

ORIGINAL ARTICLE

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The effects of intermittent exposure to hypoxia during endurance exercise training on the ventilatory responses to hypoxia and hypercapnia in humans

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Abstract The present study was performed to investigate the effects of a combination of intermittent exposure to hypoxia during exercise training for short periods on ventilatory responses to hypoxia and hypercapnia (HVR and HCVR respectively) in humans. In a hypobaric chamber at a simulated altitude of 4,500 m (barometric pressure 432 mmHg), seven subjects (training group) performed exercise training for 6 consecutive days ($30 \text{ min} \cdot \text{day}^{-1}$), while six subjects (control group) were inactive during the same period. The HVR, HCVR and maximal oxygen uptake ($\dot{V}O_{2\text{max}}$) for each subject were measured at sea level before (pre) and after exposure to intermittent hypoxia. The post exposure test was carried out twice, i.e. on the 1st day and 1 week post exposure. It was found that HVR, as an index of peripheral chemosensitivity to hypoxia, was increased significantly ($P < 0.05$) in the control group after intermittent exposure to hypoxia. In contrast, there was no significant increase in HVR in the training group after exposure. The HCVR in both groups was not changed by intermittent exposure to hypoxia, while $\dot{V}O_{2\text{max}}$ increased significantly in the training group. These results would suggest that endurance training during intermittent exposure to hypoxia depresses the increment of chemosensitivity to hypoxia, and that intermittent exposure to hypoxia in the presence or absence of exercise training does not induce an increase in the chemosensitivity to hypercapnia in humans.

Key words Exercise training · High altitude · Ventilatory response to hypoxia · Ventilatory response to hypercapnia

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Introduction

An increase in alveolar ventilation, during acclimatization, has been demonstrated to be one of the most important adaptations to high altitude for maintaining an adequate oxygen partial pressure in the alveolae (Schoene 1982). It has been generally accepted that the ventilatory response to hypoxia is mainly mediated by the sensitivity of peripheral chemoreceptors (Vizek et al. 1987; Dwinell et al. 1997) and is dependent on the individual's chemosensitivity to hypoxia (Weil et al. 1970). Thus, the increase of pulmonary ventilation at altitude has been considered to be closely related to an alteration of the ventilatory response to hypoxia (HVR), as an index of peripheral chemosensitivity to hypoxia. Most studies have shown that HVR at rest increases during varying lengths of stay at altitude or during chronic exposure to hypoxia (Forster et al. 1971; White et al. 1987; Schoene et al. 1990; Sato et al. 1992, 1994).

In addition to HVR, the ventilatory response to hypercapnia (HCVR) has also been found to increase during sojourns at altitude or during chronic exposure to hypoxia (White et al. 1987; Schoene et al. 1990). Studies in elite climbers have demonstrated a high HVR (Schoene 1982) and HCVR (Schoene 1982; Masuyama et al. 1986) compared with sedentary subjects. Based on these results, Schoene et al. (1984) have suggested that a large ventilatory response to chronic hypoxia may be advantageous for performance at altitude as it produces an increase in arterial oxygen partial pressure and saturation (S_aO_2). To our knowledge, however, there are no data available concerning the effects of intermittent exposure to hypoxia for short periods on HVR and HCVR in humans.

On the other hand, it has hitherto been observed that HVR and HCVR at rest in endurance athletes is lower than in untrained subjects (Byrne-Quinn et al. 1971; Miyamura et al. 1976; Schoene 1982; Harms and Stager 1995). The blunted chemosensitivity to HVR and HCVR in the endurance athletes has been considered to be due

to endurance training over long periods (Miyamura and Ishida 1990). From these results, one can suggest that exercise training and exposure to hypoxia might have opposite effects on HVR and HCVR. To investigate this possibility, Levine et al. (1992) have examined the effect of intermittent exposure to hypoxia on HVR during endurance training in a hypobaric chamber at a simulated altitude of 2,500 m for 5 weeks. They have observed an increase in HVR determined at rest after endurance training in a hypobaric chamber. Since a control subject was not used and HCVR was not measured in their study, it is relevant to ascertain whether or not HVR and HCVR would be altered by intermittent exposure to hypoxia for short periods during endurance training.

The aim of this study, therefore, was to examine the hypothesis that exercise training for endurance combined with intermittent exposure to hypoxia may contribute to depressing the HVR and HCVR in healthy humans. To this purpose, resting HVR and HCVR were determined in both training and control groups before and after exposure to the combined effects of intermittent hypoxia in the presence or absence of training for endurance for 6 consecutive days.

Methods

Subjects

A group of 13 healthy male volunteers not involved in any regular physical training programme, who had no history of cardiorespiratory diseases, and who were not taking any type of medication volunteered to participate in this study. The subjects were assigned at random to either a training ($n = 7$) or a control group ($n = 6$). Average values for age, height and body mass were 19.0 (SD 2.6) years, 173.5 (SD 6.9) cm, and 62.0 (SD 0.9) kg for the training group, and 19.5 (SD 2.7) years, 170.4 (SD 6.1) cm, and 65.7 (SD 4.4) kg for the control group, respectively. There were no significant differences in age or physical characteristics between the groups before the experiments. The subjects were informed of the experimental protocol and possible risks involved in this study and their informed consent was obtained. The study was approved by the Human Research Committee of the Research Center of Health, Physical Fitness and Sports of Nagoya University.

Experiment procedures

The subjects came to the laboratory at least five times before any actual measurements were made. On the 1st day, all the subjects were familiarized with the equipment and procedures involved in the study at sea level and in the hypobaric chamber. On a 2nd day, about 1 week later three tests were conducted on each subject to determine (1) HVR, (2) HCVR and (3) maximal oxygen uptake ($\dot{V}O_{2\max}$). All these measurements were performed at sea level (pre) and post exposure to hypoxia. The post exposure test was conducted twice, i.e. on the 1st day after the 6 days of exposure to intermittent hypoxia (post) and again 1 week later. A hypobaric chamber was used for the intermittent exposure to hypoxia and for the exercise training. The barometric pressure (P_b) in the hypobaric chamber was gradually lowered to 432 mmHg (corresponding to an altitude of 4,500 m) for about 30 min while the subjects were in the chamber. All the subjects stayed at P_b 432 mmHg for about 1 h. The subjects in the training group performed exercise training on a cycle ergometer at a pedalling frequency of 60 rpm, while the

subjects in the control group were relaxed in comfortable chairs. The training protocol consisted of two 15-min periods of exercise, interspersed with 15-min of recovery at rest. The exercise intensity was set at 40% of $\dot{V}O_{2\max}$ at sea level. At the same time as the subjects in the training group were exercising, the subjects in the control group were required to sit and rest in the hypobaric chamber at the same P_b . The S_aO_2 was measured at rest in both groups and during the cycle ergometer exercise in the training group. All the subjects lived at sea level during the 22 h \cdot day⁻¹ they were outside the chamber.

HVR and HCVR

Resting HVR at sea level for each subject was measured using a progressive isocapnic hypoxia test as proposed by Weil et al. (1970). The HVR was measured using a rebreathing system similar to the rebreathing closed circuit connected to a small bag that has been used by Ohyabu et al. (1990). The subjects breathed through a mouthpiece attached to a hot wire flowmeter (Minato Ikagaku, type RF-H, Japan). Tidal volume, minute inspiratory volume (\dot{V}_I), end-tidal CO_2 and O_2 fraction ($F_{ET}CO_2$ and $F_{ET}O_2$) and S_aO_2 were determined continuously during rebreathing. The peak $F_{ET}CO_2$ and $F_{ET}O_2$ were analysed using a Minato Ikagaku gas analyser (type MG-360, Japan), samples of gas being drawn through a sampling tube connected to the mouthpiece in order to calculate end-tidal partial pressure of CO_2 and O_2 ($P_{ET}CO_2$ and $P_{ET}O_2$).

The S_aO_2 was measured on the tip of the left forefinger during rebreathing using a pulse oximeter (Nihon Koden, OLV-1200, Japan). All ventilatory and circulatory signals were displayed on the screen of an oscillograph and converted from analogue to digital by an A-D converter (Canopus, ADX-98X, Japan) at a sampling frequency of 100 Hz, stored on a hard disk unit and analysed afterwards using our own software on a personal computer (NEC, PC-9801XA, Japan).

After the subjects had been seated comfortably chairs for 30 min, they began breathing room air through a mouthpiece with a noseclip applied. When stable levels of $P_{ET}O_2$, $P_{ET}CO_2$, and S_aO_2 had been achieved, the subjects switched to a rebreathing closed circuit system consisting of a bag containing 10–12 l of room air. The rate of fall of $P_{ET}O_2$ was approximately 10 mmHg \cdot min⁻¹. During the HVR test, $P_{ET}CO_2$ was held constant at ± 2 mmHg by drawing a part of the expired gas through a CO_2 absorber and returning it to the circuit. Rebreathing was usually continued for 7 to 10 min until either $P_{ET}O_2$ decreased from the base-line value (95–105 mmHg) to 40 mmHg or S_aO_2 decreased from 97%–98% to 70%–75%.

The HVR was estimated as the value of the slope of $\Delta\dot{V}_I/\Delta S_aO_2$ (litres per minute per percentage oxygen saturation) and presented as positive numbers. On the other hand, the HCVR at rest was measured by the rebreathing method of Read (1967), i.e. the subjects rebreathed a gas mixture of 7% CO_2 in O_2 from bags (5–6 l each) for 3–4 min. The \dot{V}_I and $P_{ET}CO_2$ were measured continuously during rebreathing. The slope of the HCVR curve was calculated using the following equation, $\dot{V}_I = S(P_{ET}CO_2 - B)$, where S is the slope of the line expressed as the change in ventilation per unit change in $P_{ET}CO_2$ ($\Delta\dot{V}_I/\Delta P_{ET}CO_2$, in litres per minute per millimetre of mercury) and the intercept B represents the CO_2 threshold. The HCVR was estimated as the values of S.

Maximum oxygen uptake

The $\dot{V}O_{2\max}$ was determined at sea level using an incremental protocol on an electromagnetically braked cycle ergometer. After a 2-min warm-up at an exercise intensity of 60 W, the intensity was increased 30 W every 2 min until 210 W, after which the exercise intensity was increased by 15 W every 2 min until the subject was exhausted. The pedalling rate was kept constant at 60 rpm with the aid of a metronome. To measure oxygen uptake ($\dot{V}O_2$), expired gases were collected into a Douglas bag during the last 30 s of each intensity level until the subject was exhausted. Expired gas volume

was measured with a wet-gas meter (Shinagawa Dev., type WE, Japan) and gas analysis was performed using O₂ and CO₂ analysers (Minato Ikagaku, type MG-360, Japan).

Heart rate (HR) was monitored during the maximal cycle ergometer test from an electrocardiogram. The peak pulmonary ventilation (\dot{V}_E , body temperature and pressure saturated) at each intensity was estimated as $\dot{V}_{E\max}$. The $\dot{V}O_2$ derived during maximal exhausting exercise was considered to be $\dot{V}O_{2\max}$ when two of the following three criteria were satisfied: identification of a plateau in $\dot{V}O_2$ with an increase in power output (<200 ml $\dot{V}O_2$ increase), HR \pm 10% of age predicted maximum (220-age), and respiratory exchange ratio \geq 1.0.

S_aO₂ in hypobaric chamber

In the hypobaric chamber, S_aO₂ was measured by a pulse oximeter (Nihon Koden, OLV-1200, Japan) on the tip of the left forefinger at rest in both groups and during exercise training on the cycle ergometer in the training group. The S_aO₂ during exercise was measured during the last 30 s of each session of exercise training. During measurement of S_aO₂, the subjects were not allowed to grip the handlebars or move their left hands and to keep the position of their left hands as constant as possible to avoid motion artefacts.

Statistics

The changes in the parameters for each group during the experimental periods were compared using a one-way analysis of variance (ANOVA) with repeated measurements. When significant differences were observed, a contrast test was done to compare with each session (pre, immediately post, and 1 week later). The relationships among the parameters were determined by a simple linear regression analysis. The level of significance was set at 5%.

Results

Mean values of HVR measured at pre, immediately post and 1 week later were 0.50 (SD 0.29), 0.75 (SD 0.40) and 0.74 (SD 0.41) l · min⁻¹ · %⁻¹ in the control group, and 0.74 (SD 0.70), 0.83 (SD 0.50) and 0.75 (SD 0.41) l · min⁻¹ · %⁻¹ in the training group, respectively. There were no significant differences in the HVR measured at pre in either group. The HVR was significantly increased ($P < 0.05$) in the control group after intermittent exposure to hypoxia for 6 consecutive days, but not in the training group. The elevated HVR in the control group remained for 1 week as shown in Fig. 1. On the other hand, mean values of HCVR measured at pre, immediately post and 1 week later were 1.58 (SD 0.62), 1.53 (SD 0.67) and 1.41 (SD 0.52) l · min⁻¹ · mmHg⁻¹ in the control group, and 2.04 (SD 1.46), 1.94 (SD 1.08) and 1.99 (SD 1.23) l · min⁻¹ · mmHg⁻¹ in the training group, respectively. As shown in Fig. 2, there was no statistical change in HCVR in either of the groups after intermittent exposure to hypoxia for 6 days.

Table 1 indicates $\dot{V}O_{2\max}$, $\dot{V}_{E\max}$, ventilatory equivalents for oxygen ($\dot{V}_E/\dot{V}O_2$) and carbon dioxide ($\dot{V}_E/\dot{V}CO_2$) obtained at exhaustion during the maximal cycle ergometer test at sea level at pre, immediately post and 1 week later in the two groups. The $\dot{V}O_{2\max}$ in the training group was significantly increased by 6% ($P < 0.05$) immediately after combined hypoxia and exercise training and the increased $\dot{V}O_{2\max}$ remained

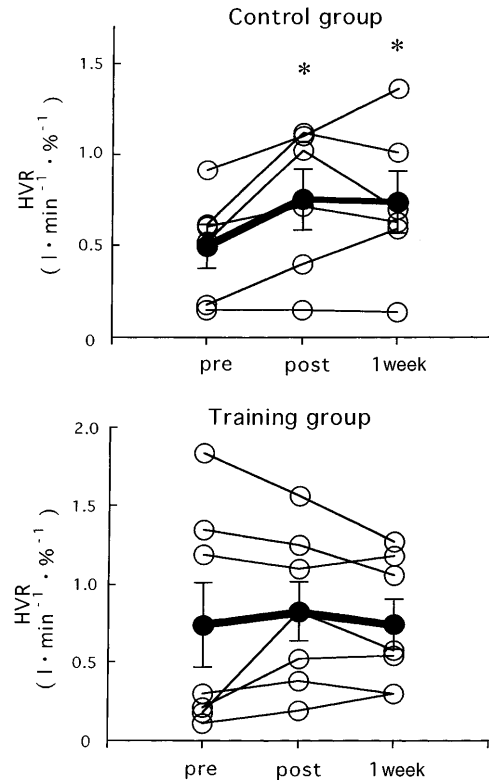


Fig. 1 Comparison of ventilatory response to hypoxia (HVR) determined before (*pre*), on the 1st day (*post*) and 1 week after intermittent exposure to hypoxia for each subject. Mean values with standard errors are shown as filled circles. * $P < 0.05$ Compared with pre exposure to hypoxia

1 week later. On the other hand, there was no statistical differences in $\dot{V}O_{2\max}$ in the control group pre, immediately post, and 1 week after the intermittent exposure to hypoxia. The mean values of $\dot{V}_{E\max}$ during maximal exercise also increased significantly ($P < 0.05$) in the training group after the combination of intermittent exposure to hypoxia and exercise training, but not in the control group (Table 1). The mean values of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ obtained at exhaustion during exercise were not increased significantly in either of the groups (Table 1).

Table 2 shows the results of S_aO₂ in both groups measured in the hypobaric chamber during the 6 consecutive days. The S_aO₂ at rest consistently increased over the 6 days in both the control and training groups. The S_aO₂, during exercise in the training group, also increased over the 6 days as shown in Table 2.

The magnitude of the changes in the HVR (Δ HVR, litres per minute per percentage oxygen saturation) and S_aO₂ (Δ S_aO₂) were calculated as the difference (Δ) between the HVR obtained at pre and immediately post exposure, and the S_aO₂ value obtained at the 1st and 6th day in the hypobaric chamber, respectively. There was a significant relationship ($r = 0.57$, $P < 0.05$) between Δ HVR and Δ S_aO₂ in all the subjects as indicated in Fig. 3.

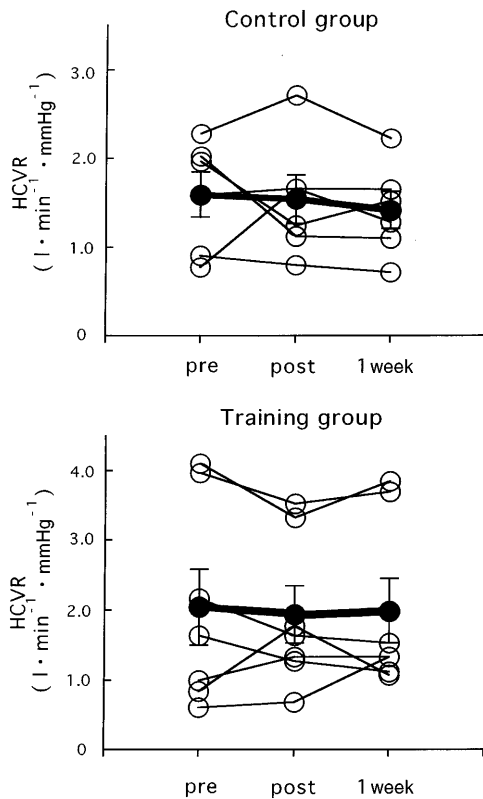


Fig. 2 Comparison of ventilatory response to hypercapnia ($HCVR$) determined before (*pre*), on the 1st day (*post*) and 1 week after intermittent exposure to hypoxia for each subject. Mean values with standard errors are shown as filled circles

Discussion

After intermittent exposure to hypobaric hypoxia (4,500 m) combined with exercise training in humans for 6 consecutive days, we found that

1. The HVR at rest had increased significantly in the control group, but not in the training group

2. The $HCVR$ at rest did not change in either of the groups
3. The $\dot{V}O_{2\max}$ increased significantly in the training group, but not in the control group.

It has been reported that the regulation of \dot{V}_E in hypoxia is primarily determined by the sensitivity of peripheral chemoreceptors (Vizek et al. 1987; Dwinell et al. 1997). Most studies have hitherto shown that HVR, as an index of the peripheral chemoreceptor sensitivity to hypoxia, increases during varying durations of continuous stay at altitude (Forster et al. 1971; White et al. 1987; Schoene et al. 1990; Sato et al. 1992, 1994). In the present study, we found that HVR remained significantly increased ($P < 0.05$) for at least 1 week in the control group after intermittent exposure to hypoxia for 6 consecutive days (Fig. 1). This result is also in agreement with previous studies that have used exposure to short-term chronic hypoxia (Forster et al. 1971; Sato et al. 1994).

By contrast, it is of interest that in the training group the HVR at sea level did not increase significantly as shown in Fig. 1. These results would suggest that exercise training for endurance in hypoxia as applied here played a role in depressing the HVR at rest even though the training period was relatively short (for 6 days). However, our data did not agree with the report of Levine et al. (1992) who have demonstrated that HVR increased in the training group after the combined exposure to intermittent hypoxia and exercise training for endurance. The discrepancy between their study and present one may be related to various factors such as the differences in altitude (2,500 m vs 4,500 m), training time ($45 \text{ min} \cdot \text{day}^{-1}$ vs $30 \text{ min} \cdot \text{day}^{-1}$), training period ($5 \text{ days} \cdot \text{week}^{-1}$ for 5 weeks vs 6 days) and the characteristics of the subjects.

Concerning the characteristics of the subjects, in neither study had the subjects been engaged in physical training. Since it was observed in the present study that HVR increased significantly in the control group but not in the training group, it could be suggested that an

Table 1 Changes in maximal oxygen uptake ($\dot{V}O_{2\max}$), maximal pulmonary ventilation ($\dot{V}_{E\max}$) and ventilatory equivalents for oxygen ($\dot{V}_E/\dot{V}O_2$) and carbon dioxide ($\dot{V}_E/\dot{V}CO_2$) in both groups before (*pre*), immediately after (*post*), and 1 week after exposure to hypoxia. C Control group, T training group

	Pre		Post		1 Week	
	Mean	SD	Mean	SD	Mean	SD
$\dot{V}O_{2\max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)						
C	50.3	3.1	51.5	3.2	48.4	4.4
T	55.1	5.7	58.5	5.1*	57.9	5.6*
$\dot{V}_{E\max}$ ($\text{l} \cdot \text{min}^{-1}$)						
C	121.9	16.2	135.0	10.0	134.1	19.6
T	127.4	21.2	141.5	25.8*	144.3	16.8*
$\dot{V}_E/\dot{V}O_2$						
C	37.9	5.0	40.6	2.9	42.9	6.3
T	37.5	4.9	39.2	5.8	40.5	3.7
$\dot{V}_E/\dot{V}CO_2$						
C	36.3	5.6	39.9	4.3	38.7	3.2
T	36.9	5.6	39.1	4.8	39.1	3.7

* $P < 0.05$ Compared with pre-exposure to hypoxia

Table 2 Changes in arterial oxygen saturation (S_aO_2) at rest in both groups and during exercise in the trained group in a hypobaric chamber during 6 days of intermittent exposure to hypoxia. C Control group, T training group

Days	1		2		3		4		5		6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
(S_aO_2) (%) at rest												
C	70.0	9.5	73.3	7.4	73.3	5.1	76.8	4.5*	78.0	4.2*	80.0	5.7*
T	75.4	4.6	76.7	3.6	80.6	4.0*	80.6	3.9*	81.1	3.4*	80.7	2.8*
(S_aO_2) (%) during exercise												
T	65.1	4.3	64.4	2.3	63.6	4.8	67.3	4.5*	67.0	4.6*	66.4	4.9

* $P < 0.05$ Compared with 1st day

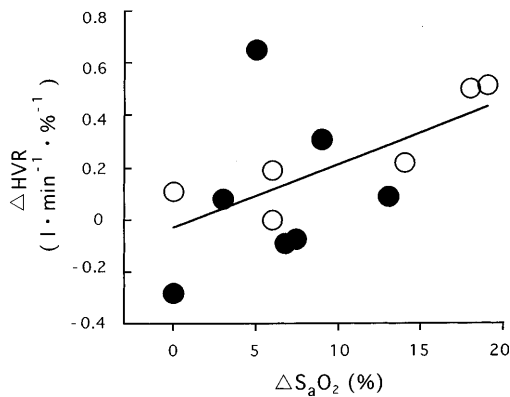


Fig. 3 Relationship between changes in ventilatory response to hypoxia (ΔHVR) and arterial oxygen saturation (ΔS_aO_2) in both control (unfilled circles) and training (filled circles) subjects. The line indicates the relationship between the two variables for both groups taken together ($r = 0.57$, $P < 0.05$)

increase in HVR is depressed by exercise training in hypobaric hypoxia.

It has been demonstrated that the HCVR also increases during prolonged exposure to high altitude (White et al. 1987; Schoene et al. 1990). To our knowledge, the effect of intermittent exposure to hypoxia on HCVR has not been reported in the literature. It was found in this study that in neither group was there any evidence of an increase in HCVR (Fig. 2). Schoene et al. (1990) have demonstrated that HCVR did not increase at P_B 428 mmHg, while it did increase at P_B 305 mmHg. Therefore one of the reasons why there was no increase in HCVR in this study could have been due to the difference in the altitude, i.e. the P_B of the hypobaric chamber was set at 432 mmHg in our study. Moreover, in the present study, the exposures to hypoxia were only approximately $2 \text{ h} \cdot \text{day}^{-1}$ for 6 days.

Since most previous studies in humans have suggested an increase in the slope of HCVR with time at altitude (Forster et al. 1971; White et al. 1987), another reason may have been the duration of the exposure to hypoxia. In addition, it has been demonstrated by Miyamura and Ishida (1990) that exercise training over long periods induced a decrease in HCVR. In other

words, it can be speculated that hypoxia and exercise training may have opposite effects on HCVR. However, further research is required to examine this speculation.

Numerous studies have found that arterial oxygenation and/or exercise performance at moderate and high altitudes are related to HVR. Thus, an evaluation of HVR at sea level can be used as an indicator of a climber's capability at high altitude (see Schoene et al. 1984; Masuyama et al. 1986; White et al. 1987). The HVR in the training group was not increased post exercise training combined with hypoxia. On the other hand, S_aO_2 in the hypobaric chamber was consistently increased ($P < 0.05$) over 6 days in both groups as shown Table 2. The mean values of S_aO_2 at rest in the control group had increased by 14% [70.0 (SD 9.5)% to 80.0 (SD 5.7)%] by the 6th day in the hypobaric chamber at a simulated 4,500 m compared with the mean values of the 1st day. It had also increased significantly ($P < 0.05$) in the training group although the amount of the increase in S_aO_2 at rest was less than that in the control group (by 7% at rest and 2% during exercise by the 6th day). Furthermore, there was a significant relationship ($r = 0.57$, $P < 0.05$) between ΔHVR and ΔS_aO_2 at rest in all the subjects as indicated in Fig. 3.

Therefore, it seems reasonable to suppose that the increased HVR led to enhanced arterial oxygenation in the hypobaric chamber. It is of interest, furthermore, that a significantly large increase in S_aO_2 in the control group was observed resulting from intermittent exposure to hypoxia for approximately $2 \text{ h} \cdot \text{day}^{-1}$ for 6 days. These results agree with the data of Savourey et al. (1996) who have demonstrated that S_aO_2 at rest was increased after 5 consecutive days of intermittent acclimation (8 h daily for 5 days, 1 day at 4,500 m, 5 day at 8,500 m) in a hypobaric chamber at a simulated altitude of 4,500 m; however, they did not show any increase in S_aO_2 during exercise in hypoxia. Benoit et al. (1995) have shown that HVR at sea level did not correlate with the magnitudes of $\dot{V}O_{2\max}$ ($\Delta \dot{V}O_{2\max}$), which were calculated as the difference between the $\dot{V}O_{2\max}$ value obtained at sea level and in hypoxia, while there was a significant correlation between S_aO_2 during exercise and $\Delta \dot{V}O_{2\max}$.

Therefore, it is evident that physical performance capacity in hypoxia can be predicted by both S_aO_2 during exercise in hypoxia and HVR at sea level. Because we did not measure both the physical performance in each group and S_aO_2 during exercise in the control group during hypoxia, the influence of differences of changes in HVR for both groups on physical performance in hypoxia cannot be adequately discussed. However, these results would suggest that approximately $2 \text{ h} \cdot \text{day}^{-1}$ for 6 consecutive days of intermittent exposure to hypoxia without exercise training can increase both the arterial oxygenation at rest in hypobaric hypoxia and HVR at rest at sea level.

Some studies have argued for a relationship between HVR and the ventilatory response to exercise at sea level or altitude (Martin et al. 1978; Schoene et al. 1984; Benoit et al. 1995), but other investigators have demonstrated that HVR does not contribute to $\dot{V}_E/\dot{V}CO_2$ or $\dot{V}_E/\dot{V}O_2$ at sea level (Schoene et al. 1984; Levine et al. 1992). In this study, there was no significant change in $\dot{V}_E/\dot{V}O_2$ or $\dot{V}_E/\dot{V}CO_2$ during maximal exercise in either group after intermittent exposure to hypoxia (Table 1). This result is in agreement with the results of the study of Levine et al. (1992) which had used a combination of intermittent exposure to hypoxia and training.

On the other hand, Benoit et al. (1995) have found relationships between HVR and \dot{V}_E and $\dot{V}_E/\dot{V}CO_2$ during maximal exercise in normoxia and acute hypoxia. In addition, they have also demonstrated that the relationships obtained in hypoxia were stronger than those obtained in normoxia. Therefore, if these ventilatory parameters during maximal exercise had been measured in the hypoxia of the present study, it may have appeared that there were significant correlations among HVR and these parameters.

In conclusion, we found that the HVR had increased significantly in the control group after intermittent exposure to hypoxia. In contrast, there was no significant increase in HVR in the training group found post compared with pre exposure. In addition, HCVR was not increased after intermittent exposure to hypoxia either in the presence or absence of exercise training. These results would suggest that endurance training during exposure to hypobaric hypoxia plays a role in depressing the increment in sensitivity of chemoreceptors to hypoxia. It would also suggest that intermittent exposure to hypoxia for short periods does not induce an increase in the sensitivity of chemoreceptors to hypercapnia in humans.

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