Lack of effects of moderate-high altitude upon lung function in healthy middle-aged volunteers

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This study investigates the effects of moderate–high altitude on lung function and exercise performance in 46 volunteers (19 females, 27 males), with a mean age of 42.4±1.4 years (±SEM) and varying smoking and exercise habits, who were not previously acclimatized.

Measures obtained in the base camp (1140 m) and at altitude (2630 m), in random order, included forced spirometry, maximal voluntary ventilation, maximal inspiratory and expiratory pressures, arterial oxygen saturation and capillary lactate concentration after a standardized exercise test. The smoking history, Fagerström test and degree of habitual physical activity were also recorded for each participant.

The percentage of smokers was similar in males (19%) and females (21%) (P=n.s.). Mean habitual physical activity index was 8.2±0.2 (range, 5.8-11.6). At the base camp, all lung function variables were within the normal range. Lactate concentration after exercise averaged 3.7±0.3 mm–1. No significant change was observed at altitude, except for a higher heart rate and a lower arterial oxygen saturation (SaO₂) (both at rest and after inspiratory manoeuvres). The smoking history and the degree of physical activity did not influence lung function or exercise performance at altitude.

The results of this study show that in middle-aged, healthy, not particularly well-trained individuals, lung function is not significantly altered by moderate–high altitude, despite the absence of any acclimatization period and independent of their smoking history and previous exercise habits.

Introduction

The effects of high altitude on lung function has been the subject of numerous studies in the past (1-4). These studies were generally conducted in healthy, highly trained, young individuals, after some period of acclimatization. Yet, in real life, many middle-aged, untrained smokers often travel to sky resources around the world (which are located at a lower altitude, 200-3000 m) without any acclimatization period (5,6). Whether or not, and to what extent, lung function and/or exercise performance can be jeopardized under these conditions is unclear. The potential influence of smoking history and/or previous exercise habits of these subjects upon their physiological response to this moderate–high altitude is not known either. Accordingly, we conducted the present study in a group of middle-aged volunteers (with varying smoking and exercise habits) who were studied without previous acclimatization in order to: 1. determine the acute effects of moderate–high altitude (2630 m) upon lung function and exercise performance and 2. investigate the potential influence of smoking history and/or previous exercise habits upon this response.

Methods

STUDY SUBJECTS

We studied 46 healthy volunteers (19 females, 27 males) among participants in a medical convention held in Benasque (Huesca, Spain). Table 1 shows their main anthropometric characteristics. They all normally lived at an altitude that range from sea level to 600 m. The smoking habits and the degree of habitual physical activity varied widely among them (Table 1). All gave their consent to participate after being fully informed of the nature, characteristics, risks and potential benefits of the study.
### Table 1. Mean (±SEM) of the main anthropometric and functional variables of all the subjects studied at the base camp (1140 m)

<table>
<thead>
<tr>
<th></th>
<th>Males (n = 19)</th>
<th>Females (n = 19)</th>
<th>Total (n = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>45.5 ± 1.5</td>
<td>37.8 ± 2.4**</td>
<td>42.4 ± 1.4</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.5 ± 1.2</td>
<td>59.8 ± 1.9**</td>
<td>70.8 ± 1.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.0 ± 1.2</td>
<td>162.1 ± 1.1**</td>
<td>168.5 ± 1.1</td>
</tr>
<tr>
<td>Smokers (n, %)</td>
<td>5 (19%)</td>
<td>4 (21%)</td>
<td>9 (20%)</td>
</tr>
<tr>
<td>PAI</td>
<td>8.5 ± 0.3</td>
<td>7.9 ± 0.3</td>
<td>8.2 ± 0.2</td>
</tr>
<tr>
<td>FVC (% ref)</td>
<td>97.3 ± 2.3</td>
<td>105.3 ± 2.4*</td>
<td>100.6 ± 1.7</td>
</tr>
<tr>
<td>FEV1 (% ref)</td>
<td>98.1 ± 2.5</td>
<td>100.0 ± 2.4</td>
<td>101.0 ± 1.8</td>
</tr>
<tr>
<td>FEV1/FVC (%)</td>
<td>77 ± 1</td>
<td>80 ± 1</td>
<td>78 ± 1</td>
</tr>
<tr>
<td>MMFF (% ref)</td>
<td>88.7 ± 4.6</td>
<td>93.9 ± 6.2</td>
<td>90.8 ± 3.7</td>
</tr>
<tr>
<td>PEF (% ref)</td>
<td>108.1 ± 3.9</td>
<td>111.8 ± 4.1</td>
<td>109.7 ± 2.8</td>
</tr>
<tr>
<td>MVV (% ref)</td>
<td>152.4 ± 2.5</td>
<td>104.2 ± 1.7</td>
<td>132.0 ± 3.9</td>
</tr>
<tr>
<td>MIP (% ref)</td>
<td>120.0 ± 5.1</td>
<td>111.8 ± 6.0</td>
<td>116.0 ± 3.9</td>
</tr>
<tr>
<td>MEP (% ref)</td>
<td>118.3 ± 4.9</td>
<td>126.0 ± 60</td>
<td>121.6 ± 3.8</td>
</tr>
<tr>
<td>Heart rate (min⁻¹)</td>
<td>75.8 ± 2.3</td>
<td>82.0 ± 2.2</td>
<td>78.4 ± 1.7</td>
</tr>
<tr>
<td>SaO2 (%)</td>
<td>96.3 ± 0.2</td>
<td>96.8 ± 0.3</td>
<td>96.5 ± 0.2</td>
</tr>
</tbody>
</table>

A physical activity index (PAI) lower than 8 was considered indicative of sedentarism (8). Asterisks indicate significance of differences between sexes (*P < 0.05; **P < 0.01). FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s; MMFF: maximum mid-expiratory flow; PEF: peak expiratory flow; MVV: maximum voluntary ventilation; MIP: maximal inspiratory pressure; MEP: maximum expiratory pressure; SaO2: arterial oxygen saturation.

### STUDY DESIGN

We organized two different laboratories. The base camp was installed in Benasque (1140 m). The altitude laboratory was located at 2630 m in Pica Gallinero (Pyrenees, Spain). Table 2 presents the atmospheric conditions of both laboratories. For each participant, we recorded the smoking history and the degree of habitual physical activity. We also measured forced spirometry, maximal voluntary ventilation, maximal inspiratory and expiratory pressures, arterial oxygen saturation and capillary lactate concentration after a standardized exercise test (see below). The anthropometric measures, as well as the clinical determinations (smoking history and degree of habitual physical activity), were determined at the base camp only. The remaining functional measures were taken both at the base camp and at altitude, in random order. All participants were studied within the first 24 h after leaving home.

### METHODS

The smoking history and the Fagerström test (7) were recorded for each subject. The exhaled concentration of carbon monoxide (CO) was measured by a Mini III smokerlyzer EC50 (Bedfont Instruments, U.K.). The degree of habitual physical activity for each participant was quantified using the method proposed by Baecke et al. (8). Using this method, a physical activity index (PAI) lower than 8 was considered indicative of sedentary lifestyle (9). Spirometry (Fleish pneumotacograph, Datospir-500, Sibelmed, Barcelona, Spain) was obtained according to international guidelines (10). Reference values were those of a Mediterranean population (11). Maximal voluntary ventilation (MVV) was determined over 15 s with the same spiroometer (and compared to reference values) according to the method of Cotes (12). Maximal inspiratory and expiratory pressures (MIP and MEP, respectively) were measured (manometer-163, Sibelmed, Barcelona, Spain) according to the method described by Black and Hyatt (13). Reference values were those published by these same authors (13). The arterial oxygen saturation (SaO2) was determined by pulse oxymetry (Ohmeda, Biox 3740, BOC, Health Care, Louisville, CO, U.S.A.) at rest and after three deep inspiratory manoeuvres. We recorded the time (s) from the last deep inspiration until the maximal SaO2 value (recovery time). To assess exercise performance, capillary lactate concentration (mM⁻¹) was measured by photometric analysis (Dr Lange Microphotometer Mini8, Berlin, Germany) from an arterialized blood sample obtained from the ear lobe 30–60 s after exercise (leg flexions at 1 Hz during 90 s) (14).

### ANALYSIS

Data are shown as mean ±SEM and range. Measurement at different altitudes were compared using the paired t-test. The statistical significance of differences between participants of different sex, smoking history or exercise habits was assessed using the t-test for independent samples. Correlations between variables of interest were analysed...
**TABLE 2. Atmospheric working conditions (mean ± SEM) at the base camp and at altitude**

<table>
<thead>
<tr>
<th></th>
<th>Base camp (1140 m)</th>
<th>Altitude (2650 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric pressure (mmHg)</td>
<td>593 ± 0.1</td>
<td>563 ± 3*</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>24 ± 0.2</td>
<td>12 ± 0.3*</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>39 ± 0.4</td>
<td>27 ± 1*</td>
</tr>
</tbody>
</table>

*P < 0.0001.

**TABLE 3. Mean (± SEM) values of several physiological variables studied at the base camp and at altitude**

<table>
<thead>
<tr>
<th></th>
<th>Base camp (1140 m)</th>
<th>Altitude (2650 m)</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (l)</td>
<td>4.45 ± 0.12</td>
<td>4.45 ± 0.12</td>
<td>0.03 ± 0.6</td>
</tr>
<tr>
<td>FEV1 (l)</td>
<td>3.47 ± 0.10</td>
<td>3.50 ± 0.10</td>
<td>0.8 ± 0.7</td>
</tr>
<tr>
<td>FVC/FVC (%)</td>
<td>78 ± 0.9</td>
<td>79 ± 0.8</td>
<td>0.8 ± 0.5</td>
</tr>
<tr>
<td>MMEF (l min⁻¹)</td>
<td>3.11 ± 0.14</td>
<td>3.21 ± 0.15</td>
<td>3.8 ± 1.8</td>
</tr>
<tr>
<td>PEF (l s⁻¹)</td>
<td>9.04 ± 0.40</td>
<td>9.41 ± 0.40</td>
<td>3.1 ± 1.2</td>
</tr>
<tr>
<td>MVV (l)</td>
<td>144.2 ± 4.3</td>
<td>145.6 ± 4.1</td>
<td>1.0 ± 1.5</td>
</tr>
<tr>
<td>MIP (cm H₂O)</td>
<td>99.8 ± 4.0</td>
<td>98.2 ± 4.0</td>
<td>-0.9 ± 1.8</td>
</tr>
<tr>
<td>MEP (cm H₂O)</td>
<td>144.5 ± 5.9</td>
<td>143.2 ± 5.8</td>
<td>-0.1 ± 2.1</td>
</tr>
<tr>
<td>Heart rate (min⁻¹)</td>
<td>78.4 ± 1.7</td>
<td>88.4 ± 2.2*</td>
<td>13.9 ± 2.8</td>
</tr>
<tr>
<td>SaO₂ basal (%)</td>
<td>96.5 ± 0.2</td>
<td>92.5 ± 0.3*</td>
<td>-4.1 ± 0.3</td>
</tr>
<tr>
<td>SaO₂ hyper Vₑ (%)</td>
<td>98.2 ± 0.1†</td>
<td>96.4 ± 0.3*†</td>
<td>-1.8 ± 0.2</td>
</tr>
<tr>
<td>Recovery time (s)</td>
<td>16.5 ± 1.2</td>
<td>24.3 ± 1.4*</td>
<td>91.7 ± 28.3</td>
</tr>
<tr>
<td>Lactate (mM 1⁻¹)</td>
<td>3.7 ± 0.3</td>
<td>3.2 ± 0.2</td>
<td>-13.7 ± 7.2</td>
</tr>
</tbody>
</table>

*P < 0.01 between altitudes. †P < 0.01 with respect to basal values. FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s; MMEF: maximum mid expiratory flow; PEF: peak expiratory capacity; MVV: maximum voluntary ventilation; MIP: maximal inspiratory pressure; MEP maximal expiratory pressure; SaO₂: arterial oxygen saturation of haemoglobin with oxygen in internal blood.

Results

The mean age of all participants was 42.4 ± 1.4 years. Females were younger, lighter and smaller than males (Table 1). The percentage of smokers was similar in males (19%) and females (21%) (P = n.s.). Among smokers (n = 9) the Fagerström test averaged 4.9 ± 0.7 points and exhaled CO 8.7 ± 1.6 ppm. On average, participants could be classified as sedentary as shown by a mean PAI of 8.2 ± 0.2 (Table 1); however, this value varied widely between participants, ranging from 5.88–11.63.

At the base camp, all lung function variables were well within the normal range and no significant differences between males and females were observed, except for forced vital capacity (FVC) which was slightly higher in females (though normal in both cases) (Table 1). At altitude, these values remained basically unchanged, except for a higher heart rate and a lower SaO₂ value (both at rest and after ventilatory manoeuvres) and a prolongation of recovery time (Table 3). Interestingly, lactate concentration after exercise was similar at the base camp and at altitude (Table 3). Table 4 presents the percent change at altitude of these physiological variables according to the smoking (yes/no) and exercise habits (PAI greater or lower than 8) of all subjects studied. In most cases, differences were not statistically significant. Only two variables (PEF in those with PAI > 8, and MEP in regular smokers) showed a statistical significant difference (Table 4). However, the absolute value of these changes are small and well within the variability of the measure.

Discussion

This study does not pretend to investigate the physiological effects of altitude upon lung function. This has been the subject of numerous studies in the past (1–4). It tries to fill a gap in the literature which relates to the potential effects of
Table 4. Percent change at altitude (mean ± SEM) of several physiological variables according to the smoking and exercise habits of the subjects studied

<table>
<thead>
<tr>
<th>Smoking history</th>
<th>Exercise habitually</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (n = 37)</td>
</tr>
<tr>
<td></td>
<td>No (n = 18)</td>
</tr>
</tbody>
</table>

FVC (% change)  
FEV\(_1\) (% change)  
FEV\(_1\)/FVC (% change)  
MMEF (% change)  
PBF (% change)  
MVV (% change)  
MIP (% change)  
MEP (% change)  
Heart rate (% change)  
SaO\(_2\) basal (% change)  
SaO\(_2\) hyper V\(_E\) (% change)  
Recovery time (% change)  
Lactate (% change)  

-0.1 ± 0.7  
1.0 ± 0.7  
1.1 ± 0.6  
48.2 ± 2.1  
3.4 ± 1.1  
0.6 ± 1.7  
12.2 ± 2.0  
-0.5 ± 2.4  
13.8 ± 3.0  
-4.0 ± 0.4  
-1.8 ± 0.2  
105.0 ± 34.8  
-16.4 ± 8.5  
0.6 ± 1.6  
0.3 ± 1.8  
-0.6 ± 0.9  
-0.1 ± 3.1  
1.4 ± 5.2  
2.6 ± 3.1  
-9.6 ± 3.5*  
1.6 ± 4.3  
14.3 ± 7.6  
-4.6 ± 0.6  
1.6 ± 0.7  
40.2 ± 23.9  
0.7 ± 1.0  
-0.1 ± 1.0  
0.4 ± 1.0  
-0.01 ± 1.1  
1.6 ± 1.0  
-0.6 ± 0.7  
1.4 ± 0.8  
3 ± 2.9  
5.5 ± 2.8  
0.9 ± 1.4  
6.3 ± 1.4*  
2.5 ± 1.9  
-0.2 ± 2.2  
-2.8 ± 2.4  
1.5 ± 2.8  
-4.4 ± 3.5  
3.7 ± 2.8  
13.3 ± 4.4  
13.8 ± 3.9  
-4.5 ± 0.6  
-3.7 ± 0.4  
-1.8 ± 0.4  
-1.9 ± 0.3  
67.6 ± 33.5  
125.4 ± 49.3  
-18.7 ± 10.7  
12.0 ± 9.7

Asterisks indicate significance of differences between conditions (smoke vs. Non smoker and sedentarism vs. Non-sedentarism, respectively). (*P < 0.05; **P < 0.01). FVC forced vital capacity; FEV\(_1\): forced expiratory volume in 1 s; MMEF: maximum mid expiratory flow; PEF: peak expiratory flow; MVV: maximum voluntary ventilation; MIP: maximal inspiratory pressure; MEP maximal expiratory pressure; SaO\(_2\): arterial oxygen saturation of haemoglobin with oxygen in internal blood.

moderate (not extreme) altitude upon healthy (not athletic) subjects studied without previous acclimatization. This may be of interest for a vast number of individuals who are exposed to this altitude for tourist or recreational reasons worldwide. In this context, the main findings of this study were that, in a group of middle-aged, untrained, healthy subjects, the ascent to moderate–high altitude does not influence lung function significantly. Further, this was not modified either by the smoking history or the exercise habits of the subject.

The vast majority of studies investigating the effects of altitude upon lung function included young, highly-trained athletes, obtained measurements at very high altitude (6000–8000 m), and/or focused on the consequences of acclimatization or maximal exercise in these extreme conditions (1–4). Few other studies have been aimed at investigating the performance of the required measurement equipment in these circumstances (15,16). By contrast, there is very little information on the effects of moderate–high altitude (2000–3000 m) upon lung function in middle-age, sedentary (or mildly active) healthy individuals, who are not specifically acclimatized and who ascend to this altitude only occasionally (5,6). Our study was specifically designed to investigate this particular type of individual under these special atmospheric conditions (Table 2). In this context, it is worth noting that because participants were not selected, they do not normally live at altitude and they were studied within the first 24 h of arrival in the ski resort, they are fully comparable to the normal middle-aged healthy population. Thus, our results provide a missing piece of information which, we believe, is important because all over the world, many of these subjects often move to this type of altitude for recreational purposes.

In theory, moderate–high altitude can influence lung function through several putative mechanisms. Firstly, the decrease of atmospheric pressure that occurs with altitude reduces SaO\(_2\). The magnitude of SaO\(_2\) reduction is modulated by the ventilatory response to hypoxia, a response that varies widely between individuals (17) and is significantly influenced by previous acclimatization (18). In our study, we observed that SaO\(_2\) fell with altitude from 96.5 to 92.5%. This change is fully explained by the 1490 m difference between the base camp and the altitude laboratory. Interestingly, even after the three ventilatory manoeuvres, SaO\(_2\) was still lower at altitude than in the base camp (Table 3). Likewise, recovery time was prolonged at altitude (Table 3). This is probably a reflection of the lower starting SaO\(_2\) value, although the cooler ambient temperature of the altitude laboratory may have induced some peripheral vasoconstriction that also contributed to the delay in transit time from the lung to the finger capillary bed where SaO\(_2\) was measured.

Secondly, several factors may significantly influence spirometry at altitude (19). On the one hand, air becomes less dense with altitude. Therefore, airway resistance should decrease and both the inspiratory and expiratory flows should increase (20). On the other, the low ambient temperature characteristic of high altitude can induce bronchoconstriction, particularly in subjects with mild airway hyper-reactivity (21). In keeping with previous studies (22, 23), we did not observe either an increase or decrease in any of the different spirometric indices assessed.
at altitude (Table 3). Probably, this lack of effect is due to the moderate altitude at which we measured lung function in our study and to an ambient temperature (Table 2), which was not low enough to elicit significant bronchoconstriction in our subjects. The reduction of FVC that may and/or interstitial oedema, occurs at a higher altitude (> 5000 m) (19).

Thirdly, if SaO₂ decreases with altitude substantially (e.g. to less than 90%), respiratory and skeletal muscles may become poorly oxygenated. Theoretically, this may jeopardize their function, decreasing their strength and/or endurance capacity. In our subjects, respiratory muscle function (MIP, MEP, MVV) was not impaired at altitude (Table 3). This is probably related to the fact that very few individuals showed a SaO₂ value at altitude lower than 90%. Also of note is the fact that lactate concentration after exercise at altitude was not different from that seen in the base camp (Table 3). This indicates that skeletal muscle function was not impaired by altitude in these groups of subjects.

Two final aspects of our study deserve comment. Firstly, neither smoking or exercise habits appeared to influence the response of lung function to altitude in these individuals. However, the number of smokers was small and the range of physical training relatively narrow. Secondly, the design of our study allowed us to test the reliability of several pieces of equipment, routinely used to measure lung function in many laboratories at sea level (spirometers, manometers and computers), under more extreme atmospheric conditions (Table 2). It was reassuring to observe that all of them worked correctly.

In summary, our results show that lung function is not significantly altered by moderate-high altitude in middle-aged, healthy, not particularly well-trained individuals, despite the absence of any acclimatization period and independently of their smoking history and exercise habits.

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References