Effects of Exercise at High Altitudes on Young Adults

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Outward Bound programs are carried out throughout the world, and many of these courses occur at altitudes above 3000 m (10,000 ft). As more knowledge is accumulated about health problems at high altitudes, exercise has been implicated as a factor contributing to acute mountain sickness in susceptible individuals. Thus, exercise conditioning programs occurring at high altitudes have come under scrutiny. Twenty-eight young men and women were enrolled in an Outward Bound course at an altitude over 3000 m for a 21-day period. Twelve of the 28 individuals developed shortness of breath, cough, or both by the third day of the course. Of these 12, seven had pulmonary function abnormalities: three having evidence of large airway involvement and four having findings of small airway involvement. The symptoms were not significant enough to interfere with acclimatization and the muscular conditioning aspects of the program. Although at altitudes between 3000 m and 4300 m, pulmonary function abnormalities of acute mountain sickness develop in a significant number of participants, the abnormalities were not significant enough to prevent persons from completing the course or achieving marked improvements in fitness measurements.

The Outward Bound program has offered an arduous outdoor experience designed to improve stamina, strength, self-confidence, leadership skills, and self-esteem. The psychological effects of the program have been evaluated,[1,2] but the physiological effects, especially at high altitudes, have not been measured. Also, since most of the Colorado courses take place at altitudes between 3000 m (10,000 ft) and 4300 m (14,000 ft) in the central Colorado Rocky Mountains, some critics have voiced concern about an endurance program at high altitudes, as hypoxia will limit the goals of the program, and acute mountain sickness (especially pulmonary edema) could be a danger to some individuals participating in the high-altitude programs. A preliminary survey of previous experiences by the Outward Bound staff in Denver indicated that acute mountain sickness had not been a major problem, with only one student dropping out per year because of respiratory difficulty. To answer some of the above concerns, one Outward Bound group was studied in the summer of 1984. This study was based at St. Vincent's General Hospital in Leadville, Colorado, at an altitude of 3100 m.

The study had three objectives: (1) to determine whether the intense physical experience of the Outward Bound course affected the body composition of the subjects, (2) to determine whether an improvement in measurements of physical performance, unique for this course, occurred in each student, and (3) to determine whether acute mountain sickness, especially pulmonary involvement, interfered with the course.

METHODS

Twenty-eight Outward Bound students, eight women and 20 men, were studied on day 1 of a standard 21-day summer course. Informed consent was obtained. The students arrived in Denver from various parts of the country early on day 1. They were then bused to St. Vincent's General Hospital in Leadville, Colorado, at 3100 m (10,170 ft), where testing was done. Past medical history, cardiopulmonary examination, and anthropometric measurements were obtained on each student. The following five general categories of tests were done on each student:

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1. Anthropometric measurements
2. Ventilatory tests: vital capacity, respiratory flow rates, and ventilatory response to hypoxia
3. Aerobic fitness as measured by a submaximal work test
4. Agility, dynamic strength, and running tests
5. Laboratory determination of hemoglobin, hematocrit, and red blood cell counts

Anthropometric Measurements

Anthropometric data consisted of standing height, weight, and skinfold fat thickness. Each subject was initially weighed and body fat assessed by means of Lange skinfold calipers. All measurements were done by one observer (K.E.C.). Three measurements were taken and averaged from three sites: triceps, suprailiac, and medial thigh. The sum of the three averages was recorded during each of the two testing periods, before and after the Outward Bound course. Since skinfold thickness is correlated with fat weight,[3,4] a decrease in the sum of the three skinfold thicknesses was interpreted as a decrease in fat weight.

Ventilatory Tests

Vital capacity and forced flow rates were determined by having the student blow into a spirometer (DeVilbiss Surveyor). The forced vital capacity (FVC), timed vital capacity for one second ($FEV_{1.0}$), peak flow rate (PEF), and flow between 25 and 75 percent of vital capacity (FEF_{25-75}) were measured for each subject and repeated for a total of three maneuvers. Subjects were tested in a sitting position. All values were corrected for temperature and pressure.

Ventilatory response to hypoxia was measured on each subject sitting in a pressure-volume plethysmograph with the student breathing ambient air through a wide-bore tube in the wall of the plethysmograph. Minute volume, arterial pressure (P_A), alveolar oxygen (P_AO_2), carbon dioxide (P_ACO_2), and nitrogen (P_AN_2) were determined while the student breathed 30 percent oxygen, then 10 percent oxygen. The hypoxic response was calculated by determining the A value of the hyperbolic response curve, using the method of Weil.[5]

Spirometric testing of the vital capacity and respiratory flow rates was repeated on each student at the three-day camp, which was located at 3943 m (13,100 ft). All values were corrected for temperature and pressure. Each student had walked to this camp and had run one mile the day before. No exercise had been performed on the morning of the testing. Subjects were tested in the sitting position. These tests were done on the third day, since previous reports indicate that acute mountain sickness with respiratory involvement most frequently becomes manifest at that time.[6]

Aerobic Fitness Methods

Aerobic fitness was measured by a submaximal work test. An electronically calibrated bicycle ergometer was used to test the students at workloads of 300 kilopondmeters per minute (KPM/min), 600 KPM/min, and 900 KPM/min. Heart rate and electrocardiogram were monitored continuously, and heart rate was recorded during the last five seconds of each minute. At the end of five or six minutes, if a plateau in heart rate had been reached, the test was concluded. Each student was evaluated at two workloads, and predicted maximum oxygen uptake (V_{O_2MAX}) was obtained from the Astrand/Rhyming nomogram for each of the chosen workloads.[7] The average of the tests at two workloads was taken as the predicted V_{O_2MAX} for the individual. On three occasions the heart rate was outside the limits of the Astrand/Rhyming nomogram for one of the chosen workloads. For these three students, only one workload level was used to give a predicted V_{O_2MAX}.

Agility, Dynamic Strength, and Running Tests

Each subject was also given five physical fitness tests loading on factors thought to be trained by the three-week Outward Bound experience. These factors and the tests used were as follows: (1) the vertical jump was used to test the explosive leg strength factor, (2) the 40-yard dash was used to test the speed factor, (3) the 60-second sit-up test was used to test dynamic trunk strength, (4) the 880-yard run was used to test cardiovascular endurance, and (5) an obstacle course was used to combine factors felt to be important in Outward Bound training: dynamic arm strength, dynamic balance, and gross body coordination.[8–10]

Blood Tests

Hemoglobin, hematocrit, and red blood cell count were determined on each participant by a model MHR Coulter counter. Blood was obtained by venipuncture.

Upon completion of these tests the students left for the standard Outward Bound course. The tests were repeated at the conclusion of the 21-day course.

Statistics

The data are expressed as mean values plus or minus standard error. Differences between groups were com-

TABLE 1. BODY COMPOSITION, HEMOGLOBIN, MAXIMUM OXYGEN UPTAKE AND FITNESS TEST RESULTS BEFORE AND AFTER THE OUTWARD BOUND COURSE (EXPRESSED AS A MEAN ± STANDARD ERROR)

Test Results	Men (mean age 18.4 years)		Women (mean age 18.3 years)	
	Before	After	Before	After
Weight (lb)	155.6 ± 2.5	149.2 ± 2.0*	136.3 ± 5.7	133.1 ± 5.7*
Sum skinfolds (mm)	69.5 ± 5.5	51.1 ± 4.1*	114.0 ± 4.1	95.6 ± 5.2*
V_{O_2MAX} predicted (mL/kg/min)	37.3 ± 0.9	46.2 ± 2.8*	32.8 ± 1.8	40.4 ± 3.4*
880-yd run (sec)	199.1 ± 8.3	174.8 ± 4.4*	257.1 ± 10.9	234.6 ± 8.2*
40-yd dash (sec)	10.7 ± 0.1	11.3 ± 0.2*	12.8 ± 0.2	14.6 ± 0.8*
Sit-ups per minute	46.6 ± 1.9	47.9 ± 1.6	37.6 ± 3.9	42.9 ± 3.7*
Vertical jump (inches)	20.1 ± 0.8	18.7 ± 0.7*	12.1 ± 0.7	11.2 ± 0.7
Obstacle run (sec)	163.2 ± 6.5	142.6 ± 4.7*	270.3 ± 22.6	206.5 ± 16.9*
Hemoglobin (g/dL)	16.02 ± 0.86	16.4 ± 0.85*	13.7 ± 1.0	14.8 ± 0.8*

* *Significantly different from precourse (P < .05)*

pared using the paired *t* statistic. Differences were considered significant at P values of less than .05.

RESULTS

Subject Data

Thirty students were initially studied. They ranged in age from 16 to 23 years. Twenty students came from sea level environments and had not been above 270 m (900 ft). Ten subjects lived at altitudes between 1800 and 3100 m.

Twenty-eight students, 20 men and 8 women, finished the course. Two students dropped out, one because of pain from a recent rib injury and the other for motivation reasons. Neither of these students had clinical or laboratory evidence of high-altitude pulmonary edema as determined at the three-day camp; both were sea level residents.

Anthropometric Results

Weight in men and women showed statistically significant drops over the course. Mean weight in men dropped from 155.6 lb to 149.2 lb for a 4.1 percent drop. Mean weight in women dropped from 136.3 lb to 133.1 lb for a 2.4 percent drop (Table 1).

Skinfold fat thickness decreased markedly and was highly statistically significant (P < .005) in both men and women.

Exercise Testing

Predicted V_{O_2MAX}, 880-yard run performance, and the obstacle run showed marked and statistically significant improvements for both men and women. For men, predicted V_{O_2MAX} improved from a mean of 37.3 mL/kg/min to a mean of 46.2 mL/kg/min for an increase of 24.8 percent. Women similarly improved their mean predicted V_{O_2MAX} by 24.3 percent from an initial mean of 32.8 mL/kg/min to a mean of 40.4 mL/kg/min by the end of the course. This improved aerobic capacity was reflected in the 880-yard run, where men decreased their time by a mean of 25 seconds and women cut their time by a mean of 23 seconds. Likewise, the obstacle run times improved. Men improved their time by a mean of 21 seconds; women improved their time by a mean of 54 seconds. These changes were highly significant.

Events that measured explosive leg strength, the 40-yard dash and the vertical jump, showed a small but statistically significant deterioration over the three-week course. In the men's 40-yard dash, times increased from a mean of 10.7 seconds to a mean of 11.3 seconds. In the women's 40-yard dash, times increased from a mean of 12.8 seconds to a mean of 14.6 seconds. Vertical jump means for men declined from 20.1 in. to 18.7 in. For women, vertical jump means declined from 12.1 in. to 11.2 in.

Pulmonary Function Results

As compared with predicted sea level values, lung volumes and flow rates were normal on the initial day except for three students, who had mild reduction of $FEV_{1.0}$ and FEF_{25-75}. These students had a history of asthma.

At the three-day camp, 12 of the 30 persons initially involved with the study had shortness of breath or cough, or both. Of these 12, only seven had pulmonary function abnormalities. Four had laboratory evidence of acute mountain sickness. Of these four, two had shortness of

TABLE 2. VITAL CAPACITY AND FLOW RATES ON SUBJECTS WHO HAD SIGNIFICANT REDUCTION OF THEIR VITAL CAPACITY AT THREE-DAY CAMP

	Initial Pulmonary Functions			Pulmonary Functions at Three-Day Camp			
Subject	VC*	$FEV_{1.0}$**	FEF_{25-75}***	VC	$FEV_{1.0}$	FEF_{25-75}	Airway Involvement
1	4.32	3.75	4.04	3.98	3.48	3.88	Large
2	5.16	4.35	4.26	4.70	3.97	3.71	Small
3	3.63	3.15	4.50	3.32	3.08	4.59	None
4	4.07	3.76	6.13	3.69	3.61	3.85	Small
5	4.60	4.14	4.75	4.09	2.41	2.37	Combined
6	5.39	4.18	3.65	4.68	4.02	4.12	None
7	5.25	4.26	4.01	4.54	3.78	3.46	Small
8	5.21	4.28	3.99	4.42	2.86	3.16	Combined
9	3.65	3.07	3.29	3.12	2.70	2.74	Combined
10	4.31	3.76	4.43	3.65	3.28	3.63	Small
11	4.53	3.73	3.56	3.85	3.24	3.20	Combined
12	3.29	2.91	4.28	2.68	2.57	6.13	Large
13	4.13	3.45	4.16	3.16	2.66	2.62	Combined
14	5.37	4.83	5.96	4.00	3.18	2.86	Combined

** Vital capacity (liters)*
*** Force expiratory volume at 1 sec (liters)*
**** Forced expiratory flow between 25 and 75 percent of vital capacity (L/sec)*

breath and cough, and two were asymptomatic. For the entire group, 45 percent had symptoms related to altitude.

A drop in the vital capacity was considered to be a rough indicator of pulmonary edema; however, since reactive airway disease could also cause a vital capacity decrease, flow rates had to be analyzed. Since reactive airway disease is mainly a large airway disease, the $FEV_{1.0}$ would be decreased and the FEF_{25-75} can also be low. Early or mild pulmonary edema involves small airways, which would lower FEF_{25-75} and leave the $FEV_{1.0}$ normal. A decrease in vital capacity without significant decrease in $FEV_{1.0}$ could therefore indicate acute mountain sickness with pulmonary involvement.

The results of the pulmonary functions at the three-day camp on the subjects who had significant (greater than 5.0 percent) decrease in their vital capacity is displayed in Table 2.

Four subjects (2, 4, 7, 10) had lowered their vital capacity by affecting only their small airways (FEF_{25-75} was decreased and FEV_1 was normal). These four subjects were considered to have mainly small airways involvement. It was not possible to obtain a flow-volume loop at the three-day camp, so specific testing for flows at 25 percent of the vital capacity was not done. Six students had decreased both flows, which implies both large and small airway involvement. The four subjects who were felt to have acute mountain sickness with pulmonary involvement had normal pulmonary function tests on final testing. Only one student (13) had worsening pulmonary function tests on final testing and was found to have reactive airway disease by response to bronchodilator.

The response to hypoxia as tested on day 1 and repeated on day 21 was normal. The A values for the hyperbolic response curve were between 90 and 120 for all subjects. None of the subjects had A values that would represent a hyporesponder or hyperresponder to hypoxia. The A value did not change after the three-week stay at high altitudes. The P_ACO_2 values were between 28 and 36 torr on all subjects while breathing 30 percent oxygen and dropped to 24 to 32 torr with 10 percent oxygen.

In looking at the ventilatory response to hypoxia and the carbon dioxide values, any predictors indicating an individual's susceptibility to acute mountain sickness could not be established. Also, in comparing subjects living at a high altitude (above 1600 m) with those living at sea level, no differences were found in the final exercise performance. Of the four subjects who developed acute mountain sickness with pulmonary involvement, two lived at high altitudes and two lived at sea level.

DISCUSSION

This study indicated that a vigorous exercise program taking place between altitudes of 3000 and 4200 m is not detrimental to the health of young adults who have not been previously conditioned for the program. No attempt was made to compare or speculate whether this young

adult group would have outperformed their high-altitude performance if these studies had been done at sea level.

Six major components of physical performance were identified: strength, endurance, speed, flexibility, balance, and coordination.[8-10]

The obstacle course, with several structures requiring dynamic balance, dynamic arm strength, agility, and general coordination, was chosen as a test of gross body coordination. The results demonstrated marked improvements of both men and women in their performance as tested by the obstacle course.

The aerobic benefit of this Outward Bound course is apparent from the results of the submaximal work test and the 880-yard run. V_{O_2MAX} improved by 24.8 percent for men and by 24.3 percent for women. These results could be predicted based on the itinerary of the course, which included almost daily hikes of up to 10 miles with 40- to 60-lb packs over difficult terrain at high altitude. Several mountain ascents are also included in the course, as well as daily runs of one to five miles. Part of the aerobic improvement could be secondary to the adaptation process that occurs from residence at this altitude, as evidenced by the significant increase in the hemoglobin values for men and women.[11] Part of the aerobic improvement can be ascribed to the vigorous aerobic activities of the course. The relative weight of these two factors (adaptation and aerobic activities) in the improvement of V_{O_2MAX} is open to conjecture. It would be of interest to study a similar course taking place at a lower altitude.

In addition to running and hiking, mountain-climbing techniques such as rappelling, glissading, and technical rock climbing were included in the course. It was postulated that these activities may benefit not only dynamic balance, arm strength, agility, and gross body coordination, but also abdominal muscle strength and explosive leg strength. Such was not found to be the case, however, as tests for explosive leg strength, eg, the 40-yard dash and the vertical jump, actually showed a small deterioration at the end of the course for both sexes. Sit-up performance improved very slightly in women, but not at all in men. It could be argued that testing of explosive leg strength and trunk strength at the end of the course was done before sufficient recovery of the muscle groups had occurred, and that a waiting period of perhaps 24 hours should be allowed before repeat testing.

Although not so marked as the improvements in aerobic capacity, improvements in anthropometric values of the groups were noted. Decreased weight and a corresponding decrease in skinfold thickness imply improved body composition, increase in lean body mass, for both men and women. Since caloric intakes were not monitored, however, it was not possible to exclude decreased body mass on diet alone.

The ventilatory tests were an attempt to assess the more dangerous problem of respiratory involvement with acute mountain sickness. Laboratory evidence of respiratory involvement was found in four people as shown by a decrease in vital capacity and in airway flow rates in small airways. To find markers for estimating predilection of an individual to acute mountain sickness, the chemoreceptor response to hypoxia, P_ACO_2 values prior to beginning the course, and initial lung volumes and flow rates values were reviewed. There was no single value or combination of values that could have predicted the pulmonary abnormalities in any of the individuals. One reported study[13] indicated that hyporesponders or people with higher end-tidal carbon dioxide are more susceptible to lung problems at high altitude, though this was not borne out in this study.

Larson and his colleagues[15] reported no statistical change in vital capacity with climbers going between altitudes of 3000 and 4394 m. Their study indicated that a time factor is present if a subject is going to develop a pulmonary problem with acute mountain sickness. Larson's report[10] evaluated the effects under 24 hours at high altitude. This study was therefore based on the findings of Anholm et al,[6] who found on testing 126 individuals arriving at high-altitude ski areas that on the third day maximum decrease occurred in forced vital capacity (FVC). They did not delineate between reactive airway disease and high-altitude pulmonary edema, and accepted any drop in FVC to be related to altitude. In this study, 13 of the 30 subjects studied had a drop in FVC on day 3. This would have given a 43 percent incidence of lung problems for the group by FVC determination alone. Although bronchodilator was not given to determine reversibility, by historical and pulmonary function findings nine of the thirteen subjects were having reactive airway symptoms. Four of the 30 subjects, therefore, were considered to have altitude lung problems, giving a 13 percent incidence. The pulmonary problems remained subclinical and transient and did not cause a decrease in the activity of the individual or in discontinuance of the program. It was not possible to predict by clinical symptoms the persons who had laboratory evidence of acute mountain sickness with pulmonary abnormalities.

CONCLUSIONS

Three weeks of a vigorous Outward Bound course at altitudes between 3000 m and 4300 m improved mean aerobic capacity, body composition, and hemoglobin values of young adult participants. Explosive leg strength as measured by the 40-yard dash and vertical jump test did not improve, but actually declined slightly. Twenty-eight

of 30 individuals initially tested completed the course. Two individuals left the course for nonmedical reasons. Four persons (13 percent) developed subclinical pulmonary problems. These problems were not debilitating, nor did they decrease performance.

Although transient or early or reversible pulmonary function abnormalities develop in a significant portion of individuals in an Outward Bound course held between 3000 m and 4300 m, these abnormalities were not significant enough to deter from acclimatization or the conditioning effects of the course or to prevent completion of the course.

References

1. Nye RP: The influence of an Outward Bound program on the self-concept of the participants. Dissertational Abstracts Int 1976; 34: 436
2. Anderson ED: Psychological aspects of the course at Outward Bound. NZ Med J 1972; 76:349–351
3. Doxey GE: Body composition assessment and methodology in nonathletic and athletic adolescent and adult males and females. J Orthop Sports Physical Ther 1984; 5:336–347
4. Borkan GA, Hults DE, Cardonelli J, Burrows BA: Comparison of ultrasound and skinfold measurements in assessment of subcutaneous and total fat. Am J Physical Anthropol 1982; 58:307–313
5. Weil JV, Zwillich CW: Assessment of ventilatory response to hypoxia. Chest 1976; 70:124–128
6. Anholm JD, Houston CS, Hyers TM: The relationship between acute mountain sickness and pulmonary ventilation at 2,835 meters. Chest 1979; 75:33–36
7. Astrand I: Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand 1960; 49:1–49
8. Eckert HM: Practical Measurement of Physical Performance. Philadelphia, Lea & Febiger, 1974
9. Fleishman E: Structure and Measurement of Physical Fitness. Englewood Cliffs, NJ, Prentice Hall, 1964
10. Larson LA (ed): Fitness, Health and Work Capacity International Standards for Assessment. International Committee for the Standardization of Physical Fitness Tests. New York, Macmillan, 1974
11. Smith MH, Sharkey BJ: Altitude training: Who benefits? Physician Sports Med 1984; 12:48–59
12. Hultgren HN: Sickness in high places. Emerg Med 1980; 12:24–52
13. Mathew L, Gopinathan PM, Purkayastha SS, et al: Chemoreceptor sensitivity and maladaptation to high altitude in man. Eur J Appl Physiol 1983; 51:137–144
14. Tenney SM, Ou LC: Hypoxic ventilatory response of cats at high altitude: An interpretation of blunting. Respir Physiol 1977; 30: 185–199
15. Larson EB, Roach RC, Schoene RB, Horbein TF: Acute mountain sickness and acetazolamide. JAMA 1982; 248:328–332