Effect of Acute Hypoxia on Maximal Exercise in Trained and Sedentary Women

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ABSTRACT

WOORONS, X., P. MOLLARD, C. LAMBERTO, M. LETOURNEL, and J.-P. RICHALET. Effect of Acute Hypoxia on Maximal Exercise in Trained and Sedentary Women. Med. Sci. Sports Exerc., Vol. 37, No. 1, pp. 147–154, 2005. Purpose: The purpose of this study was to determine the physiological responses of sedentary and endurance-trained female subjects during maximal exercise at different levels of acute hypoxia. Methods: Fourteen women who were sea level residents were divided into two groups according to their level of fitness: 1) endurance-trained women (TW) (N = 7), VO2max = 56.3 ± 4.7 mL·kg−1·min−1; and 2) sedentary women (SW) (N = 7), VO2max = 34.8 ± 5.6 mL·kg−1·min−1. Subjects performed four maximal cycle ergometer tests in normoxia and under hypoxic conditions (FIO2 = 0.187, 0.154, and 0.117, corresponding to altitudes of 1000, 2500, and 4500 m, respectively). Results: VO2max decreased significantly by 3.6 ± 2.1, 14 ± 2.5, and 27.4 ± 3.6% in TW, and by 5 ± 4, 9.4 ± 6.4, and 18.7 ± 7% in SW at 1000, 2500, and 4500 m, respectively. The drop of VO2max (ΔVO2max) was greater in TW at and above 2500 m. Arterial O2 saturation (SpO2) at maximal exercise was lower in TW at every altitude (1000 m: 90.9 ± 1.9 vs 94.6 ± 1.4%; 2500 m: 82.8 ± 2.8 vs 90.0 ± 2.1%; 4500 m: 65.0 ± 4.7 vs 73.6 ± 4.5%). Maximal heart rate decreased significantly from 1000 m in the two groups. SpO2 was correlated to ΔVO2max at 4500 m (r = −0.81, P < 0.01) and 2500 m (r = −0.81, P < 0.01), but not below. Furthermore, we noted a relationship between SpO2 and O2 pulse (VO2/HR) at every FIO2. Conclusion: These results demonstrate that endurance-trained women show a greater decrement in VO2max at high altitudes. This could be explained mainly by a higher arterial desaturation, which is largely caused, according to our results, by diffusion limitation. Key Words: ALTITUDE, PERFORMANCE, ARTERIAL OXYGEN SATURATION, FEMALE.

The changes in aerobic performance at various levels of hypoxia are well documented in men. On the contrary, very few such studies have been carried out on women. Yet men and women may not have similar metabolic responses during maximal exercise in acute hypoxia. Besides, some studies report a greater decrease in maximal oxygen consumption (VO2max) in men (10,24,28). Some authors hypothesize that women have a stronger protective mechanism against acute exposure to hypoxia during maximal exertion because of a higher relative ventilatory response than males of similar age (24). Consequently, a better hyperventilation could enhance arterial oxygen saturation (SaO2) and oxygen delivery to the active muscles (34). Other investigators found a higher ventilatory equivalent (VE/VO2max) in women at maximal exercise without a lesser SaO2 (10). But despite this assumed adaptive phenomenon, some studies did not find any difference in gender concerning VO2max decrement in acute hypoxia (35), and others even reported a higher decrease in women (6,31). These conflicting results could be partly explained by 1) a low number of subjects in some studies, 2) differences in fitness level between males and females, and 3) participation of acclimated subjects.

Furthermore, the few experiments carried out in women concerned sedentary or physically active, but very rarely endurance-trained, subjects. It would appear important for this population (endurance-trained subjects), for practical reasons, to know the changes in performance with altitude. Indeed, training intensity at altitude must be calculated by taking these changes into account to avoid overtraining or even undertraining. Moreover, if sedentary women can enhance their ventilatory response in hypoxia, it is not certain that trained ones would be able to do so. In that respect, some authors report that women’s smaller lungs could affect hyperpnea, especially in highly fit women (21). These mechanical constraints of ventilation may make it hard to maintain a high level of alveolar oxygen pressure (PAO2) and consequently exacerbate the arterial desaturation, especially at high altitude.

The studies that have compared trained and sedentary men at maximal exercise in acute hypoxia report a higher drop of aerobic performance in the former (7,18,20). This could be mainly due to the greater arterial desaturation in
these subjects, which leads to a lower arterial oxygen content (CaO₂) (7,18). At an altitude as low as 580 m, Gore et al. (9) reported a reduced VO₂max in highly trained men compared with at sea level, whereas there was no change in untrained men. Although these authors attribute those results to SaO₂ level, another hypothesis can be proposed to explain the lack of drop in aerobic performance at low altitudes in sedentary people. According to Cardus et al. (1), these subjects could be limited at sea level by the oxidative capacity of muscle mitochondria. In a predominantly male group (17 men, 7 women), these authors have reported no change in leg VO₂max at an inspired oxygen fraction (ḞO₂) of 0.15 compared with 0.21, whereas this variable was lower at ḞO₂ = 0.12. On the contrary, O₂ transport could be the main limiting factor of VO₂max in athletes (35). With regard to these aspects, a small reduction in ḞO₂, and consequently in CaO₂, may not significantly affect aerobic performance in untrained men, whereas it is likely in trained ones.

Nevertheless, in an exclusively female group, this assessment could not be verified, because women have a lower hemoglobin (Hb) concentration than men, and therefore a lower CaO₂. Thus, we can hypothesize that even at mild degrees of hypoxia, the decrease in O₂ supply could be sufficient to reduce VO₂max in sedentary women. However, we assume that differences in training status could be the same as in men. Since no study has ever compared trained and sedentary females in hypoxia, we aimed to determine the changes in aerobic performance and evaluate the limiting factors of O₂ transfer in these subjects, at different levels of acute hypoxia.

METHODS

Subjects. Fourteen women, all sea-level natives and residents, participated in this study. They were all nonsmokers and had no history of cardiovascular or respiratory disease. We obtained written, informed consent from each subject, and all procedures were approved by the ethical committee of Necker Hospital, Paris, France. Women provided information about their menstrual cycle, including the days since the end of their last menstruation, and use of oral contraceptives. Two groups were studied: trained women (TW) (N = 7) and sedentary women (SW) (N = 7). The trained subjects were runners or triathletes with at least four training sessions per week. Subjects were asked to avoid strenuous physical activity 48 h before the tests. The physical characteristics of the subjects are shown in Table 1.

Protocol. Each subject performed four maximal exercise tests on an electrically braked cycle ergometer (Jaeger ER 900) in two different sessions. Each session, composed by two tests, was separated by 7 d. The first test was always carried out in normoxia (inspired oxygen fraction (ḞI O₂) = 0.209, inspired oxygen pressure (P I O₂) = 150 mm Hg). In the other tests, which were randomly assigned, we used a F I O₂ of 0.187, 0.154, and 0.117 (P I O₂ of 132, 108, and 81 mm Hg, respectively) for the simulated altitudes of 1000, 2500 and 4500 m, respectively. To simulate these altitudes we used the AltiTrain® (S.M. TEC, Geneva, Switzerland), which produces a normobaric hypoxic mixture (reduced oxygen fraction) by the addition of nitrogen in ambient air. The gas mixture is stocked in a buffer tank (30 L) before being inhaled by the subjects. P O₂ is continuously monitored throughout the tests by an oxygen probe, located in the buffer tank. A digital display allowed us to monitor either P I O₂ or the equivalent altitude (m). This device is reliable for altitudes below 5500 m and for ventilation inferior to 200 L min⁻¹.

Before exercise, the subjects breathed the desired gas mixture for 3–4 min. Then the exercise test began with a 3-min warm-up at a power output (PO) of 45 W. Thereafter, PO was increased by 25 W every 2 min, until the subjects could no longer maintain a pedaling frequency of 65 rpm. The subjects were verbally encouraged to continue exercise as long as possible.

Measurements. Gas exchange was recorded breath by breath at rest, during exercise, and during recovery using an integrated computer system. We used a rigid mouthpiece connected to a “Y” system fixation with a two-way valve, which ensured anti return (Jaeger, Germany). An inspiratory valve, connected to the AltiTrain® allowed the subject to inhale the hypoxic mixture. Expired gases were collected into a metabograph (Oxycon, Jaeger, Germany) to measure expired minute volume of gas at body temperature and pressure saturated (Ve BTPS). O₂ consumption (VO₂), end-tidal O₂ pressure (PetO₂), and end-tidal carbon dioxide pressure (PetCO₂). Electrocardiogram and heart rate (HR) were recorded continuously, as well as transcutaneous arterial O₂ saturation (SpO₂), by an ear pulse oximeter (Ohmeda Biox 3740, U.S.). To obtain reliable values of arterial O₂ saturation (SpO₂), we corrected SpO₂, measured with the oximeter, from a linear regression established from 142 simultaneous measurements of SaO₂, by capillary blood samplings and SpO₂ [SpO₂ = 0.86° Sp¹ O₂ + 12.99, r = 0.98, P < 0.01]. The breath-by-breath measurements, HR and SpO₂, were averaged over 30-s intervals. For assessment of VO₂max, data were averaged over the two highest consecutive 30-s periods, and at least two of the three criteria were met. These criteria were 1) a heart rate in excess of 90% of age predicted maximum (220 – age), 2) a respiratory exchange ratio (RER) of ≥1.10, and 3) a plateau in VO₂ (≥150 mL increase over 2 min) with an increase in workload.

Before placing the ear sensor of the oximeter and obtaining capillary blood sampling, a vasodilator cream (capsaicin) was applied on each ear lobe to obtain a local hyperaemia. An arterialized blood sample (95 μL) was drawn at rest and after 2 min of recovery. Analyses were made

<table>
<thead>
<tr>
<th>TABLE 1. Physical characteristics of the subjects.</th>
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<tr>
<td>TW (N = 7)</td>
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<td>Age (yr)</td>
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<tr>
<td>Height (cm)</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td>VO₂max (L·min⁻¹)</td>
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<td>VO₂max (L·kg⁻¹·min⁻¹)</td>
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Values are mean ± SD; TW, trained women; SW, sedentary women; VO₂max, maximal oxygen consumption; * significantly different from SW (P < 0.05).
immediately after sampling for SaO₂, PaO₂, PaCO₂, pH, Hb concentration (HbB), blood lactate (La), and P50 (Radiometer ABL 700, Copenhagen, Denmark).

**Statistical analysis.** A two-way analysis of variance (ANOVA) was performed to analyze the effect of F₁O₂ on measured parameters and the differences between the two groups. If a significant effect of F₁O₂ was found, a Tukey post hoc test was used to analyze the differences between normoxia and hypoxia. Considering the relatively small number of subjects in each group, we used Pearson product moment correlations with pooled population data to determine relationships between all dependent variables. Data are expressed as the mean ± SD. The level of significance was established at P < 0.05 for all statistics.

**RESULTS**

Measured and calculated metabolic variables at VO₂max are presented in Table 2.

**Oxygen consumption and power output at maximal exercise.** At any F₁O₂, PO (W), VO₂max and O₂ pulse (VO₂/HR) were higher in TW than in SW. When compared with sea level, VO₂max was significantly lower at and above 1000 m for the two groups. PO decreased from 1000 m for TW and from 2500 m for SW. VO₂/HR decreased from 2500 m for TW and SW. ΔVO₂max (Fig. 1) and ΔPO were higher at 2500 and 4500 m for TW, but not at 1000 m. There was a significant correlation between normoxic VO₂max and ΔVO₂max at 2500 m (r = 0.8; Fig. 2b) and 4500 m (r = 0.91; Fig. 2b), but not at 1000 m (Fig. 2a).

**Oxygen saturation.** At VO₂max, SpO₂ was always lower in TW. SpO₂ decreased with decreasing F₁O₂ from 1000 m in TW, and from 2500 m in SW (Fig. 3). ΔVO₂max was correlated with SpO₂ at maximal exercise at 2500 m (r = −0.81; Fig. 4b) and 4500 m (r = −0.81; Fig. 4b), but not at 1000 m (Fig. 4a). Normoxic VO₂max was correlated to SpO₂ at maximal exercise at every F₁O₂ (sea level: r = −0.68; 1000 m: r = −0.79; 2500 m: r = −0.82; 4500 m: r = −0.75). There was a strong relationship between VO₂/HR and SpO₂ at sea level (r = −0.86; Fig. 5a), 1000 m (r = −0.85; Fig. 5a), 2500 m (r = −0.92; Fig. 5b), and 4500 m (r = −0.74; Fig. 5b).

**Ventilatory parameters at maximal exercise.** There was no altitude effect on VE/VO₂max. This parameter was significantly higher in TW at 2500 m, but not at the other altitudes. In contrast, VE/VO₂ and PetO₂ were always lower at maximal exercise in TW, except at 4500 m. Compared with sea level, VE/VO₂ was higher at and above 2500 m for TW and at 4500 m for SW. PetO₂ decreased from 1000 m for the two groups. At VO₂max, the mean PetCO₂ was higher in TW until 2500 m, but the difference was not significant. Compared with sea level, PetCO₂ was lower from 1000 m for TW, and from 2500 m for SW. At VO₂max, there was no significant correlation between SpO₂ and the ventilatory parameters, except at sea level (r = 0.55, 0.55, and 0.53 for VE/VO₂, PetO₂, and PetCO₂, respectively).

**Heart rate.** HR at maximal exercise (HR/VO₂max) was lower at every altitude in TW, and at 1000 m and 4500 m in SW. The decrement in HR/VO₂max (ΔHR/VO₂max) was higher in TW at 4500 m, but not at the other altitudes. A significant relationship was found between ΔHR/VO₂max and ΔVO₂max at

**TABLE 2. Metabolic and cardiorespiratory variables at VO₂max, at each altitude.**

<table>
<thead>
<tr>
<th>Sea level</th>
<th>1000 m</th>
<th>2500 m</th>
<th>4500 m</th>
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<tr>
<td>TW</td>
<td>SW</td>
<td>TW</td>
<td>SW</td>
</tr>
<tr>
<td>VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>56.3 ± 4.7</td>
<td>34.8 ± 6</td>
<td>54.4 ± 5.2</td>
</tr>
<tr>
<td>Δ VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>3.6 ± 2.1</td>
<td>5.0 ± 4</td>
<td>14.0 ± 2.5</td>
</tr>
<tr>
<td>Δ VO₂max (%)</td>
<td>7.8 ± 1.1</td>
<td>1.8 ± 1.5</td>
<td>102 ± 19</td>
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<tr>
<td>PO (W)</td>
<td>219 ± 17</td>
<td>135 ± 25</td>
<td>209 ± 19</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>179 ± 8</td>
<td>188 ± 8</td>
<td>176 ± 11</td>
</tr>
<tr>
<td>Δ HR (bpm)</td>
<td>3.4 ± 4</td>
<td>2.6 ± 2.1</td>
<td>4.9 ± 3.2</td>
</tr>
<tr>
<td>VO₂/HR (mL·beat⁻¹)</td>
<td>17.5 ± 1.9</td>
<td>11.3 ± 2</td>
<td>17.2 ± 1.8</td>
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<tr>
<td>SpO₂ (%)</td>
<td>94.0 ± 1.5</td>
<td>96.2 ± 1.2</td>
<td>90.9 ± 1.9</td>
</tr>
<tr>
<td>VE (L·min⁻¹·TPS)</td>
<td>107 ± 17.5</td>
<td>89.7 ± 15.4</td>
<td>106.7 ± 17.1</td>
</tr>
<tr>
<td>VE/VO₂</td>
<td>34.8 ± 5.1</td>
<td>47.2 ± 5.6</td>
<td>35.9 ± 4.4</td>
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<tr>
<td>PetO₂ (mm Hg)</td>
<td>117.4 ± 4.2</td>
<td>123.3 ± 2.9</td>
<td>101.7 ± 2.9</td>
</tr>
<tr>
<td>PetCO₂ (mL·Hg)</td>
<td>35.7 ± 6</td>
<td>30.9 ± 4.8</td>
<td>33 ± 3.9</td>
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</table>

Values are mean ± SD. TW, trained women; SW, sedentary women; VO₂max, maximal O₂ consumption; PO, power output; HR, heart rate; VO₂/HR, O₂ pulse; SpO₂, arterial O₂ saturation; VE, expired ventilation; VE/VO₂, ventilatory equivalent; PetO₂, end-tidal O₂ pressure; PetCO₂, end-tidal carbon dioxide pressure.

* Significant difference from SW (P < 0.05); † significant difference from sea level (P < 0.05).
4500 m ($r = -0.61$; Fig. 6b), but not at the other altitudes (Fig. 6a).

**Blood gases.** At rest, there was no difference between the two groups for $\text{PaO}_2$, $\text{SaO}_2$, pH, [Hb], and P50, whatever the altitude (Table 3). Although $\text{PaCO}_2$ appeared always higher in TW, the difference was significant only at 2500 m. $\text{PaO}_2$ and $\text{SaO}_2$ decreased with decreasing $F_\text{I}O_2$ from 1000 m and 2500 m, respectively. After 2 min of recovery, we did not find any difference in lactate concentration and pH between the two groups. There was no altitude effect on lactate. pH was higher from 1000 m in SW, and from 2500 m in TW. We failed to demonstrate any difference in [Hb] between the two groups or at altitude compared with sea level.

**DISCUSSION**

As expected, $\text{VO}_{2\text{max}}$ decreased with hypoxia, but this is the first study demonstrating a $\text{VO}_{2\text{max}}$ decrement at an altitude as low as 1000 m for sedentary sea-level native women. Previously, it has been shown that trained women had a lower $\text{VO}_{2\text{max}}$ at 580 m compared with at sea level (10). The difference in $\Delta \text{VO}_{2\text{max}}$ between the two groups from 2500 m, and the strong relationship we found between sea-level $\text{VO}_{2\text{max}}$ and $\Delta \text{VO}_{2\text{max}}$ at 2500 and 4500 m, show that trained subjects are more sensitive to the drop of aerobic performance in hypoxia. This confirms the results of several studies carried out in men (7,18,20). In SW, the decrease in $\text{VO}_{2\text{max}}$ is inferior to the ones reported by several studies carried out in conditions similar to ours (4,31,34). Nevertheless, our subjects are real sedentaries, with less than 1 h of physical practice per week, and their $\text{VO}_{2\text{max}}$ is much lower than the subjects of the studies mentioned above. Concerning TW, there is a great lack of data in the literature. However, our results are coherent with those of Paterson et al. (24) in highly active participants. $\Delta \text{VO}_{2\text{max}}$ in TW is also in agreement with the experiment of Gore et al. (10), which was carried out at 580 m in women with a higher aerobic capacity than that of our subjects.

$\text{SaO}_2$ decreased in hypoxia, but a comparison with other studies is not possible in women, because the present study is the first to provide data at high altitude. Arterial desaturation could explain the major part of the drop of $\text{VO}_{2\text{max}}$ in hypoxia (7,18). The strong relationship found between $\Delta \text{VO}_{2\text{max}}$ and $\text{SpO}_2$ at 2500 m ($r^2 = 0.66$) and 4500 m ($r^2 = 0.66$) could sustain this hypothesis. Indeed, a low $\text{SaO}_2$ could reduce the convective O$_2$ delivery to the tissues, and consequently induce a larger drop in $\text{VO}_{2\text{max}}$. However, this cannot be established directly from these data. At 1000 m, we did not find any significant correlation between these two parameters. It is possible that, at low altitudes, some subjects can compensate the decrease in $\text{CaO}_2$ by a lower venous oxygen content ($\text{CvO}_2$). Chapman et al. (2), using the Fick equation ($\text{VO}_{2\text{max}} = Q[\text{CaO}_2 - \text{CvO}_2]$) to calculate $\text{CvO}_2$, showed that trained subjects who did not suffer from exercise-induced arterial hypoxemia (EIH) had a lower $\text{CvO}_2$ during exercise at 1000 m. This apparent compensation would allow these athletes to maintain their

**FIGURE 2**—Relationship between $\Delta \text{VO}_{2\text{max}}$ decrement ($\Delta \text{VO}_{2\text{max}}$) and sea-level $\text{VO}_{2\text{max}}$ at 1000 m (A), and at 2500 m (solid line) and 4500 m (dashed line) (B). Closed symbols represent sedentary women; open symbols represent trained women.

**FIGURE 3**—Arterial O$_2$ saturation ($\text{SpO}_2$) at maximal exercise at various altitudes. ○, Sedentary women; ●, trained women; * significant difference between groups; ‡ significant difference compared with sea level; bars indicate SD.
arterial-mixed venous oxygen difference (Da-\(\bar{v}\)O\(_2\)) in the face of a reduced arterial O\(_2\) content. As none of our subjects had hypoxemia (SaO\(_2\) < 92%) during maximal exercise at sea level, the same phenomenon has perhaps happened. At a higher altitude, we could assume that the subjects have reached the limits of this adaptation and therefore have a lower Da-\(\bar{v}\)O\(_2\) and, as a consequence, a larger drop in \(\dot{V}O_2\)\(_{max}\).

At maximal exercise, SpO\(_2\) was always lower in TW at all \(F_{O_2}\) levels. Consequently, \(CaO_2\) was also lower in those subjects because we did not find any difference in [Hb] between groups. The reason why trained subjects have a greater arterial desaturation remains unclear. Four hypotheses are commonly advanced to explain the variance in SaO\(_2\): 1) venoarterial shunt, 2) ventilation-perfusion inequality (VA/Q), 3) hypoventilation, and 4) diffusion limitation.

The first two factors probably do not play an important role in SaO\(_2\) difference between subjects. Concerning the first one, it is now admitted that, if venoarterial shunt is responsible for about one half of the alveolar-arterial O\(_2\) differences at rest, it plays a very minor role in gas exchange limitation during maximal exercise at sea level (11) and at altitude (33). Concerning VA/Q inequality, Gale et al. (8) showed that it could account for one third in alveolar-arterial difference during exercise, at about 4500 m. But it is unlikely that trained subjects would have a greater VA/Q mismatching than sedentary ones.

Hypoventilation could play an important role in SaO\(_2\) variability. Considering VE/\(\dot{V}O_2\) and PetO\(_2\) at \(\dot{V}O_2\)\(_{max}\), our results showed a lower ventilatory response in TW from sea level to 2500 m. This reduced hyperventilation could be due to a lower hypoxic ventilatory response, which reflects the peripheral chemoreceptor sensitivity. Additionally, athletes are reported to have a low chemosensitivity (30). A second reason that might explain the relative hypoventilation in athletes is mechanical limitation of ventilation (13). However, Norton et al. (23) have shown that endurance-trained subjects who exercise at supramaximal intensity could enhance VE significantly beyond the level reached at maximal intensity. Nevertheless, it is possible, as suggested by McClaran et al. (21), that smaller lung volumes in women affected exercise hyperpnea of some of our subjects. But this probably happens in the most trained females, and
FIGURE 6—Relationship between \( \Delta V_{O_{2\max}} \) decrement (\( \Delta V_{O_{2\max}} \)) and change in maximal heart rate (HR\(_{\max}\)) at 1000 m (solid line) and 2500 m (dashed line) (A), and at 4500 m (B) compared with sea level. Closed symbols represent sedentary women; open symbols represent trained women.

our participants were not elite athletes. Whatever the causes of this lower ventilatory response, it does not seem to play a significant role in the variability of SaO\(_2\) in hypoxia, as shown by the lack of correlation between this variable and the ventilatory parameters.

A diffusion limitation across the alveolar-arterial interface might compromise gas exchange, especially in highly trained athletes. During maximal exercise, these subjects have a high metabolic demand of 4–5 L·min\(^{-1}\) with elevated maximal cardiac output (Q\(_{\max}\)). The consequences could be an erythrocyte transit time in pulmonary capillaries as low as 0.25 s (3). Moreover, athletes have a great muscular O\(_2\) extraction capacity, which leads to a reduced C\(\text{vO}_2\) (29). In hypoxia, a low C\(\text{vO}_2\) associated with a high Q\(_{\max}\) leads to diffusion limitation, and finally exacerbates arterial desaturation. Although we did not measure these two parameters, the strong correlations found between SaO\(_2\) and normoxic \( V_{O_{2\max}} \) and between SaO\(_2\) and VO\(_2\)/HR at sea level and at each level of hypoxia suggest that aerobic capacity, and probably Q and C\(\text{vO}_2\), play an important role in SaO\(_2\) variability.

Compared with sea-level measurements, HR\(_{\max}\) was lower at every altitude in TW and SW. The decrease in HR\(_{\max}\) in acute hypoxia is still controversial. While some studies have shown a lower maximal heart rate in these conditions compared with normoxia in men (17,19,24) or women (4,24,28), many others did not find any difference (2,6,18,20,26,32,34). Among these latter studies, the majority have found a drop in HR\(_{\max}\), but without significant differences (2,18,20,26,34). This may be due to a small sample size or an interindividual variability in the HR responses. Although the drop in HR\(_{\max}\) was reported until now at medium or high altitudes, it is surprising to note that the decrease appears in our study at altitudes as low as 1000 m in the two groups.

In chronic hypoxia, the well-known decrease in maximal heart rate has been attributed to a densitization of the adrenergic pathway and/or an upregulation of the parasympathetic system (27). Although these changes in receptor function could be rapidly triggered by exposure to hypoxia and high adrenergic activity, it is improbable that these mechanisms might be involved in a short exposure of less than 30 min. Lundby et al. (19) have hypothesized that, in acute hypoxia, an increase in the parasympathetic traffic, rather than a decreased sympathetic function, might be responsible for the blunting of the cardiac chronotropic function, although there is no direct experimental evidence available. An interesting alternative hypothesis is that performance limitation originates centrally during maximal exercise in hypoxia. Some authors have reported no typical signs of neuromuscular fatigue during chronic (15) or acute hypoxia (25). Thus it is possible that, in those conditions, a “central governor,” probably located in central nervous system (CNS) (16), regulates the mass of skeletal muscle that is recruited during maximal exercise and that protects the heart from developing myocardial ischemia (22) with, consequently, a decrease in HR\(_{\max}\). Nevertheless, the drop in HR\(_{\max}\) appears from 1000 m in our study, and it is improbable that so low an altitude would constitute a significant alert for the CNS. On the other hand, such a feedback mechanism protecting the myocardium has been evoked in prolonged hypoxia, and could be triggered by purely local mechanisms involving adrenergic and muscarinic pathways through G-regulating proteins (14,27).

This reduction in HR\(_{\max}\) likely induces a reduction in Q\(_{\max}\) and in maximal oxygen delivery to the working muscles, and therefore a higher \( \Delta V_{O_{2\max}} \). Thus, the decrease in HR\(_{\max}\) could be partly responsible for the drop in aerobic performance with altitude. Besides, the relationship we found between \( \Delta HR_{\max} \) and \( \Delta V_{O_{2\max}} \) at 4500 m \((r = 0.61, P < 0.05)\) is in favor of this hypothesis. Nevertheless, it is unclear whether \( Q_{\max} \) decreases in acute hypoxia. Although some studies showed a decrement of this parameter with altitude (26) or carbon-monoxide–induced hypoxia (5), others failed to find any change compared with sea level (12,34). Moreover, the consequences of a possible decrease in Q\(_{\max}\) on \( V_{O_{2\max}} \) seem unclear. Indeed, although this could lead to a reduced \( O_2 \) delivery, it may also improve \( O_2 \) transfer in the lungs, attenuate the decrease in SaO\(_2\), and, finally, limit the decrease in \( V_{O_{2\max}} \). Further experiments...
will have to be carried out to determine whether \( Q_{\text{max}} \) changes in acute hypoxia.

This study provides new information on the metabolic and cardiorespiratory responses of trained and sedentary women during maximal exercise in acute hypoxia. The study shows that even at \( F_1O_2 = 0.187 \), which is close to normoxia, the consecutive small reduction in \( CaO_2 \) probably because of their lower [Hb]. These results also concerning the decrease in \( V\dot{O}_2 \text{max} \) and maximal power output in endurance-trained subjects compared with sedentary ones. This decrease is apparent in women only from 2500 m, and can be attributed largely to declining \( SpO_2 \). The variability of \( SpO_2 \) between trained and untrained women could be explained for a great part by diffusion limitation. Nevertheless, in hypoxia, we cannot rule out, with regard to the lower HR\( _{\text{max}} \), the possible role of a decrease in \( Q_{\text{max}} \) in the fall of \( V\dot{O}_2 \text{max} \) at an altitude close to 4500 m. The measurement of \( Q \) at different levels of hypoxia is now essential to confirm, on the one hand, the role of diffusion limitation on \( SaO_2 \), and on the other hand, to determine whether \( Q_{\text{max}} \) actually decreases with altitude, and the consequences of this decrement in the drop of \( V\dot{O}_2 \text{max} \).

In summary, these data confirm the greater decrement in \( V\dot{O}_2 \text{max} \) and maximal power output in endurance-trained subjects compared with sedentary ones. This decrease is apparent in women only from 2500 m, and can be attributed largely to declining \( SpO_2 \). The variability of \( SpO_2 \) between trained and untrained women could be explained for a great part by diffusion limitation. Nevertheless, in hypoxia, we cannot rule out, with regard to the lower HR\( _{\text{max}} \), the possible role of a decrease in \( Q_{\text{max}} \) in the fall of \( V\dot{O}_2 \text{max} \) at an altitude close to 4500 m. The measurement of \( Q \) at different levels of hypoxia is now essential to confirm, on the one hand, the role of diffusion limitation on \( SaO_2 \), and on the other hand, to determine whether \( Q_{\text{max}} \) actually decreases with altitude, and the consequences of this decrement in the drop of \( V\dot{O}_2 \text{max} \).

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### REFERENCES


