

高酸素気下での身体トレーニングの方が正常気下でのトレーニングよりも呼吸循環系能力および代謝に及ぼすトレーニング効果が大い

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Hyperoxic Training Results in Greater Training Effects on Cardiorespiratory Function and Metabolism than Normoxic Training

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Summary

To determine the physiological effects on aerobic capacity and metabolism of hyperoxic and normoxic training, fourteen healthy male college volunteers participated in the training study. The training intensity and period were 90% $\dot{V}O_{2max}$ and 3 days per week for 4 weeks. Subjects were divided into a hyperoxic training group (HT group: $n=7$, $\dot{V}O_{2max}=54.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), and a normoxic training group (NT group: $n=7$, $\dot{V}O_{2max}=54.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) according to their $\dot{V}O_{2max}$. The training duration in the HT group was 12'00", and that in the NT group ranged from 12'24" to 13'06" in order to equalize the amount of work performed by the two groups. Maximal and submaximal graded exercise tests were conducted at pre- and post-training. At post-training, $\dot{V}O_{2max}$ in the HT group was increased from 54.7 to 60.2 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. $\dot{V}O_{2max}$ in the NT group was also increased from 54.6 to 56.8 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The change ratio of $\dot{V}O_{2max}$ ($\Delta\dot{V}O_{2max}$) in the former group (about 10.0%) was significantly larger than in the latter group (about 4.2%). At post-training, respiratory exchange ratio and blood lactate concentration during the submaximal exercise test in the HT group were significantly lower than in the NT group. These results indicated that hyperoxic training was more useful for improving the $\dot{V}O_{2max}$ and might inhibit carbohydrate consumption and promote lipid utilization.

Key Words : hyperoxic training, maximal oxygen uptake, respiratory exchange ratio, blood lactate concentration

高酸素気吸入下および正常気吸入下での身体トレーニングが、有酸素能力および代謝に及ぼす影響を明らかにするために、14名の健康な男子大学生がトレーニング実験に参加した。被検者を任意に $\dot{V}O_{2max}$ がほぼ同じくらいになるよ

うに高酸素気吸入下での身体トレーニング群 (HT群: $n=7$, $\dot{V}O_{2max}=54.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), 正常気下での身体トレーニング群 (NT群: $n=7$, $\dot{V}O_{2max}=54.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) に分け、自転車エルゴメーターを用いて90%

$\dot{V}O_{2max}$ の強度で週 3 回, 4 週間のトレーニングを行った。トレーニング時間は HT 群では 1 回につき 12 分間, NT 群では総仕事量を同じにするために 12 分 24 秒から 13 分 6 秒の範囲であった。また, 漸増負荷法による最大運動テストと 90, 150 および 210 W で 3 分間, 合計 9 分間の最大下運動テストをトレーニング前後に行った。その結果, トレーニング後, HT 群では $\dot{V}O_{2max}$ が 54.7 から 60.2 ml \cdot kg⁻¹ \cdot min⁻¹ に, NT 群では 54.6 から 56.8 ml \cdot kg⁻¹ \cdot min⁻¹ に増加した。両群の増加率を比べてみると HT 群 (10.0%) の方が NT 群 (4.2%) よりも有意に大きいことが明らかになった。また, トレーニング後, HT 群では最大下運動テスト時の呼吸交換率および血中乳酸濃度が有意に低いことが明らかになった。これらのことから, 高酸素気吸入下での身体トレーニングは $\dot{V}O_{2max}$ を改善する点, 最大下運動時において糖質の消費を抑制し, 脂質の利用を促進する点で有効なトレーニングと考えられる。

Introduction

The effect of continuous exercise under hyperoxic condition (breathing high oxygen gas) on cardiorespiratory function differs from that under normoxic condition^{1,2)}. The improvement of performance time and work rate at maximal exercise load under hyperoxic condition is more marked than that under normoxic condition; minute ventilation volume, heart rate and blood lactate concentration at submaximal exercise load are more markedly decreased. The reported causes of these responses are the delayed fatigue of respiratory muscles^{3,4)} and inhibited blood acidosis due to Pasteur-effect^{5,6,7)}. Bye et al.³⁾ reported that fatigue of respiratory muscles was delayed by cycling under hyperoxic condition and that this response was related to the improved performance time. Hogan and Welch⁷⁾ reported that the

increased performance time under hyperoxic condition was caused by low blood lactate concentration at the beginning of exercise. Thus, subjects breathing hyperoxic gas can perform maximal exercise at higher intensity and/or for longer duration, and may be able to perform submaximal exercise with less fatigue.

Based upon the overload principle, high intensity is important to improve the aerobic capacity. Breathing hyperoxic gas allows greater and more prolonged exercise at an intense exercise level. Therefore, endurance training under hyperoxic condition (hyperoxic training) may be useful in acquiring greater training effects on cardiorespiratory function. In an animal experiment, hyperoxic training may have a decreased carbohydrate consumption and increased lipid utilization during exercise⁸⁾. Though a few studies concerning hyperoxic training have been made on the improvement of aerobic capacity⁹⁾, little is known about the metabolic responses such as respiratory exchange ratio or blood lactate concentration in human beings.

Therefore, we tried to determine the influence of hyperoxic training on metabolism from the respiratory exchange ratio and blood lactate concentration responses.

Methods

Subjects

Fourteen healthy male college volunteers (age = 19.5 \pm 1.2 years) participated in the present study. They were divided into a hyperoxic training group (HT group: n = 7) and a normoxic training group (NT group: n = 7) according to their $\dot{V}O_{2max}$. Written consent was obtained from each subject as to the nature of the study, and its possible risks and benefits were explained. Table 1 shows

Table 1. Physical characteristics of subjects

Variable		HT group	NT group
Age	(yrs)	19.7 ± 1.2	19.3 ± 1.1
Weight	(kg)	61.5 ± 8.8	60.9 ± 6.0
Height	(cm)	171.2 ± 4.6	171.6 ± 1.7
Training Intensity	(W)	236.8 ± 22.5	210.0 ± 15.0
Training Duration	(min)	12.0 ± 0.0	12.8 ± 0.8

Values are mean ± SD.

the physical characteristics and training condition of the subjects.

Protocol

To determine the training intensity, we conducted two maximal exercise tests under normoxic and hyperoxic conditions and one submaximal exercise test under normoxic condition in random order. These tests were conducted at an interval of two days to minimize the influence of subject fatigue or training effect. All tests were done during a ten-day period. Although the subjects were told that all experiments were done while they were breathing hyperoxic gas, in fact, they inspired either air or hyperoxic gas from the Douglas bags. Before testing, they sat on a cycling ergometer for twenty minutes and breathed either hyperoxic gas or air through a mouthpiece. This method is required to equilibrate alveolar nitrogen to the inspired nitrogen content when hyperoxic gas is inhaled¹⁰⁾. The maximal exercise test consisted of progressive cycling until exhaustion. After resting, the subjects pedaled at the work rate of 120, 180 and 210 W for two minutes each, followed by 15 W increase every two minutes. The pedaling rate was 60 revolution per minute (rpm). The pedaling rate below 45 rpm was used as the criterion for exhaustion. For submaximal exercise test after resting, the subject pedaled at 90, 150 and 210 W for three minutes each for a

total of nine minutes.

Training

The training intensity in the HT group was 90% of $\dot{V}O_{2max}$, which was obtained using the formula for the relationship between $\dot{V}O_2$ and work rate under hyperoxic condition. The training duration was twelve minutes. The training intensity in the NT group was 90% of $\dot{V}O_{2max}$, obtained by the formula for the relationship between $\dot{V}O_2$ and work rate under normoxic condition. The training duration in this group varied from 12'24" to 13'06". In both groups, the training frequency and period were 3 days per week for 4 weeks.

Hyperoxic Gas

A gas mixture of 58.9% O₂ in N₂ was used as the hyperoxic gas. The mixture was selected because no oxygen toxicity has been reported for breathing 60% oxygen gas in animal experiments¹¹⁾ and because the most marked improvement of performance time and work rate has been reported when 60% oxygen gas is breathed^{1,2)}. In the oxygen breathing experiments, the subjects inhaled from 200-liter Douglas bags, in which the hyperoxic gas had been flushed from a pressure cylinder. The gas was moistened by bubbling it through a water bottle.

Measurements

In the maximal exercise tests, the expired gas was collected in Douglas bags every minute ; in the submaximal exercise tests, it was collected every minute at each work stage. $\dot{V}E$ was measured by evacuating the Douglas bags through a DS-2A-T dry-gas meter (Shinagawa Co., Ltd.). The O_2 and CO_2 fractions were measured using a 1H-21B gas analyzer (Sanei Co., Ltd.), and $\dot{V}O_2$, $\dot{V}CO_2$ and respiratory exchange ratio (RER) were calculated. The gas analyzer was calibrated with known gas concentrations. Heart rate (HR), systolic blood pressure (SBP) and diastolic blood pressure were measured using a DS-503 dynascope (Fukuda Denshi Co., Ltd.) and STBP-780B automatic blood pressure device (Fukuda Denshi Co., Ltd.), respectively. Oxygen pulse ($O_{2\text{ pulse}} : \dot{V}O_2/HR$) during the maximal exercise tests and pressure rate product (PRP : $HR \times SBP$) during the submaximal exercise test were calculated. The blood lactate concentration (BL) was analyzed by the enzymatic technique using a YSI-23A Lactate Analyzer (YSI Co., Ltd.). Samples of $50 \mu m^3$ blood were drawn from the tip of the middle finger at each work stage. Performance time (P.

Time) until exhaustion was measured using a digital computer watch.

Statistics

In each group, pre-training data were compared with post-training data using paired Student's t-test. Data in the HT group were compared with those in the NT group using non-paired Student's t-test. The P level of 0.05 was used to determine statistical significance.

Results

As shown in Table 2, P.Time, $\dot{V}O_{2\text{max}}$ and $O_{2\text{ pulse}}$ at post training were significantly increased compared with pre-training data in both groups. There was no significant difference between the two groups in $\Delta P.$ Time or $\Delta O_{2\text{ pulse}}$. However, $\Delta \dot{V}O_{2\text{max}}$ in the HT group was significantly larger than in the NT group.

The results for the submaximal exercise tests under normoxic condition are presented in Figure 1 and 2. In the HT group, RER and HR at 150 W and 210 W were significantly decreased, and BL and PRP were also significantly decreased at all three work rates after

Table 2. Results of the maximal exercise test under normoxic condition at pre- and post-training

Variable		HT group	NT group
P. Time	pre (min)	9.5 ± 2.8	9.3 ± 2.2
	post (min)	11.4 ± 2.6**	10.9 ± 2.4**
	Δ (%)	25.3 ± 12.5	21.0 ± 10.9
$\dot{V}O_{2\text{max}}$	pre ($ml \cdot kg^{-1} \cdot min^{-1}$)	54.7 ± 3.5	54.6 ± 4.2
	post ($ml \cdot kg^{-1} \cdot min^{-1}$)	60.2 ± 3.2**	56.8 ± 4.0**
	Δ (%)	10.0 ± 4.5 §	4.2 ± 2.3
$O_{2\text{ pulse}}$	pre ($ml \cdot beat^{-1}$)	18.2 ± 2.4	18.1 ± 1.5
	post ($ml \cdot beat^{-1}$)	19.8 ± 2.0**	19.1 ± 1.7**
	Δ (%)	8.1 ± 4.3	5.2 ± 4.0

Values are mean ± SD.

P. Time : performance time ; Δ : (post - pre)/pre × 100

** ($p < 0.01$) : significant difference between pre- and post-training values

§ ($p < 0.05$) : significant difference between HT and NT group

training. In the NT group, RER, HR, BL and PRP at 210 W were significantly decreased. After training, there were significant differences in RER and BL at all three work rates, and in HR and PRP at 150 W and 210 W between the two groups.

Discussion

Many studies have indicated that there is greater improvement of cardiorespiratory function, performance time and work rate under the hyperoxic condition than under normoxic condition¹⁻⁷. However, few studies have been carried out on endurance

training while breathing a hyperoxic gas for the purpose of increasing loading intensity⁹.

The major findings of the present study were that, compared with normoxic training, hyperoxic training resulted in greater improvement in $\dot{V}O_{2max}$ and more marked decline of RER, HR, BL and PRP under normoxic condition.

To our knowledge, there have been no studies concerning hyperoxic training effects on cardiorespiratory function and metabolism at submaximal exercise. In the HT group, RER, HR, BL and PRP after training were more markedly decreased compared with those in the NT group (Figure 1 and 2).

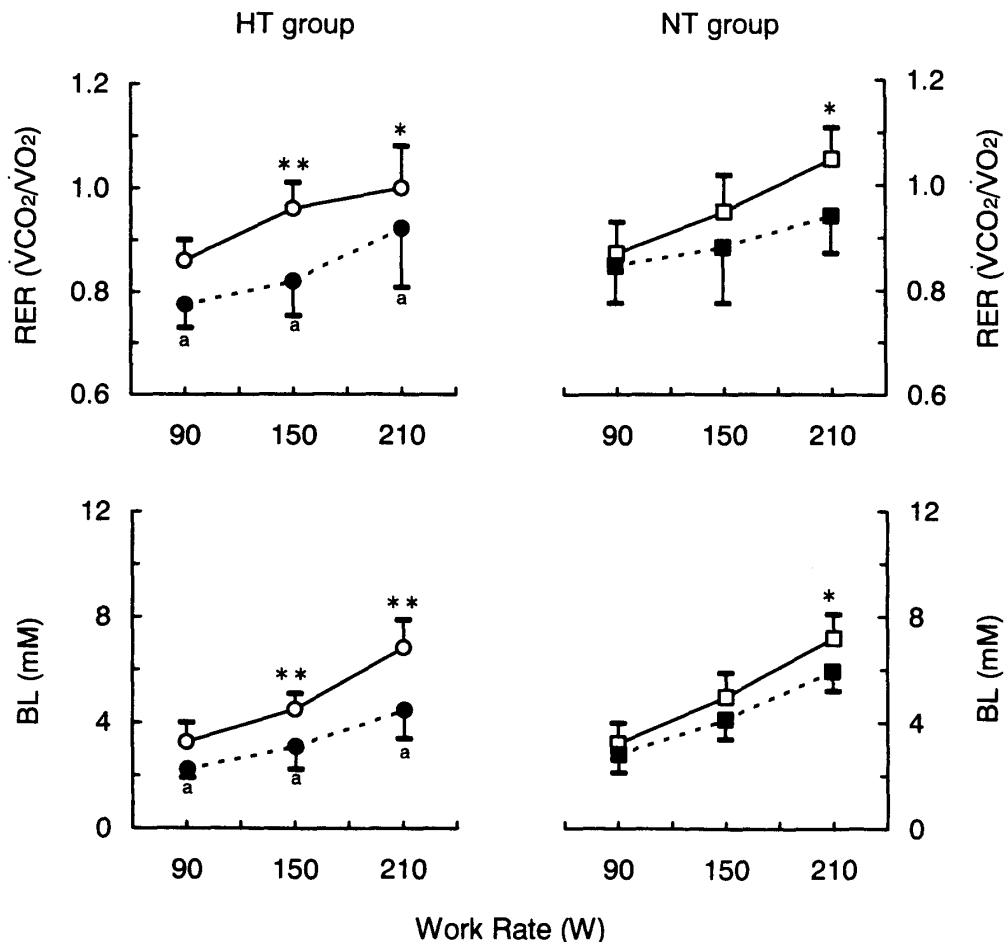


Figure 1. RER and BL in the HT group (left figure) and the NT group (right figure) at three submaximal work rates under normoxic condition pre- (solid line) and post- (dotted line) training.

Data are presented as mean \pm SD.

* ($p < 0.05$), ** ($p < 0.01$): significant difference between pre- and post-training values

a ($p < 0.05$): significant difference between HT and NT training

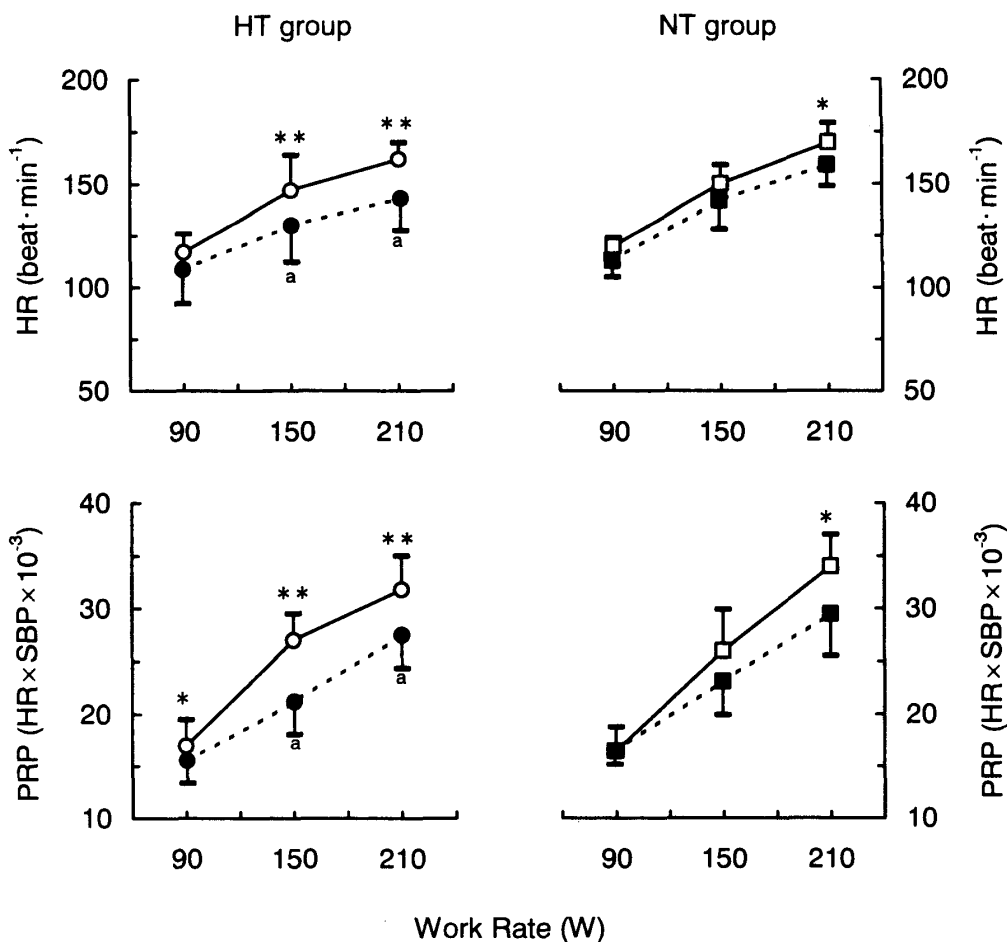


Figure 2. HR and PRP in the HT group (left figure) and the NT group (right figure) at three submaximal work rates under normoxic condition pre- (solid line) and post- (dotted line) training.

Data are presented as mean \pm SD.

* ($p < 0.05$), ** ($p < 0.01$): significant difference between pre- and post-training values

a ($p < 0.05$): significant difference between HT and NT training

Fujise et al.⁸⁾ reported that hyperoxic training caused a decrease of $\dot{V}CO_2$ during exercise and the maintenance of blood glucose content after training, and they indicated that hyperoxic training might alter the content of tissue glycogen and triglyceride in rats. Although RER during exercise is not always an accurate indicator of the metabolic state of active muscle, it has been reported to be an index of the carbohydrate and lipid oxidative ratio¹²⁾. Therefore, the larger decrement of RER during exercise after hyperoxic training in our experiment would depend on the increase of lipid utilization caused by the

increase of PO_2 ¹³⁾. On the other hand, BL during exercise has also been reported to be negatively correlated with lipid oxidation capacity¹⁴⁾. In addition, the decrease of RER and BL after hyperoxic training suggests the inhibition of the carbohydrate metabolism and the promotion of the lipid metabolism.

PRP is used as an indirect index of the oxygen requirement in the heart muscle¹⁵⁾. Kitamura et al.¹⁵⁾ reported that PRP change was highly correlated to myocardial oxygen consumption. So, we consider the decrease of HR and PRP after hyperoxic training to be the decreased burden on the heart muscle

and/or the increased stroke volume following endurance training at higher intensity.

Many studies have been carried out concerning the physiological training effects of normoxic training^{16~19)}. Training effects on cardiorespiratory function and metabolism acquired by hyperoxic training were the same in nature as the effects by normoxic training. The most characteristic feature of hyperoxic training in our experiment was the greater improvement of cardiorespiratory function and metabolism at shorter duration.

P. Time, $\dot{V}O_{2max}$ and $O_{2\ pulse}$ were significantly increased by both hyperoxic and normoxic training. Although these values in the HT group were not significantly different from those in the NT group, the $\Delta\dot{V}O_{2max}$ in the former group was significantly larger than in the latter. These findings are consistent with the results of previous study⁹⁾. Many researchers have reported that training intensity is the most important factor in improving $\dot{V}O_{2max}$ ^{17,20~22)}. Wenger and Bell²²⁾ reported that $\Delta\dot{V}O_{2max}$ was increased in direct proportion to training intensity (% $\dot{V}O_{2max}$) up to 90% $\dot{V}O_{2max}$, but that no further increase was observed at 100% $\dot{V}O_{2max}$ due to lack of training duration. In the present study, the training intensity in the HT group was about 12.7% greater than in the NT group and corresponded to approximately 97.8% $\dot{V}O_{2max}$ under normoxic condition. According to Wenger and Bell's opinion²²⁾, in the present study $\dot{V}O_{2max}$ might not be increased after training. However, the $\Delta\dot{V}O_{2max}$ in the HT group was significantly larger than in the NT group. One reason for this difference is that the exercise under hyperoxic condition was of sufficient duration.

Conclusion

Short-term hyperoxic training resulted in greater improvement of $\dot{V}O_{2max}$ and might inhibit carbohydrate consumption and promote lipid utilization, judging from the RER and BL decrease during submaximal exercise.

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