

EFFECTS OF NORMOBARIC HYPOXIC EXERCISE FOR 6-WEEKS ON ENDURANCE PERFORMANCE IN MODERATELY TRAINED ROWERS

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Abstract

The purpose of this experiment was to investigate the effects of normobaric hypoxic training by rowing ergometer on aerobic performance and anaerobic threshold. Fourteen healthy male participants perform 30 min of continuous training in either a normoxic ($\text{FiO}_2 = 0.209$) or hypoxic ($\text{FiO}_2 = 0.145$) condition. The participants were randomly assigned into two groups, with 7 participants per group. Both the Control ($n = 7$) and Hypoxic ($n = 7$) group participants exercised on a rowing ergometer at an intensity corresponding to 80-90% of heart rate at anaerobic threshold attained in normoxia. Before the training (PRE), after three-week training (MID) and after six-week training (POST), the subject's aerobic performance and anaerobic threshold were determined by 7×4 rowing ergometer incremental test under the normoxic condition. The results showed that there was a significant improvement in the normoxic anaerobic threshold only for the Hypoxic groups ($p < 0.05$) at PRE-training compared to POST-training value. There was no difference in normoxic aerobic performance and the normoxic anaerobic threshold between the Control group; CON and the Hypoxic group; HYP ($p < 0.05$). In conclusion, the normobaric hypoxic training protocol manipulated in this experiment had a significant effect on development in the anaerobic threshold but no significant difference between Control and Hypoxic groups.

Keywords: Normobaric hypoxic exercise, aerobic performance, anaerobic threshold, rowing ergometer

Introduction

Rowing is a strength-endurance sport, which is mainly the aerobic activity with the anaerobic system contributing approximately 10-30% (Thornton *et al.*, 2017) because energy stores and glycolysis are limited to cover the energy demand. During a 2,000-m race, rowers perform maximal intensity activity, 95-98% of male rowers $\text{VO}_{2\text{max}}$ (Hagerman *et al.*, 1978) and 91% of female rowers $\text{VO}_{2\text{max}}$ (Pripstein *et al.*, 1999) usually lasts 5.5-7.5 min with the forces being exerted on the rowers handle for

each stroke is the equivalent of 400-500 N. The characteristics that provided the best discrimination between successful and unsuccessful rowers are physical characteristic such as long limb that relative to height (Hahn, 1990), lean body mass (Gayer, 1994) and physiological characteristic such as a high maximal aerobic power (Secher *et al.*, 1982), peak power, the lactate threshold (Gayer, 1994) and the ability to maintain high blood lactate concentrations during a race time (Hagerman,

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1984). Previous investigations strongly have supported that maximal oxygen consumption (VO_2max) and anaerobic thresholds are the meaningful predictor of rowing endurance performance and successful competition (Cosgrove *et al.*, 1999; Bourdin *et al.*, 2004; Shirai *et al.*, 2015).

Altitude or hypoxic training is a common and widespread practice among various athletes, coaches, and sports scientists for enhancing many aspects associated with endurance performance that may be altered by hypoxic training, including increases in erythrocyte volume, maximal aerobic exercise capacity, capillary density, and economy (Sinex and Chapman, 2015). Several approaches and modifications for altitude or hypoxic training have been proposed such as “live high-train high” (LHTH) - athletes live and train at moderate altitude (2,000-3,000 m) to high altitude (3,000-5,500 m), “live high-train low” (LHTL) - athletes live at moderate altitude (2,000-3,000 m), but train closer to sea-level (0-500 m) or subsequent sports performance (Levine and Stray-Gundersen, 1997) and “live low - train high” (LLTH) - athletes live at sea-level or normoxic condition and train some sessions at altitude or hypoxic conditions.

The concept of live low - train high (LLTH) or intermittent hypoxic training (IHT) approach is one of the techniques to improve endurance performance and recommended by many athletes and coaches for a potential benefit during the sea-level condition. The mechanisms underlying the enhancement in athletes' endurance performance at sea-level with hypoxic training are generally attributed to either cardiovascular, haematological, or ventilatory effects (Czuba *et al.*, 2017). Exercise in the hypoxic condition is to elicit a decrease in blood oxygen saturation (SO_2) that will lead to specific physiological adaptations in response to acute and chronic exposure to hypoxic condition (2,000-3,000 m) improves oxygen transport capacity by enhancing erythropoietin secretion and the significant increase in total haemoglobin mass-resulting in augmented maximal oxygen uptake (VO_2max) and enhanced endurance exercise performance. Current research results on the effectiveness of hypoxic training for enhancing endurance performance at sea-level are equivocal.

Only a few studies (Zoll *et al.*, 2006; Czuba *et al.*, 2011) reported enhanced endurance performance at sea-level following IHT, Meng *et al.* (2019) showed that four weeks of hypoxic training the increased cutaneous blood flow and improve endothelial function that seems to be one mechanism for improving endurance performance in rowers. While many research projects have failed to demonstrate improvement in sea-level performance after IHT (Morton and Cable, 2005; Roels *et al.*, 2007).

Such as the recent study of Czuba *et al.* (2017) showed the improvement in anaerobic capacity and swimming performance after the IHT but no effect on absolute values of VO_2max and haematological variables.

There have been studies that have investigated the effects of hypoxic training (LLTH) methods for endurance athletes' improvement, such as long-distance runners, long-distance swimmers, and cyclists. However, there have few studies on the effects of the other hypoxic training approach (Hinckson *et al.*, 2006; Neykov *et al.*, 2019), but not for IHT in rowers who performed a strength-endurance sport. This study aimed to investigate the effect of hypoxic training on endurance performance in moderately trained rowers. Such information will be useful for coaches and athletes to develop their hypoxic program and for sports scientists to help guide future research direction in the area.

Materials and Methods

Subject's Characteristics

Fourteen young male moderately trained rowers (mean $\pm$ SD: age = 20.0 $\pm$ 1.7 years; height = 1.72 $\pm$ 0.5 m; body mass = 69.1 $\pm$ 9.8 kg; VO_2max = 45.28 $\pm$ 6.0 ml/kg/min) volunteered to participate in the present study. Purposive sampling was used to select the grouping by using Cohen's sample table (Cohen, 1988) at the statistical significance level at 0.05, determining the effect size at 0.70 the power of the test at 1.30. The essential inclusion criteria were a minimum of at least 3 months of rest from previous hypoxic training. All participants had current medical examinations, without any contraindications to performing exhaustive exercise in a hypoxic condition. All participants gave written informed consent before participation in the study. The Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University approved the study and performed under the guidelines of the Helsinki Declaration.

The participants were randomly assigned to either the Hypoxic ($n = 7$), which exercised in a normobaric hypoxic condition ($\text{F}_i\text{O}_2 = 0.145$, corresponds to 3,000 m above sea-level) or the Control ($n = 7$) group, which exercised in normoxic conditions ($\text{F}_i\text{O}_2 = 0.209$).

Study Design

The exercise training consisted of twenty-four training sessions on a rowing ergometer over a period of six weeks (4 sessions per weeks). Normoxic aerobic performance and anaerobic

threshold were determined before the training (PRE), after week three training (MID), and after week six training (POST) by 7×4 rowing ergometer incremental test (adaptation from Rice and Osborne 2013). The participants were asked not to participate in any physical activity and not to drink caffeinated beverages prior to performance testes.

The training program included six weeks (24 sessions). The hypoxic group performed training in a normobaric hypoxic chamber; $F_iO_2 = 0.145$ equivalent to 3,000 m (see Figure 1 for study schematic). The control group performed the same training program in the normobaric hypoxic chamber at the Faculty of Sports Science, Chulalongkorn University. Training intensity was adjusted individually based on the results of anaerobic threshold determined in normoxia. Each workout was performed on a rowing ergometer and consisted of a 10-min general warm-up (60% of maximum workload determined in normoxia), a 30-min rowing ergometer exercise at an intensity corresponding to 80-90% of heart rate at anaerobic threshold attained in normoxia, and a 10-min cool-down (60% of maximum workload determined in normoxia).

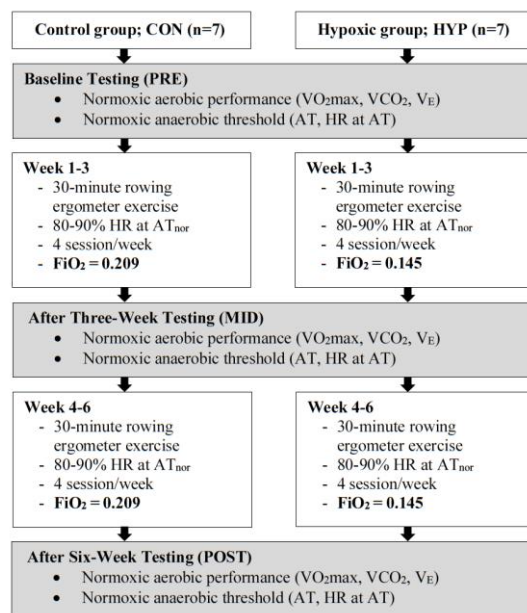


Figure 1. Schematic outlining the design and order of training and testing in the study

Physiological Fitness Testing

Before the training (PRE), after three-week training (MID), and after six-week training (POST), the participants performed an incremental test until exhaustion on a rowing ergometer (Concept2 model D, Concept2 Inc., USA) in the laboratory at sea level

conditions (Sports Science Laboratory, Chulalongkorn University, Bangkok, Thailand). In accordance with the Australian Institute of Sport (Rice and Osborne, 2013), the 7×4 min incremental test protocol used to measure the normoxic maximal oxygen consumption (VO_{2max}) and anaerobic threshold in this study. In the incremental test, the participants who considered as moderately trained rowers were asked to perform rowing exercise on a rowing ergometer (Concept2 model D, Concept2 Inc., USA) and complete six of 4 min submaximal at predetermined workload separated by 1 min rest period. The incremental test began at a 110 W workload while the sliding ergometer drag factor was set as 105, followed by increments of 20 W after the completion of each workload. In the final maximal workload, the participants were required to complete a maximal effort as possible in the 4 min period. Normoxic maximal oxygen consumption (VO_{2max}) and anaerobic threshold were determined using a cardiopulmonary gas exchange system (Metamax 3B, Cortex, Leipzig, Germany) during the incremental test. Maximal oxygen consumption (VO_{2max}) was determined as the highest value actually attained during a full min, and the anaerobic threshold was determined as the oxygen consumption (VO_2) at which a non-linear relationship between pulmonary ventilation (VE) and VO_2 during the incremental test.

Statistical Analyses

The obtained data were analyzed statistically with the use of SPSS version 20 for Windows statistical software package (SPSS Inc., Chicago, USA). The results were presented as arithmetic means and standard error of mean (S.E. Mean). The one-way ANOVA with repeated measures was applied to determine the influence of training in a normobaric hypoxic condition on aerobic performance and the anaerobic threshold at the normoxic condition. When significant differences in F ratio were found, the post hoc Tukey's test was used. The t-test for paired samples was applied to determine significant differences in values of aerobic performance and the anaerobic threshold between the PRE-, MID- and POST-training. The level of statistical significance was set at $p < 0.05$.

Results and Discussion

The physiological characteristics of the participants are summarized in Table 1. There were no significant differences in age, body weight, height, body mass index, resting heart rate, and maximal oxygen consumption (VO_{2max}) between the CON and HYP groups, they were homogeneous.

Table 1. Physiological data in the control (CON) and the hypoxic (HYP) groups

Variables	CON (n = 7)	HYP (n = 7)	p-value
Age (years)	20.85±2.47	19.14±0.37	NS
Body Weight (kg)	71.78±11.69	67.07±7.32	NS
Height (m)	1.72±0.06	1.72±0.05	NS
BMI (kg/m ²)	24.15±3.22	22.43±2.04	NS
Resting HR (bpm)	77.14±8.68	77.85±9.77	NS
VO ₂ max (mL/kg/min)	42.57±8.75	46.71±7.71	NS
VO ₂ max (L/min)	2.88±0.37	3.13±0.59	NS

Data are mean ± SD. CON = Control group, HYP = Hypoxic group. NS = Non-significant

Table 2. Aerobic performance and anaerobic threshold variables measured in normoxic incremental test before the training (PRE), after week 3 training (MID), and after week 6 training (POST) period

	CON group (n = 7)			HYP group (n = 7)		
	PRE- Training	MID- Training	POST- Training	PRE- Training	MID- Training	POST- Training
VO ₂ max (L/min)	2.88±0.14	3.09±0.30	3.43±0.26	3.13±0.22	3.35±0.20	3.46±0.19
VCO ₂ (L/min)	2.96±0.15	3.11±0.29	3.33±0.20	3.37±0.28	3.37±0.22	3.51±0.15
V _E (L/min)	112.87±3.29	110.38±3.74	124.14±6.68	124.78±7.38	126.98±6.65	126.58±5.98
HR at AT (bpm)	166.71±5.18	177.42±5.50	179.00±5.04	165.71±3.54	174.42±3.69	183.00±3.68
AT (mL/kg/min)	34.42±2.65	39.00±2.28	40.42±1.43	38.57±1.30	40.71±1.44	44.85±1.08*

Data are mean ± S.E. Mean. *Statistical difference from PRE-training at p<0.05, CON = Control group, HYP = Hypoxic group.

All participants completed 22-24 exercise sessions. The mean SpO₂ of the control group remained between 92% and 98% during exercise, whereas the mean SpO₂ of the Hypoxic group's decreased from 91±0.8%, at rest, to 82-89% during exercise.

There was no significant improvement in absolute maximal oxygen consumption and heart rate at anaerobic threshold value between PRE-training, MID-training and POST-training in both groups. However, only the HYP group showed significant improvement anaerobic threshold between PRE-training and POST-training, but no significant improvement in the anaerobic threshold between PRE-training, MID-training and POST-training in the CON group as shown in Table 2.

There were no significant differences in absolute maximal oxygen consumption (VO₂max), heart rate at anaerobic threshold (HR at AT) and anaerobic threshold (AT) measured in the normoxic condition when compared between the CON and the HYP groups.

The results showed that a 30-min continuous training including four weekly exercises on a rowing ergometer at an intensity corresponding to 80-90% of heart rate at normoxic anaerobic threshold performed over six weeks caused a significantly improve anaerobic threshold only the participants who performed in hypoxic (FiO₂ = 0.145) condition, without significant improvement in maximal oxygen consumption (VO₂max) in CON or HYP group. These results in the present experiment are following Roels *et al.* (2007) who investigated the effects of intermittent hypoxic

training, the simulated altitude of 3,000 m; 2 intervals and three continuous sessions per week for three weeks, improve only normoxic maximal power output in endurance-trained athletes, but not improve in VO₂max. The finding of this study shows that intermittent hypoxic training was less efficient for enhancing endurance performance at sea-level than training in normoxic condition. Similarly, Morton and Cable (2005) concluded that moderate- to high-intensity intermittent exercise 3 times per week for four weeks at a simulated altitude of 2,750 m (FiO₂ = 0.15) did not improve in either aerobic or anaerobic performance. Interestingly, Czuba *et al.* (2017) found that improved in relative values of VO₂max after IHT with high intensity (FiO₂ = 0.15) was correlated with a variation in body mass but not for absolute values of VO₂max, that was most likely caused by the insufficient time of a single repetition during the interval training protocol, which prevented a sufficient load to the cardiorespiratory system, and higher adaptive responses. These authors suggest that if there were any advantages to training in hypoxia for sea-level performance, they would not arise from the short-term protocol employed in these studies.

The studies, as mentioned above, have failed to demonstrate intermittent hypoxic training enhanced aerobic performance. On the contrary, many studies reported that intermittent hypoxic training improves sea level aerobic performance. Czuba *et al.* (2011) indicate that three sessions of intermittent hypoxic training per week for three weeks at lactate threshold intensity with medium duration (30-40 min) is a practical training means

for improving aerobic capacity and endurance performance at sea level. Similarly, Czuba *et al.* (2013) found that an intermittent hypoxic training protocol with high-intensity intervals, 4 to 5×4-min bouts at 90% of $\dot{V}O_{2\max}$ separated by 4 min of active recovery at 60% of $\dot{V}O_{2\max}$, at a simulated altitude of 2,500 m ($FiO_2 = 0.152$) improved sea level aerobic capacity in basketball players.

Consideration of the result of this investigation and studies mentioned above, there are several training variables in a hypoxic training program such as exercise intensity, a fraction of inspired oxygen (FiO_2) that related simulated altitude, frequency of training and duration of training. According to the review of Bonetti and Hopkins (2009) reported that exercise intensity is a dominant factor determining the magnitude of changes when training in hypoxic condition. Several researchers have shown that IHT training with the intensity near the anaerobic threshold and large-volume (20-30 min) led to enhancements in aerobic capacity and exercise performance. Dufour *et al.* (2006) have also shown, the moderate-duration hypoxic sessions resulting in increased endurance performance capacity, and Czuba *et al.* (2011) studies showed the medium-duration of intermittent hypoxic training at lactate threshold intensity is a practical training means for improving aerobic capacity and endurance performance at sea level that concluding the moderate- intensity (approximately anaerobic threshold) more efficiently improves performance than high-intensity exercise that manipulated in Roels *et al.* (2007) studies. However, in the present study, the exercise intensity which corresponding to 80-90% of heart rate at normoxic anaerobic threshold (below anaerobic threshold), less than the above studies (Dufour *et al.*, 2006, Roels *et al.*, 2007), caused improve only anaerobic threshold, without improvement in maximal oxygen consumption ($\dot{V}O_{2\max}$) similarly a lack of improvement was observed for prolonged low-intensity (60-70% of heart rate reserve) training sessions (Hamlin *et al.*, 2010). Czuba *et al.* (2017) suggest that accurately determined exercise intensity is not the only factor that determines improvements in endurance performance, especially $\dot{V}O_{2\max}$ following IHT protocols. The total training volume with properly adjusted exercise intensity is also essential to stimulate significant adaptive changes in well-trained athletes.

Study Limitations and Perspectives

Our study is the first in which the impact of rowing ergometer exercise in normobaric hypoxic condition on the rowing endurance performance was assessed in normoxia; however, there are certain limitations. Firstly, we conducted a study on a small

sample size. Secondly, in our study, we investigate the mechanisms underlying the enhancement in athletes' endurance performance attributed to a cardiovascular and ventilatory variable, except haematological variable. Future research haematological variables should be considered and investigated the relationship between variations in haematological variables on rowing endurance performance.

Conclusions

The results of this study demonstrate that 30-min continuous rowing exercise in normobaric hypoxic condition, four days per week for six weeks resulted in no beneficial in aerobic performance but improve only anaerobic threshold. The use of improper exercise intensity probably determines the results.

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