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Physiological Cost of Skiing in Hypoxic or Normoxic Environments

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Author's Contribution
- A – Study Design
- B – Data Collection
- C – Statistical Analysis
- D – Data Interpretation
- E – Manuscript Preparation
- F – Literature Search
- G – Funds Collection

Key words: *snow sports, skiing, altitude, hypoxia, physiology, energetic cost*

Abstract

Background: *It is well known that most of the deleterious effects of high or medium altitude on humans are caused by hypoxia and cold. Hypoxia occurs due to a decrease in barometric pressure proportionally to altitude increase, cold because of the temperature lapses with altitude and wind chill. These factors reduce exercise tolerance, maximal power output, maximal oxygen uptake, and they elevate the physiological cost of work. The purpose of this study is to examine the physiological cost of alpine skiing among students during the obligatory program of ski camp in Kaprun (Austria) in different (hypoxic and normoxic) environments.*

Material and methods: *Forty two healthy students: male (n=24) and female (n=18) volunteered for this study. Each subject performed an obligatory ski learning exercise programme (360 minutes per day) during seven days of the ski camp. During this time we measured heart rate (HR) using the POLAR Heart Rate Monitor and we also estimated exercise energy expenditure (EEE) using POLAR Precision Performance software.*

Results/Conclusions: *The obtained data showed that in a hypoxic environment students were at a higher level of physiological stress than in the normoxic one. We also showed that students in hypoxia learned faster than those in normoxia. It is contrary to what has been expected. Further studies are needed to explain the effect of environments on the effectiveness and efficiency of learning to ski.*

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Background

Participation in outdoor alpine sports such as skiing, tracking, climbing or paragliding has been on the increase over the last decade. At present there are approximately 5 million skiers in Poland with 82 million skiers around the world [1]. Most of the European skiers choose the Alps to master their sports skills. The ski revolution of carving has been on its triumphant march worldwide for about 8 to 9 years. Nowadays about 80% of all skiers use carving skis. It is well known that using carving skis makes skiing easer and faster than ever before. However, specific physical preparation for the skiing season is also more important than ever. Special attention must also be paid to general care of specific factors of the Alps environments.

It has been known since Paul Bert's publication (1878) [2] that most of the deleterious effects of high or medium altitude on humans are caused by hypoxia and cold. Hypoxia occurs due to a decrease in barometric pressure proportionally to altitude increase, cold because of the temperature lapses with altitude and wind chill. Other atmospheric factors such as low humidity and high solar radiation are also very important [3]. All these factors reduce exercise tolerance, maximal power output, maximal oxygen uptake and they elevate the physiological cost of work [3, 4, 5].

Due to this fact the purpose of this study is to examine the physiological cost of alpine skiing among students during the obligatory program of ski camp in Europa Sport Region Kaprun- Zell am See (Austria) in different (hypoxic and normoxic) environments.

Materials and methods

Forty two healthy students: male (n=24) and female (n=18) mean age 21.7 0.9 volunteered for this study (SD). Each subject performed an obligatory ski learning exercise programme (360 minutes per day) during seven days of the ski camp. They were divided into two groups. The first one performed exercise in normoxic environments (N) at the altitude of 750-850 m above the sea level (male n=11; female n=9), and the second one performed exercise in hypoxic environments (H) at the altitude of 2500-2960 m above the sea level (male n=13; female n=9). Both groups performed exactly the same exercise of ski learning programme each day, they had exactly the same diet, and spent recovery time and whole night in the same place of accommodation (710 m above the sea level). Table 1. illustrates the anthropological and physiological characterisation of the examined groups.

During seven days of the ski camp each subject performed 360 minutes of ski learning programme per day. During this time we measured heart rate (HR) using the POLAR Heart Rate Monitor and we also estimated exercise energy expenditure (EEE) using POLAR Precision Performance software, where the EEE is defined as the energetic cost of work.

On the first day of the camp, in order to estimate the psychological stress, a study of the state and features of fear (anxiety) was carried out, using the State-Trait Anxiety Inventory (S.TAI) introduced by Spielberger [6, 7, 8]. The first study was executed before skiing and the second one after exercise time (in restitution).

All reported values are mean SD. The data were statistically analysed according to the t-Student's test using the variance analysis. The level of $p<0.05$ was considered as statistically significant.

Results

In this study we examined the physiological cost of a ski learning exercise programme among forty-two students in different environments. There are no significant differences in anthropological and physiological characterization between groups of subjects skiing in normoxic (N) and hypoxic (H) environments. The obtained data showed a few significant differences in mean values of the heart rate (HR) and exercise energy expenditure (EEE) between N and H groups. Tables 2 and 3 present these differences. The most significant differences are observed on 1st, 2ndand 5th day of ski camp. Figures 1 and 2 present this trend.

The obtained data showed that mean values of psychological stress level estimated with the State-Trait Anxiety Inventory (STAI) before and after first skiing is not affected by hypoxia environments. The anxiety-state before skiing was 40.1 29 and 39.9 27 in normoxia and hypoxia, respectively. But the anxiety-trait was 29.8 22 and 28.2 26, in N and H, respectively. After skiing there were no significant differences in the anxiety-trait compared to the pre-exercise measurement. The data from other

Tab. 1. Anthropological and physiological characteristics of the examined groups

	Age [year]	**Height [cm]**	**Weight [kg]**	**BSA [m^{2}]**	**BMI [kg·m^{2} $^{-1}$]**	**VO_2 max [L·min^{-1}]**	**VO_2 max [ml·kg^{-1}·min^{-1}]**
N n=20	21.4 ± 1.0	173.5 ± 6.0	70.3 ± 10.3	1.84 ± 0.2	23.4 ± 2.0	3.2 ± 0.4	45.5 ± 2.1
H n=22	22.0 ± 0.9	175.9 ± 4.9	72.6 ± 8.0	1.88 ± 0.1	23.5 ± 1.5	3.5 ± 0.3	48.2 ± 4.1

Values are means ± SD, n - no. of subject, practices in N- normoxia environments, H- hypoxia environments
* Difference from H group (as determined by the paired t-test, $p < 0.05$)
BMI – body mass index, BSA – body surface area

Tab. 2. Mean values of heart rate of the examined groups during the successive days of the ski camp

	Heart Rate [bpm]						
	1st day	**2nd day**	**3rd day**	**4th day**	**5th day**	**6th day**	**7th day**
N n=20	124 ± 10*	120 ± 9*	119 ± 8	112 ± 10	114 ± 11*	106 ± 8	124 ± 11
H n=22	138 ± 14	127 ± 7	123 ± 9	116 ± 9	124 ± 10	112 ± 12	125 ± 13

Values are means ± SD, n - no. of subject, practices in N- normoxia environments, H- hypoxia environments
* Difference from H group (as determined by the paired *t*-test, $p < 0.05$)

Tab. 3. Mean values of exercise energy expenditure of the examined groups during the successive days of the ski camp

	Exercise Energy Expenditure [kcal]						
	1st day	**2nd day**	**3rd day**	**4th day**	**5th day**	**6th day**	**7th day**
N n=20	1296 ± 73*	1239 ± 69*	1198 ± 81	998 ± 64	1056 ± 71*	1106 ± 84	1298 ± 91
H n=22	1536 ± 78	1359 ± 75	1289 ± 91	1079 ± 89	1278 ± 61	1212 ± 72	1316 ± 67

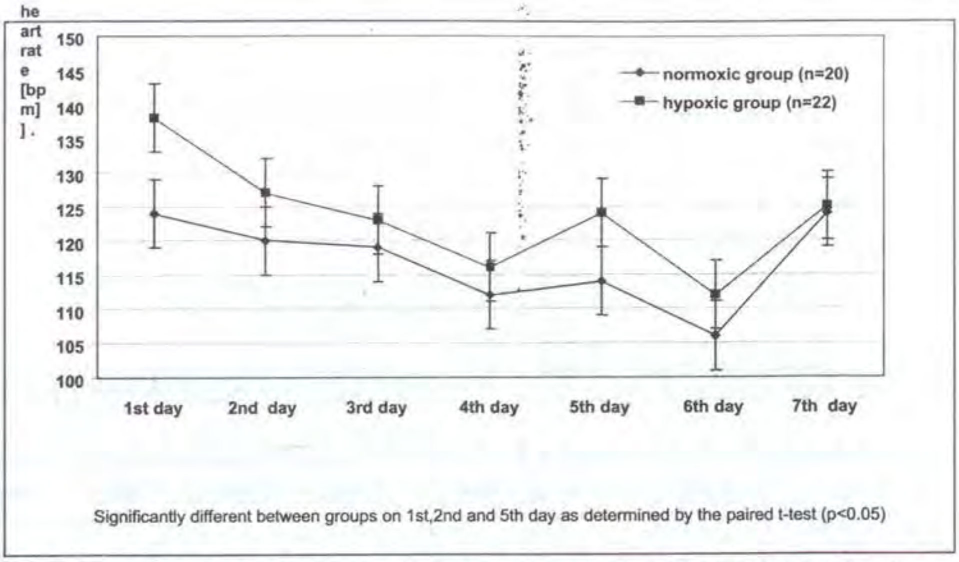
Values are means ± SD, n - no. of subject, practices in N- normoxia environments, H- hypoxia environments
*Difference from H group (as determined by the paired *t*-test, $p < 0.05$)
Basal Metabolic Rate is not included in Exercise Energy Expenditure

Tab. 4. Mean values of the psychological stress level estimated with the State-Trait Anxiety Inventory (STAI) before and after first skiing in the examined groups

	Before Skiing		**After skiing**	
	Anxiety-State	**Anxiety-Trait**	**Anxiety-State**	**Anxiety-Trait**
N n=20	40.1 ± 29*	29.8 ± 22	32.1 ± 26	27.9 ± 27
H n=22	39.9 ± 27*	28.2 ± 26	34.8 ± 24	26.1 ± 24

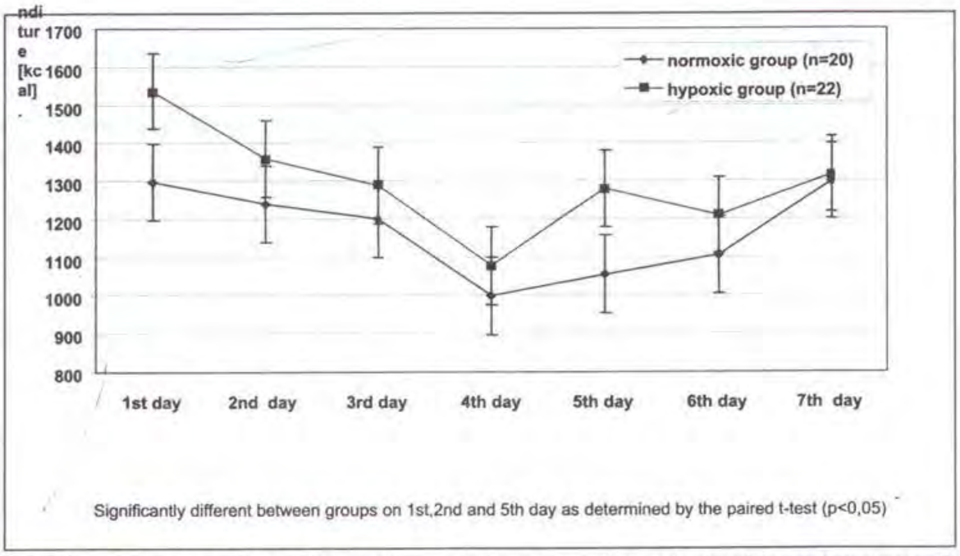
Values are means ± SD, n - no. of subject, practices in N- normoxia environments, H- hypoxia environments
*Difference from after skiing measurements (as determined by the paired *t*-test, $P < 0.05$)

studies supported our results [6, 7, 8, 9]. There is also no difference among the N and H groups. An interesting observation is that the level of anxiety-state decreased after the first day of skiing in both groups. Table 4 presents these differences.



Significantly different between groups on 1st,2nd and 5th day as determined by the paired t-test (p<0.05)

Fig. 1. Differences between normoxic and hypoxic groups in mean values of the heart rate during the successive days of the ski camp



Significantly different between groups on 1st,2nd and 5th day as determined by the paired t-test (p<0,05)

Fig. 2. Differences between normoxic and hypoxic groups in mean values of exercise energy expenditure during the successive days of the ski camp

Discussion

It is well known that exercise at high and medium altitude makes enormous demands for the oxygen transfer system of the body because of increased oxygen uptake in the face of the reduced inspired partial oxygen pressure (PO2). Consequently, reduced exercise tolerance is one of the most obvious features of exposure to high altitude [10]. Hypoxia puts stress on the oxygen transfer system of the body even at rest. Nair et al. [11] found that after a week at 3300m the basal metabolic rate (BMR) was elevated by about 12%. Exposure to cold as well as hypoxia could elevate BMR. Butterfield et al. [12] found BMR to be elevated by 27% on day 2 at the altitude of 4300 m, and then decreased over the next few days to plateau at +17% compared with sea level by day 10. This suggested that exercise energy expenditure (EEE) could be elevated in a similar trend. Our results supported this hypothesis.

Work in absolute conditions requires the same oxygen intake at altitude as at the sea level until near-maximum work rate is reached [13]. At altitude the maximum work rate is reduced and all activity seems disproportionally fatiguing because of the increased work of breathing. This is probably the most important factor having influence on reducing exercise tolerance and elevating the exercise energy expenditure in first few days' exposure to hypoxia. To survive in longer exposure and at extreme altitude, daily energy expenditure for normal activities of daily living must be reduced [14, 15, 16].

This data shows that hypoxia and cold are more important factors elevating energy expenditure in comparison to psychological stress of new activities such as skiing. An interesting observation is that the students at altitude and in hypoxic environments learned faster than those in normoxia. It is contrary to what has been expected.

Conclusions

1. Exposure to cold and hypoxia elevate basal metabolic rate and exercise energy expenditure of skiing.
2. The anxiety-state and the anxiety-trait are not affected by hypoxia environments.
3. In spite of altitude and higher physiological cost of exercise, students in hypoxic environments learned faster and more efficiently than those in normoxia.
4. Further studies are needed to explain the effect of environments on the effectiveness and efficiency of learning to ski.

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