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A Case Study on the Effect of Hypobaric-Hypoxic Intermittent Training on the Blood Constituents and Average Heart rate of Professional Handicapped Cyclists

The purpose of this study was to investigate the effects of hypobarichypoxic training program on competitive performance. This was done by observing their conditioning and measuring their blood constituents before and after a multi-staged intermittent training program, over 2 weeks. Three national handicapped cyclists were placed in a multi-leveled hypobaric-hypoxic (flat-4000 meter (m) high elevation) environment with consistent temperature and humidity (23 ± 2℃, 50 ± 5%) for 2 weeks. After the training, the blood constituents and average heart rate (HR) were measured and the following results were obtained. In all three athletes, there were no unique changes in red blood cell count, hemoglobin, and hematocrit, while there was a rise in the reticulocyte count. Observations of the difference in average HR during exercise at varying altitudes showed that athlete A had an average increase in the HR for the first 5 days at 2000 m. For athlete B, the comparison of the first and last training sessions at an altitude of 2000 m showed an HR increase of approximately 17%. For athlete C, there was a steady increase in the HR until day 7 of the training. As such, hypobaric-hypoxic training suggested that improvement of aerobic exercise performance in these athletes and it is recommended that there be a development for future training programs at high altitude, geared towards handicapped athletes of various disciplines.

Key words: *Hypobaric-hypoxic intermittent training; Constituents of Blood; Average Heart Rate*

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INTRODUCTION

Intermittent hypoxic training is an important training method for adaptation to high altitudes and is achieved through exposure to environments of both normal oxygen levels at sea level as well as hypoxic levels at irregular intervals. This type of training aims to heighten the exercise endurance capability of the athlete for performance at sea level1). There are two strategies for intermittent hypoxic training; the first is an approach that aims to acclimatize the body to high altitudes, where competitions may take place, by providing a concentration of low oxygen in stable conditions. The other method involves maximizing stimuli during training by supplying hypoxic oxygen concentrations during exercise [2, 3].

Liu et al. (1988) conducted the Living high training low (LHTL) method, which exposed subjects to altitudes at sea level and higher (1980 m), whereupon exercises were performed for the duration of 2 weeks, 12 hours or more per day. The results showed a decrease in the left ventricular systolic diameter and an increase in the ejection fraction, cardiac output, and stroke volume, revealing that through the LHTL method, there was an increase in systolic function, β-adrenergic receptors, and utilization of energy in the cardiac muscles, which stemmed from an increase in the contractility of the left ventricle [4]. Stray-Gunderson et al. (2001) carried out an LHTL, in which 22 track athletes were placed in living conditions at 2500 m and they exercised at 1250 m. The results of the study showed a 3% increase in the maximum oxygen consumption (VO^2max), a doubled erythropoietin (EPO), a 1.1% improvement in records at 3000 m, and a 12.5% duplication of personal bests, which showed that the LHTL improved blood circulation of oxygen and athletic performance [5]. In a study, which involved controlling oxygen saturation at high altitude (2000-3000 m), Wilber (2001) reported an increase in EPO and red blood cell count (RBC) after training [6]. Furthermore, Schmidt et al. (2002) showed that cyclists living at an altitude of 2600 m had an increased Hb and Lundby et al. (2005) observed eight trained men, who were exposed to the high altitude (4100 m) for 2 hours daily, for 14 days, and who later displayed no change in Hb, Hct, reticulocyte, serum transferrin receptor, and EPO. They however, did experience an increase in VO^2max [7, 8]. Brugniaux et al. (2006) conducted an LHTL studying 20 elite, middle and long distance track athletes, where for the first 6 days they were exposed to an altitude of 2500 m and for the remaining 12 days were moved to an altitude of 3000 m for a total of 18 days. Each exposure lasted for 14 hours each day and exercises were performed at an altitude of 1200 m. The study found that there was an increase in VO2max and maximum aerobic power, as well as a reduction in HR during exercise at 19.5 km/hr; these effects were shown to have a lasting effect of 15 days [9].

In contrast, Terrados (1988) trained road cyclists at an altitude of 2300 m, by performing endurance exercises at 60-70% of maximum intensity and interval training at an intensity of 100-130% for a duration of 3-4 weeks. While there appeared to be an increase in exercise capacity at high altitude, there were no changes observed in the control group at sea level [10]. Schmidt et al. (1990) conducted a study by training the average person, as well as athletes, at high altitude (2600 m) and observed no difference in Hb and Hct before and after the study, which led to the conclusion that at an altitude of 2600 m, there is not enough of a stimulus on the EPO system [11].

Excluding the results of Liu et al. (1988), a majority of the research conducted lacks an established, precise, training protocol regarding the measurement of the dependent variables, as well as most of the blood capacity for oxygen transportation, the VO^2max, the VO^2max during maximal workouts, and the exercise/athletic performance [4-11]. The considerable differences between an individual athlete's adaptive training response at natural or man made high altitudes contributes to this reality; however, it also stems from the fact that athletic disciplines have no corresponding, efficient program. This research was conducted to improve the competitive performance of cyclists, who participate in the most representative discipline of aerobic sport, through intermittent training at multi-leveled hypobaric-hypoxic environments for a duration of 2 weeks. The blood constituents and average heart rate were observed before and after the study to provide the most effective hypobaric-hypoxic training program for handicapped athletes.

SUBJECTS AND METHODS

Subjects

This study was performed on three national cyclists who have physical handicaps. The purpose and methods of the study were explained to the participants and informed consent was obtained according to the principles of the Declaration of Helsinki.

Table 1. General characteristics of the subjects

Item	Athlete A	Athlete B	Athlete C
Age	44	45	38
Height	164.2	165.3	173.4
Weight	66.2	54.0	67.5
Body Fat Percentage	24.5	19.1	21.5

Experiment Procedure

The environmental terms in which training were carried out, required consideration of the originality of the high altitude area to provide a hypobaric-hypoxic setting. Three physically handicapped, national cyclists were placed in a multi-leveled, hypobaric-hypoxic environment (sea level-4000 m high altitude) for 2 weeks for a total of 12 sessions, each session lasting 60 minutes, at a consistent temperature of 23 ± 2℃ and humidity of 50 ± 5%. The ventilatory threshold (VT) obtained through the pre-exercise load test was used as the basis of intensity for the combined (repetition, interval and continued) training on a roller type cycle.

The 12 sessions in the training program were performed as depicted in Table 2. The training intensity and altitude were determined through consideration of the athletes' daily cumulative training records and the condition of the athletes, as well as consultation with the representative athlete of the group. The initial intensity of exercise was extrapolated through the results of the maximal exercise load test, measured before the training of the athletes, whereupon the data was utilized to set a target heart rate, which corresponded to the VT.

Table 2. Training program

Sessions	Training altitude (pressure)	Mean training intensity, km/h			Comments
		Athlete A	Athlete B	Athlete C	
1st	2000 m (596 torr)	26.0	14.2	137.6	Jin – fixed type equipment on day 1
2nd	2000 m (596 torr)	25.2	14.7	30.7	
3rd	2000 m (596 torr)	26.0	16.2	31.3	
4th	2000 m (596 torr)	26.1	16.3	31.8	
5th	4000 m (462 torr)	24.4	13.9	31.5	
6th	2000 m (596 torr)	25.8	17.0	33.5	
7th	2500 m (560 torr)	26.1	17.1	33.2	
8th	2500 m (560 torr)	26.0 km/h	14.2	33.7	14-km individual time trial performed together
9th	3000 m (526 torr)	25.6 km/h	16.9	33.2	
10th	3000 m (526 torr)	24.6 km/h	15.9	29.6	5-min interval training performed together
11th	4000 m (462 torr)	24.4 km/h	14.1	33.1	
12th	2000 m (596 torr)	25.3 km/h	16.6	33.0	

In order to increase the physiological effects of the hypobaric-hypoxic training, a daily measurement of the occlusion, bilirubin, urobilinogen, ketone, protein, nitrite, glucose, pH, ratio, and leukocytes were taken using urine samples that were obtained in the mornings. In order to increase the blood capacity for oxygen transport, iron supplements (Iron 40 mg, U.S.) were also recommended. In addition, each athlete was provided with adjustments to their training program in accordance with their personal training, daily condition, and the opinions of their director.

Blood Constituent Tests

In order to analyze the blood capacity for oxygen transport, the subjects were prohibited from eating for more than 4 hours before approximately 6 ml of blood was drawn from the medial vein of the forearm, whereupon the blood was immediately refrigerated in a heparinized tube and then sent for clinical examination at the C Gen Medical Foundation. The RBC, Hb, hematocrit (Hct), and reticulocyte count were measured, using the cell counter analysis method. The complete blood count (CBC) time and the sheath rinse kit (Bayer, Ireland) of the automatic blood analyzer (ADIVA-120, U.S.) were used in order to isolate and make the red bloods and platelets spherical. Afterwards, using the light from a diode laser, the flow cell was entered at a low angle light scatter (2 – 3°), as well as a high angle light scatter (5 – 15°), and each volume and concentration was measured and analyzed by a detector. The mean erythrocyte volume (Hct × 10/RBC), blood Hb (Hb × 10/RBC), and the Hb concentration (Hb/Hct × 100) were then analyzed.

Before every training session, the Hb concentration was checked using a near infrared spectrometer, Astrim SU (Sysmax, Japan). Measurement was done by placing the left index finger into the instrument and keeping it still for about 20 seconds. During the training period, consumption of iron supplements (Iron 40 g, 3 times a day, 3 tablets, U.S.) was recommended to help improve blood oxygenation and circulation. The blood iron concentration was analyzed before and after the training using a ferritin kit (Bayer, U.S.) at the C Gen Medical Foundation.

Measurement of heart rate during exercise

The individual intensity (km/h) of the VT, obtained through a multi–level, maximum incremental load test at sea level, was used as a starting point for each athlete's initial exercise intensity. The multi–level (sea level – 4000 m high altitude), hypobaric–hypoxic environment, where the repetition, interval, and continued training programs, each of which had a corresponding altitude, took place, was developed in a joint effort between the cycling coaches.

Data analysis

The statistical analysis of the group is not included, as this study obtained data from only three athletes. Instead, this study will provide an individual presentation of the records of each athlete.

RESULTS

Change in blood constituents

Table 3 shows the results of the analysis of RBC, Hb, Hct, reticulocyte count, EPO, and ferritin in the three handicapped cyclists, before and after the hypobaric–hypoxic training, which took place for a duration of 2 weeks for 12 sessions. All three athletes displayed no particular changes in RBC, Hb, or Hct. The reticulocyte count in all three athletes showed an increase of approximately 0.7 – 1.1. The ferritin level was reduced to marginal levels of the normal range in athlete A when comparing pre–training (24.02 ng/ml) and post–training (19.98 ng/ml). The remaining two athletes also showed reduced levels within the normal range.

Table 3. Change in blood constituents

Category	Athlete A			Athlete B			Athlete C		
	before	after	variation	before	after	variation	before	after	variation
RBC(106/μl)	4.14	4.12	− 0.02	4.27	4.25	− 0.03	5.18	5.25	+ 0.07
Hb(g/dl)	13.60	13.60	0	13.00	13.10	+ 0.10	16.00	16.40	+ 0.40
Hct(%)	40.10	39.50	− 0.60	38.90	38.60	− 0.30	46.80	46.90	+ 0.10
Reticulocyte(%)	0.90	1.80	+ 0.9	1.20	1.90	+ 0.70	1.50	2.60	+ 1.10
EPO(mlU/ml	5.92	15.40	+ 9.48	15.80	22.60	+ 6.80	16.60	14.70	− 1.90
ferritin(ng/ml	24.02	19.98	− 4.04	28.23	24.67	− 3.56	117.71	72.55	− 45.16

Change in mean HR during exercises according to training

Observation of the mean HR during exercise at varying altitudes showed that, until day 5, athlete A had an increased average HR, when under an altitude of 2000 m, and on day 6, at an altitude of 6000 m, the mean HR was shown to have decreased during the training. Furthermore, between training on days 9 – 10 at an altitude of 2500 m and days 11 – 12 at an altitude of 3000 m, the average HR was lower when compared to the measurements taken at an altitude of 2000 m. However, relatively speaking, a similar level of HR was seen to have been maintained.

Athlete B had a significant increase in the average HR in the first 5 days of training within an altitude of 2000 m. Though the goal HR was set at 138.2 beats per minute (bpm), as determined through the results of the initial maximum exercise load test, and in correspondence with the VT (HRVT), athlete B had surpassed these levels. The comparison of the average HR during the first and last training sessions at the altitude of 2000 m shows

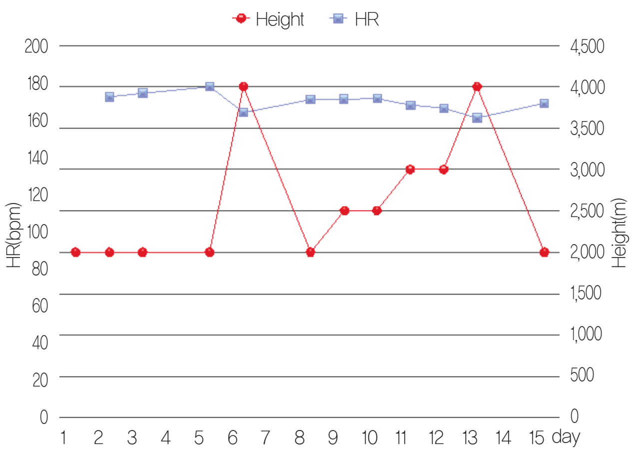

Fig. 1. A athlete, Change in mean HR during exercises according to training

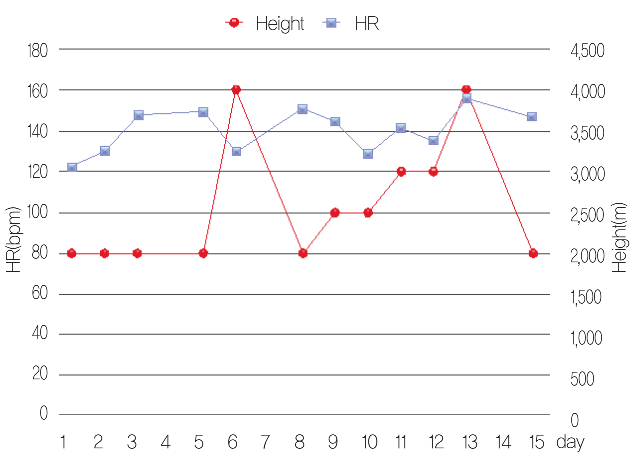

Fig. 2. B athlete, Change in mean HR during exercises according to

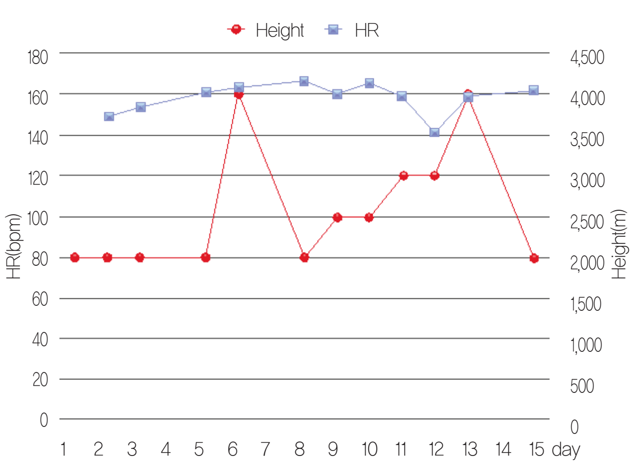

Fig. 3. C athlete, Change in mean HR during exercises according to training

an approximate 17% increase. It can be inferred that the repetition of training allowed for an increase in the ability to perform exercises with a high relative intensity.

Athlete C showed a continuous increase in the average HR for the first 7 days of the training. However, this trend was attributed to the missing calculation of the initial exercise intensity, whereupon an approximate exercise intensity (target heart rate 150 bpm) was set; this level was suspected as being lower than the fitness level of athlete C. One unique point of observation was made on day 6 at an altitude of 4000 m, where, during the exercise, the average HR appeared higher than the normal mean HR at an altitude of 2000 m. This phenomenon was used as a basis for the judgement that the exercise intensity value that was set was on the low side. Furthermore, the following training that took place at the altitudes 2500-3000 did not show a large reduction in the average HR and instead displayed a consistency, which suggests that repetitive hypobaric-hypoxic training enables athletes to perform relatively high intensity exercise through physical change.

DISCUSSION

This study observed three physically handicapped, national cyclists during a 2 week, 12 session (each session is 60 minutes) exercise program of combined (repetition, interval, continued) training on a roller style cycle in a multi-leveled, hypobaric-hypoxic (sea level-4000 m high altitude) environment with a consistent temperature of 23 ± 2℃ and humidity of 50 ± 5%. The VT obtained through the pre-exercise load test was used as the basis of intensity for the exercise training; after the training, the blood constituents and average heart rate were measured with the following results.

All three athletes showed no particular change in the RBC, Hb, and Hct due to the short duration of this study. Two weeks of training is not enough time to induce a change in the RBC and Hb. In order to observe a change in blood constituency in a high altitude environment, previous research suggests that a subject needs to be continuously exposed for a minimum of 3 weeks or longer, which the results of this study also showed [12, 13]. In a study conducted by Jung et al. (1997), which had three national alpine skiers live at an altitude of 2100 m while pursuing their training at altitudes of 2700-3500 m for a duration of 5 weeks, the RBC, Hb, and Hct increased in the blood [14]. This occurred in that study, as unlike this study, the skiers not only had a longer duration of training (5 weeks), but also were made to live in a high altitude environment.

All three athletes showed an increase in reticulocytes of around 0.7-1.1. Friedman et al. (1999) reported that after exposure to a hypobaric-hypoxic environment for approximately 1-3 weeks [15], there was an increase in reticulocytes. This study had a training period of 2 weeks and as such, the increase in reticulocytes makes sense clinically. However, during the training period, each session lasted only 3 hours in a hypobaric-hypoxic environment and therefore, when considering exposure, the lack of a significant increase in reticulocytes is also understandable. EPO changes within 2-3 days of exposure to hypobaric-hypoxic environments and, as this study had a training period of 2 weeks at an altitude of 2000-4000 m, such conditions account for the increase, which was experienced. However, it should also be noted that EPO might also increase due to a physiological response to the decrease in oxygen pressure, within the epithelium of the kidney, which has a rapid half-life; this may also be an explanation for the individual response in athlete C [16]. However, when considering that all three athletes experienced an increase in reticulocytes, it could be inferred that the EPO increased response would have appeared in all three athletes. Ferritin acts as an iron reservoir within the human body and an abnormal increase in ferritin may indicate iron deficiency anemia. If there is a decrease, there may be protein deficiency. For men and women alike, a normal range is 20-300 ng/ml [17]. Compared to before training (24.02 ng/ml), the concentration of ferritin in athlete A fell after exercise (19.98 ng/ml, the outer limits of the normal range), which indicates that there was a lack of protein during the training. In the rest of the athletes, the decrease remained within the normal range, which showed that adaptation to the hypobaric-hypoxic environment allowed for ferritin to be used to generate Hb. Therefore, athletes undergoing high intensity hypobaric-hypoxic training are advised to ensure an adequate iron intake (iron 40 mg, 3 times per day, 3 tablets), as well as an adequate protein intake (1.1-1.8 g per kg of body weight).

The change in average HR during exercise was compared and observed in relation to the training conducted at altitudes between 2000-4000 m. Exercise intensity during training was determined through consultation with the director of the team. The HR and speed for the training was variable and was adjusted depending on the condition of the athlete, as well as the situation.

In the case of athlete A, on day 5 of training at an altitude of 2000 m, the average HR increased and on day 6, at an altitude of 6000 m, the average HR decreased. This appeared to be because exercise in a hypoxic environment results in lack of energy due to a limited supply of oxygen, which in turn decreases the load during exercise. Furthermore, although the athletes training on days 9-10 at an altitude of 2500 m, and days 11-12 at an altitude of 3000 m showed a slightly lower average HR than with exercise conducted at an altitude of 2000 m, there still appeared to be a relatively uniform rate throughout. An observation worth noting was that when training was moved to higher altitudes of 2500-3000 m, the average HR remained similar, showing that the repetition of hypobaric-hypoxic training affects the relative intensity of the training [16,17]. Observation of athlete B showed that at day 5, when training at an altitude within 2000 m, there was a large increase in the average HR. Though the goal HR was set at 138.2 bpm, as determined through the results of the initial maximum exercise load test, and in correspondence with the VT (HRVT), athlete B had surpassed the levels. The comparison of the average HR during day one and day 15 of training at the 2000 m altitude shows an approximate 17% increase. It can be inferred that the repetition of training allowed for an increase in the ability to perform exercises with a high relative intensity. Until day 8 of the training, athlete C showed a steady increase in average HR, because the initial calculation of the exercise intensity was lost; therefore, an approximate exercise intensity (target heart rate 150 bpm) was set and this level was suspected to be lower than it should have been for the fitness level of athlete C. The data from the following training that took place at the altitudes of 2500-3000 m did not show a large reduction in the average HR and instead displayed a consistency, which suggests that repetitive hypobaric-hypoxic training enables athletes to perform relatively high intensity exercise through physical change. By day 15 of the training, which took place at an altitude of 2000 m, the average HR measured was increased by about 8.9%, compared to the initial measurement taken at the first training session.

This study has several limitations to be considered for future studies. First, since this study observed handicapped athletes, the findings of this study cannot be extrapolated and applied to subjects with normal physical function. Second, since this study was a case study without controls, future studies should compare the findings with normal subjects as controls. Third, the findings of this study may not be generalized, since the study was conducted with a relatively short duration and a limited number of subjects. Therefore, future studies should include greater number of subjects, mid- to long-term study duration, and comparative controls as subjects.

CONCLUSIONS

The results of the hypobaric-hypoxic training conducted for 2 weeks for 12 sessions, at an altitude of 2000 - 4000 m on three national handicapped athletes are as follows.

1. Regarding the change in blood constituency, there was no difference in the RBC, Hb, and Hct. There was, however, an increase in reticulocytes for all athletes.
2. Repeated hypobaric-hypoxic training showed that, despite the increase in altitude during training, all three athletes maintained or had a reduced HR. These trends suggest that exercise performance was improved.

Upon combining the results of this study, it can be inferred that the aerobic athletic performance of all the athletes had improved and as such it is recommended that future high-altitude training programs, which expand upon or apply hypobaric-hypoxic training, should be developed in order to improve the competitive performance of handicapped athletes from various sports disciplines.

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