 ± 7.75	52.00 ± 4.50
Ferritin (µg.l^{-1})	84.50 ± 33.50	84.75 ± 36.25	107.00 ± 34.50
Testosterone (nmol.l^{-1})	18.18 ± 4.56	17.43 ± 3.48	22.58 # ± 2.99
Cortisol (nmol.l^{-1})	405.25 ± 41.25	377.00 ± 72.00	339.50 ± 94.50
Leukocytes (/nl)	5.40 ± 0.75	5.90 ± 0.30	6.28 ± 1.03 **
Erythrocytes (/pl)	5.03 ± 0.16	5.08 ± 0.04	5.20 # ± 0.10 **
Hemoglobin (mmol.l-1)	9.33 ± 0.48	9.60 ± 0.25	9.90 ± 0.30 **
Hematocrit (%)	0.46 ± 0.02	0.47 ± 0.02	0.47 ± 0.01
MCV (fl)	90.75 ± 1.88	92.75 ± 2.63	90.50 ± 1.50
MCH (fmol)	1.87 ± 0.04	1.91 ± 0.06	1.90 ± 0.03
MCHC (mmol.l-1)	20.48 ± 0.13	20.58 ± 0.99	20.98 ± 0.18 **
Thrombocytes (/nl)	227.50 ± 40.75	218.50 ± 34.75	251.25 ± 52.25
Neut. Granulocytes (%)	52.00 ± 8.00	56.75 ± 9.25	58.50 ± 8.00
Lymphocytes (%)	36.00 ± 5.00	36.25 ± 8.25	30.75 ± 7.75
Reticulocytes (0/00)	9.00 ± 1.50	6.25 ± 0.75 **	8.25 # ± 1.75
IRF (%)	14.58 ± 2.58	14.28 ± 2.18	18.05 ± 2.25 **

********, *p<.05 from pre-test*

Table 3. Effect of simulated altitude training in a hypobaric chamber for 2 weeks on maximal oxygen uptake and cardiopulmonary parameters (mean, standard deviation) in elite speed skaters (N = 4).

Parameter	Pre-test at *day 1*	*Post-test at* day 26
VO_{2max} (ml.min^{-1}.kg^{-1})	58.13 ± 8.28	67.08 ± 2.93
VO_{2max} (l.min^{-1})	4.36 ± 0.53	5.09 ± 0.15 **
VCO_{2max} (l.min^{-1})	5.34 ± 0.42	6.04 ± 0.07 **
HR_{max} (puls.min^{-1})	195.25 ± 3.88	186.25 ± 15.13
V_{Emax} (l.min^{-1})	158.18 ± 23.28	179.78 ± 8.03
Bf (breaths.min^{-1})	60.50 ± 5.25	60.75 ± 4.88
PP (watt.kg^{-1})	20.10 ± 1.80	20.93 ± 0.93
MP (watt.kg^{-1})	11.93 ± 0.18	11.85 ± 0.28

********, *p<.05*

DISCUSSION

The aim of this study was to evaluate the effect of a simulated altitude training on blood components and aerobic and anaerobic performance in elite speed skaters. Erythrocytes and hemoglobin concentrations increased respectively from 3.4 and 6.1% ($p<.05$) between pre- and post-test. An increase in VO_{2max} of 16.7% ($p<.05$) between pre- and post-test was found while PP and MP did not change. This study shows that two weeks simulated altitude training significantly increases erythrocytes and hemoglobin concentrations, and that these haematological changes might be responsible for the rise in VO_{2max}.

With regard to potential methodological considerations, one limitation of our study is the small sample size of our study group. However, the difficulty to conduct experimental researches in large groups of elite athletes is well known: elite athletes and their staff (technical and medical) members are not easily open to empirical research, and eventual experimental procedures must fit both training and competition planification and scheme burden. Nevertheless, our study group is a convenient representation of the Dutch elite speed skaters. This aspect has had also some consequences for our experimental procedures. Randomised controlled trials (RCT) have been defined as the highest methodological quality design in scientific research and are the most rigorous way of determining whether a cause-effect relation exists between treatment and outcome, generating unbiased, accurate and applicable results.[12] In our study, we were not able to include enough participants in order to formed a control group, which is a limitation of our study.

As it is known for several decades that erythrocytes are formed from successive maturations of different erythroid progenitors (erythroid burst-forming unit BFU_e, erythroid colony forming unit CFU_e, normoblasts and reticulocytes) and that BFU_e is responsive to erythropoietin (EPO), the rise in erythrocytes and hemoglobin contents suggests that training at hypoxia increases EPO production.[13,14] EPO is a glycoprotein hormone produced by the kidneys and secreted into the plasma. As the production of EPO is influenced by catecholamines that function as neurotransmitters within the Sympathetic Nervous System (SNS), it can be suggested that simulated altitude training, by increase of FSH/LH production, enhances catecholamines release producing then haematological changes. As simulated altitude training increases erythrocytes and hemoglobin production, and that iron demand increases to support hemoglobin synthesis, the expectation was that iron concentration would decreased after hypoxia exposure as more iron would be needed to form more haemoglobin. Consequently, all subjects in our study did take iron supplement in order to prevent a too low concentration due to simulated altitude training.

With regard to the effect of simulated altitude training on performance, VO_{2max} increased from 58.13 to 67.08 $ml.min^{-1}.kg^{-1}$, representing a gain of 15.4%, improvement being consistent with others studies.[5,6,8,10,11] A possible explanation in our study could be that our subjects were already optimally trained, and therefore, their aerobic metabolism did not benefit from additional effects from simulated altitude training. While the changes in red blood cell volume have been already shown in earlier studies, empirical researches exploring the ergogenic effects of simulated altitude training on VO_{2max}. present contradictory evidence.[3,15-17] However, as hemoglobin is responsible for the transport of oxygen, it seems legitimate to expect the progression of VO_{2max} found in our study did resolve from an increase in red blood cells and haemoglobin.

With regard to the training program, all subjects followed a training in the hypobaric chamber mainly based on aerobic work out on cycle ergometer. Consequently, the increase in VO_{2max} from pre-test to post-test could have been not only due to simulated altitude training but also to training adaptation. Nevertheless, we strived to minimize the effect of aerobic training by introducing a period of 10 days of specific skate training between the last training at simulated altitude and the post-test assessment. Then, it can be assumed that rather the simulated altitude training than the aerobic training is responsible for the significant increase in Er, Hb, MCHC and VO_{2max}. No significant differences in PM and MM after the training period at simulated hypoxia were found, which is in line with previous studies.[3,10,18] One possible explanation could be the training program conducted at simulated altitude. As previously acknowledged, all subjects followed during two weeks a training program in the hypobaric chamber based mainly on aerobic work. During this period, subjects did not get much stimulation of their anaerobic system, explaining our findings. However, some other studies did found an ergogenic effect of hypoxia exposure on anaerobic metabolism by maintaining muscle buffer capacity.[19,20]

In conclusion, this study showed that two weeks simulated altitude training (5 $day.week^{-1}$) significantly ($p<0.05$) increases the erythrocytes and hemoglobin concentrations, these haematological changes being responsible for the significant rise in VO_{2max} ($p<0.05$). Despite the small sample size involved, it seems legitimate, based on our study and previous results, to advocate the use of simulated altitude training in order to enhance aerobic and anaerobic performance. Further research should be conducted in order to evaluate the effect of a longer or shorter training period in a hypobaric chamber within a large sample size of athletes.

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