Changes in Respiratory Function Following Intermittent Living in the Upland Environment and the Lowland Environment

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Abstract. [Purpose] The purpose of this study is to examine the effects on respiratory function and oxygen saturation of intermittent life in the uplands at an altitude above sea level of approximately 850 m. [Subjects and Methods] The study subjects were on 100 female student subjects attending a university located in the uplands. The subjects’ oxygen saturation, heart rates and respiratory functions were measured at the university, which has campuses both in the uplands and the lowlands. [Results] Freshmen showed differences in oxygen saturation, heart rate, and most respiratory function items between the different altitudes; however, seniors did not exhibit any differences. There were no differences in oxygen saturation and heart rate between the uplands and the lowlands either group. In the uplands, peak forced expiratory flow was shown to be high in the seniors, who also had better cardiopulmonary function. [Conclusion] Senior students, who had been exposed to the upland environment for a longer period of time, generally showed better respiratory function. Therefore, alternating living between the uplands and the lowlands can be said to improve an individual’s respiratory function.

Key words: Altitude above sea level, Oxygen saturation, Respiratory function

INTRODUCTION

As altitude increases, the weight of air decreases, and the atmospheric pressure decreases. Low atmospheric pressure means there is more space between air molecules. As a result, the number of oxygen molecules existing in the same volume of air decreases, so the amount of oxygen intake decreases in the uplands, even if the same amount of air is respired. That is, an increase in altitude reduces oxygen partial pressure in the pulmonary alveoli as well as the blood’s ability to carry oxygen due to reduced atmospheric pressure, causing hypoxia. Therefore, for an individual to consume the same amount of oxygen in the uplands as is consumed in the lowlands, the volume of air respired needs to increase1, 2). Exposure to low oxygen due to altitude change acts as a powerful stimulus to induce diverse changes in the lungs3). When exposed to upland environments, the densities of erythrocytes, hemoglobin, capillary vessels, and myoglobin in the skeletal muscles increase, which may improve the body’s ability to transport oxygen5). Since cardiopulmonary function is improved and athletic performance is affected as a result of processes adapting to the characteristics of upland environments1), upland training is widely used as a method to intensively reinforce physiological functions centering on cardiopulmonary function6). Since respiration supplies oxygen for the performance of activities of daily living (ADL), breathing disorders affect the performance of ADL7). That is, the efficiency of the respiratory function is closely related to that of the circulatory function, and is important not only for the performance of athletes, but also for the health of the general population.

Upland-related studies have mostly dealt with athletes’ training1, 7–10), and studies conducted among the general population living in the uplands are lacking. In Korea, where approximately 70% of the country’s area is mountainous, methods for improving respiratory function utilizing upland environments should be particularly useful. Accordingly, the authors of this study examined the effects of alternate living experiences in the uplands and the lowlands on respiratory function and oxygen saturation in order to provide basic data for improving cardiopulmonary function exploiting altitude.

SUBJECTS AND METHODS

The study subjects were 100 female students in the 1st through 4th grades of K University, which is located at an altitude of approximately 850 m. The study took place from March 27 to April 10, 2013. The mean age and height of the study subjects, comprising 25 freshmen (18.92±0.57 years, 163.04±4.25 cm), 25 sophomores (19.96±0.54 years, 161.52±5.45 cm), 25 juniors (21.04±0.35 years, 159.84±4.40 cm), and 25 seniors (22.12±0.67 years, 163.48±5.22 cm),
160.80±4.17 cm), were 20.51 years and 161.30 cm, respectively. The study subjects were selected from among those who had no history of smoking, and had no respiratory organ disease, or symptoms that would have affected their lung capacity. The study’s objectives and procedure were explained to the subjects and individual consent to participate was obtained from all of them. The study was approved by the ethical committee of the Kangwon National University Hospital Institutional Review Board. In Korea, one school year is divided into two semesters and each semester consists of 15 or 16 weeks. Except for the freshmen, the students who were the subjects of this study took classes at the school located at an altitude above sea level of approximately 850 m for approximately 30 weeks per year. These students spend at least 15 weeks per semester at the school located in the uplands; they then go home to the lowlands during vacations. When this study was conducted, freshmen had been attending the school for approximately one month, and the students in the more senior grades had already experienced living arrangements alternating between the uplands and the lowlands.

In this study, oxygen saturation, heart rate, and cardiopulmonary function were measured at the same time on the 8th floor of a building (altitude at least 850 m) located at the highest level of K university, and in the student life center located in the lowlands. Oxygen saturation and heart rates (beats per minute, bpm) were measured using a heart rate and arterial blood oxygen saturation measuring instrument (Pulse Oximeter, MP110P Mek-ICS Co., Korea). The pulse oximeter was attached to the subject’s middle finger with subjects and the values were measured in a stable state 6–8 times during five minutes. Then, the average of the measured values was calculated. Pulse oximetry is a non-invasive method, using an instrument that can monitor oxygen saturation easily and quickly, and indicate the measured values as SpO₂. In this study, forced vital capacity (FVC), forced expiration volume of 1 sec (FEV₁), peak forced expiratory flow (PEF), forced vital capacity of 1 sec (FVC), were measured using cardiopulmonary measuring instruments (Microplus Spirometer, UK Carefusion Co.), and the FEV₁/FVC ratio was calculated.

When a subject arrived at the location where she was to be measured, she was instructed to rest for approximately five minutes to ensure that she was stabilized. Then, oxygen saturation and heart rate were measured using the right index finger. Demonstrations and explanations about the posture required were provided before measuring the cardiopulmonary functions, which were measured three times. The averages of the measured values were used in the study. Vital capacity was measured using the method recommended in the Chronic Obstructive Pulmonary Disease treatment guidelines by referring to the standardized guidelines for the implementation and reading of pulmonary function tests published by the American Thoracic Society and the European Respiratory Society. When pulmonary functions were measured, the subject was instructed to look forward, standing in an upright position. The subject was instructed to maximally inhale and then exhale as quickly and strongly as possible for the longest time possible, while holding the nose firmly and biting the mouthpiece properly. To obtain better measurement results, the subject was encouraged by the researcher saying, “more, more, more, hoo~.” The subject was instructed to rest for approximately two seconds after each measurement so as not to record rebound measurements. When measured values could not be properly obtained, because the subject coughed or otherwise, the subject was instructed to rest, after which the measurement was repeated.

The data were analyzed using SPSS 12.0 for Windows by conducting one-way ANOVA to test respiratory functions and oxygen saturation according to grade. Scheffe’s method was conducted for ex post facto analysis. In addition, crossover analysis was conducted to distinguish cardiopulmonary functions. The statistical significance level was chosen as p=0.05.

RESULTS

This study was conducted to examine the effects of living in the uplands and the lowlands on respiratory functions and oxygen saturation. Oxygen saturation, heart rate, and respiratory functions of students in different grades at different altitudes were examined. The freshmen showed statistically significant differences between the uplands and the lowlands in all items except PEF and FEV. Heart rates were higher in the uplands, oxygen saturation was higher in the lowlands, FVC was higher in the lowlands, and FEV₁/FVC was higher in the uplands. Significant differences in oxygen saturation were noted in sophomores and significant differences in oxygen saturation and PEF were noted in juniors. On the other hand, there were no statistically significant differences in any of the items measured in the uplands and the lowlands among the seniors. Therefore, it can be said that alternating living experiences in the uplands and the lowlands affects respiratory functions (Table 1). To examine the effects of alternating living experiences in the uplands and the lowlands on oxygen saturation, heart rate, and respiratory functions, differences in the values between grades in the uplands and the lowlands were examined separately (Table 2). In the uplands, there were no significant differences in oxygen saturation and heart rate between grades. There were statistically significant differences in PEF and FEV₁/FVC (p < 0.05). PEF was shown to be the highest in seniors, followed by juniors, sophomores, and freshmen, in order of precedence, and FEV₁/FVC was the highest among juniors (97.01±3.82) and the lowest among sophomores (92.09±7.64). In the lowlands, there were no significant differences in oxygen saturation and heart rate between grades. There were significant differences in PEF, FEV₁/FVC between the grades. FVC was shown to be the lowest among juniors (2.66±0.39), PEF was the highest among seniors (356.15±57.60), and FEV₁/FVC was the highest among juniors (96.73±5.32) and the lowest among freshmen (88.92±8.51) (Table 2).

Cardiopulmonary functions by grade in the uplands and the lowlands were judged after dividing the subjects into lower grade students (freshmen, sophomores), who had less experience of alternating living between the lowlands and
the uplands, and upper grade students (juniors, seniors), who had more experience. In the uplands, the cardiopulmonary functions of lower grade students and those of upper grade students showed statistically significant differences ($\chi^2 = 0.014$). Upper grade students showed only normal spirometry (NS) (70%) and mild restriction (MR) (30%), and some lower grade students showed moderate restriction (MoR), mild obstruction (MO), and moderate severe restriction (MoSR), indicating that they were experiencing cardiopulmonary function disorders (Table 3). In the lowlands, the cardiopulmonary functions of lower grade students and those of upper grade students showed statistically significant differences ($\chi^2 = 0.005$). NS showed the highest proportion in both lower grade and upper grade students. In the lowlands, lower grade students showed NS, MO, MR, MoSR, and moderate obstruction (MoO), while upper grade students showed NS, MoR, MO, and MR (Table 3).

**DISCUSSION**

This study was conducted to examine the effects of alternating living experiences of the uplands and the lowlands on oxygen saturation and respiratory function in order to provide basic data for improving cardiopulmonary function exploiting altitude.

In this study, there were differences in oxygen saturation, heart rate, and most respiratory function items between the uplands and the lowlands among the freshmen; however, there were no differences in any of the items among the seniors. To take in the same amount of oxygen taken at sea level at 850 m in the uplands, the amount of ventilation would have to increase two-fold. To compensate for this, the body improves the oxygen carrying capacity of the blood. Therefore, long-term life in the uplands improves the body's oxygen carrying capacity. This can explain the phenomenon that was apparent in the present study in which freshmen who had just began living in the uplands showed higher oxygen saturation and heart rates, increased FVC, and decreased FEV1/FVC. Seniors who had long-term experience of alternating life between the uplands and the lowlands did not show differences in any of the items. Therefore, it can be said that alternating living experiences in the uplands and the lowlands affects pulmonary functions, even without continuous exposure to the upland environment.

When exposed to the upland environment, and the associated low-pressure, low-oxygen environment, the heart rate increases to a slightly higher level than in the lowlands due to the action of the sympathetic nerve and an increased energy metabolic rate. The heart rate it returns almost to the original level, after adapting to the upland environment, after approximately one week. Therefore, the reason why differences in oxygen saturation and heart rate between the grades did not appear in both the upland- and lowland-living students was that even the freshmen had started school at least three weeks earlier, and thus, all of the students had already adapted to their environment. In the uplands, PEF and FEV1/FVC were shown to be higher among upper grade students, who indicated smooth expiration. This indicates that upper grade students had better adaptability to the uplands than lower grade students. In the lowlands, FVC was shown to be higher among lower grade students, and PEF and FEV1/FVC were shown to be higher among upper grade students, compared to those from the uplands, indicating that the pulmonary functions of the upper grade students were better. Therefore, even alternating living between the uplands (during semesters) and the lowlands (during vacations), as opposed to continuous life in the uplands, appears to improve respiratory function. When an individual returns to the lowlands after training in the uplands, his/her maximum oxygen intake increases, aerobic enzymes are activated, mitochondria count increases, glycogen storage ability improves, capillary vessel density increases, hemoglobin concentration increases, and heart functions are activated. However, in this study, although there were differences in respiratory function tests between grades, there were no differences in oxygen saturation and heart rate, unlike the findings of the study conducted by

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**Table 1. Differences in oxygen saturation and pulmonary functions with altitude**

|                | Freshmen | Sophomores | Juniors | Seniors |
|----------------|----------|------------|---------|---------|
| **M±SD**       |          |            |         |         |
| Upland HR      | 82.88±12.02* | 81.16±11.04 | 80.64±9.83** | 79.68±9.78 |
| Lowland HR     | 78.04±10.23* | 76.84±11.85 | 75.92±7.63** | 80.12±11.31 |
| Upland saturation | 97.80±0.96** | 97.4±1.04** | 98.20±1.00 | 97.88±1.05 |
| Lowland saturation | 98.44±0.77** | 98.32±0.80** | 98.32±1.18 | 97.96±1.24 |
| Upland PEF     | 293.20±74.61 | 321.60±67.01 | 345.35±59.70** | 356.77±57.35 |
| Lowland PEF    | 283.10±84.11 | 307.04±62.84 | 326.27±62.70** | 356.15±57.56 |
| Upland FVC     | 2.73±0.48** | 2.93±0.50 | 2.70±0.31 | 2.89±0.26 |
| Lowland FVC    | 2.98±0.48** | 2.98±0.53 | 2.66±0.39 | 2.86±0.38 |
| Upland FEV     | 2.59±0.51 | 2.69±0.42 | 2.62±0.28 | 2.75±0.23 |
| Lowland FEV    | 2.65±0.46 | 2.69±0.40 | 2.57±0.35 | 2.70±0.30 |
| Upland ratio   | 92.13±6.60* | 92.09±7.68 | 97.01±3.82 | 95.37±5.40 |
| Lowland ratio  | 88.92±8.51* | 91.17±8.15 | 96.73±5.32 | 94.93±5.60 |

*p < 0.05, **p < 0.01
Table 2. Differences in vital capacity according to grade

| Place   | Item               | Grade | N  | M±SD   |
|---------|--------------------|-------|----|--------|
|         | Oxygen saturation (%) |       | 1  | 97.80±0.96 |
|         |                    |       | 2  | 97.40±1.04 |
|         |                    |       | 3  | 98.20±1.00 |
|         |                    |       | 4  | 97.88±1.05 |
|         |                    |       | 1  | 82.88±12.02 |
|         |                    |       | 2  | 81.16±11.04 |
|         |                    |       | 3  | 80.64±9.83 |
|         |                    |       | 4  | 79.68±9.78 |
|         |                    |       | 1  | 2.59±0.51 |
|         |                    |       | 2  | 2.69±0.42 |
|         |                    |       | 3  | 2.62±0.28 |
|         |                    |       | 4  | 2.75±0.23 |
|         | HR (bpm)           |       | 1  | 2.73±0.48 |
|         |                    |       | 2  | 2.93±0.50 |
|         |                    |       | 3  | 2.70±0.31 |
|         |                    |       | 4  | 2.89±0.26 |
|         |                    |       | 1  | 293.18±74.60 |
|         |                    |       | 2  | 321.60±67.00 |
|         |                    |       | 3  | 345.35±59.70 |
|         |                    |       | 4  | 356.77±57.40 |
|         |                    |       | 1  | 92.13±6.60 |
|         |                    |       | 2  | 92.09±7.68 |
|         |                    |       | 3  | 97.01±3.82 |
|         |                    |       | 4  | 95.37±5.40 |
|         |                    |       | 1  | 98.44±0.77 |
|         |                    |       | 2  | 98.32±0.80 |
|         |                    |       | 3  | 98.32±1.18 |
|         |                    |       | 4  | 97.96±1.24 |
|         |                    |       | 1  | 78.04±10.23 |
|         |                    |       | 2  | 76.84±11.85 |
|         |                    |       | 3  | 75.92±7.63 |
|         |                    |       | 4  | 80.12±11.31 |
|         |                    |       | 1  | 2.65±0.46 |
|         |                    |       | 2  | 2.69±0.39 |
|         |                    |       | 3  | 2.57±0.35 |
|         | FVC (ml)*          |       | 4  | 2.70±0.30 |
|         |                    |       | 1  | 2.98±0.48 |
|         |                    |       | 2  | 2.98±0.53 |
|         |                    |       | 3  | 2.66±0.39 |
|         |                    |       | 4  | 2.86±0.38 |
|         |                    |       | 1  | 283.09±84.10 |
|         |                    |       | 2  | 307.04±62.80 |
|         |                    |       | 3  | 326.27±62.70 |
|         |                    |       | 4  | 356.15±57.60 |
|         |                    |       | 1  | 88.92±8.51 |
|         |                    |       | 2  | 91.17±8.15 |
|         |                    |       | 3  | 96.73±5.32 |
|         |                    |       | 4  | 94.93±5.60 |

*p < 0.05, **p < 0.01, HR: heart rate, FEV₁: forced expiratory volume of one sec, FVC: expiratory flow rate obtained by fastest expiration after maximal inhalation, PEF: peak expiratory flow, FEV₁/FVC: the ratio of forced expiration volume of 1 sec to forced vital capacity.
The degrees of respiratory functional disorders by grade in the uplands and the lowlands were judged after dividing the subjects into the lower grade students (freshmen, sophomores) who had less experience of alternating living between the lowlands and the uplands, and the upper grade students (juniors, seniors) who had more experience of doing so. In the uplands, the upper grade students showed only NS (70%) and MR (30%), indicating that their breathing was normal or had slight limitations. On the other hand, some lower grade students showed moderate breathing restrictions, severe breathing restrictions, and mild breathing disorders. In the lowlands, lower grade students showed fewer breathing disorders compared to the uplands, although some had breathing disorders, and upper grade students showed more cases of slight restriction. Restriction was also observed in the lowlands. This was due to large lung capacity, as living in the uplands did not seem to inhibit breathing. The maximum oxygen intake at 1,800–2,300 m corresponds to approximately 80–85% of that at sea level and increases by approximately 2–5% after a 2- to 3-week adaptation periods. The fact that increases in the maximum oxygen intake in the uplands is not shown to be the same as those at sea level indicates the human body’s maximum oxygen intake in the uplands is considered to be an effective method for improving respiratory function; however, most people cannot move on a regular basis. In this study, we were unable to determine the period of upland living required to influence an improvement in respiratory function; therefore, further studies are necessary. Through such studies, researchers may discover methods for improving cardiopulmonary function or breathing disorders exploiting natural environmental conditions, for athletes as well as for the general population.

### Table 3. Assessment of on breathing disorders N(%)  

|        | NS    | MR    | MoR   | MoSR  | MO    | MOo   | Total |
|--------|-------|-------|-------|-------|-------|-------|-------|
| Upland* |       |       |       |       |       |       |       |
| A      | 29 (58%) | 10 (20%) | 5 (10%) | 2 (4%) | 4 (8%) | 0 (0%) | 50 (100%) |
| B      | 35 (70%) | 15 (30%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 50 (100%) |
| Lowland** |       |       |       |       |       |       |       |
| A      | 30 (60%) | 7 (14%) | 0 (0%) | 2 (4%) | 10 (20%) | 1 (2%) | 50 (100%) |
| B      | 29 (58%) | 19 (38%) | 1 (2%) | 0 (0%) | 1 (2%) | 0 (0%) | 50 (100%) |

A: Freshmen+sophomore, B: juniors+seniors, NS: Normal Spirometry, MR: Moderate Restriction, MoR: Moderate Severe Restriction, MoSR: Moderate Severe Restriction, MO: Mild Obstruction, MoO: Moderate Obstruction.