Original Article

Cardiorespiratory Responses to Exercise under Moderate Hypoxia

M Akhtar, Ranjit Kumar, PK Banerjee, PC Chatterjee

Forty normal healthy service personnel were subjected to a comparative study of treadmill exercise at ground level (GL) and under moderate hypoxia at a simulated altitude of 4,572 m in a decompression chamber. Twenty of them belonging to younger age group (mean age 21.3 ± 5.1 yrs) were given maximal exercise whereas the other twenty, with mean age of 30.6 ± 4.86 yrs, were exercised upto submaximal heart rate. Electrocardiographic analysis in all, both during treadmill exercise at GL and under hypoxia, was normal excluding ischaemic heart disease. Treadmill exercises carried upto the target heart rates under hypoxia were of significantly shorter duration compared to GL values both in cases where the subjects were taken to submaximal target heart rate (Phase I study) and maximal heart rate (Phase II study). Oxygen consumption rate as determined in Phase I study at target submaximal heart rate was found significantly reduced at hypoxia compared to GL value. Resting heart rate was found significantly higher under hypoxia as compared to GL in both phases whereas rate of recovery from exercise heart rate was faster during hypoxia particularly following maximal exercise. The systolic, diastolic and mean arterial blood pressures recorded at peak submaximal exercises at GL and under hypoxia did not show any significant difference.

Keywords: Stress test, treadmill exercise in decompression chamber, electrocardiographic changes.

Graded multistage treadmill (TM) exercise with on-line recording of heart rate, blood pressure, ECG and oxygen consumption is frequently employed for diagnosis and rehabilitation of coronary artery disease. It is also used for assessment of physical fitness and physiological parameters. While all these studies are carried out at ground level (GL), very few reports are available on TM exercise under hypoxia. This study was carried out in normal healthy subjects exercised at GL as well as under moderate hypoxia as simulated in a Decompression Chamber with a view to evaluate the changes in cardio respiratory responses to exercise under this altered environment.

Materials and Method

Forty healthy service personnel were included in this study carried out in two phases. The mean age of the 20 subjects of Phase I study involving submaximal exercise was 30.0 + 4.86 years. In Phase II study subjects comprised of relatively younger age groups (21.3 + 5.1 years) and were taken to maximal exercise. The mean height, weight and body surface area of the subjects of both phases are presented in Table I.

All subjects were evaluated in detail with recording of present, personal, past and family histories, general physical and systamic examinations, relevent laboratory investigations, skiagram of chest and heart and resting 12 lead ECG followed by Double Master two step (DMT) exercise and were considered as healthy.

Exercises were performed on a treadmill specially fabricated to fit inside the decompression chamber at the Institute of Aviation Medicine, Bangalore. ECG was constantly monitored on an oscilloscope during the test and periodically recorded on a Grass Model 5 D Polygraph installed outside the Decompression Chamber.

Day 1 study included TM exercise at GL. Pre-exercise resting blood pressure, respiratory rate, 12 lead and CM5[1] ECG were recorded. TM exercise was conducted as per Bruce Protocol [2]. Phase I subjects were exercised upto 85% of the age predicted maximal heart rate whereas Phase II subjects were exercised upto age predicted maximal heart rate. Heart rate, ECG (CM5), and blood pressure were recorded at the end of each stage, at 85% of maximal heart rate and at peak exercise in Phase II subjects. The post exercise recordings of ECG and blood pressure were done at 5 min, 10 min and 15 min after end of exercise.

Day 2 evaluations consisted of TM exercise at simulated altitude of 4572 m (15000 ft) in the decompression chamber raised at the rate of 3000 ft per min. After 45 min of rest at this simulated altitude, recordings of heart rate, blood pressure, respiratory rate and ECG (12 lead and CM5) were completed. The TM exercise was then carried out till the achievement of target submaximal heart rate in Phase I subjects and maximal heart rate in Phase II subjects as in Day 1.

Measurement of oxygen uptake was made in all subjects of Phase I study, on reaching submaximal (target) heart rate during TM exercise at GL as well as under hypoxia, expired air being collected through a low resistance breathing valve into a Douglas bag. Expired air analysis was made by Micro Scholander apparatus. Oxygen uptake values were corrected to STPD.

Table - I Age and physical characteristics of the subjects. [mean ± (sd)]

Parameters	Phase I (n=20)	Phase II (n=20)
Age (yrs)	30.6 (4.86)	21.3 (5.10)
Weight (kg)	59.8 (5.29)	58.8 (6.70)
Height (cm)	168.5 (4.96)	173.4 (5.10)
Body surface area (m^2)	1.66 (0.20)	1.68 (0.10)

Results

Analysis of resting 12 lead ECG after 45 min stay at simulated hypoxia as compared to GL is presented in Table II. Both Phase I and Phase II subjects showed significantly higher heart rates under hypoxia than at GL. The mean values of P amplitude, PR interval, QRS duration and QT interval of the subjects did not show significant differences between hypoxia and GL. The mean QRS frontal axis showed significant deviation to the right in subjects of both phases under hypoxia as compared to GL. There were also increases in R amplitude in V1 and V2 under hypoxia, though the differences between hypoxia and GL values were not found significant.

Table III presents the mean values of cardio-respiratory functions during rest, submaximal exercise (85% of the target maximal heart rate) and at 15 min recovery from exercise from exercise under hypoxia and GL as obtained in Phase I study.

The mean exercise time to reach target heart rate was found significantly ($p < 0.05$) reduced under hypoxia (7.8 min) than at GL (10.3 min). While the mean target submaximal heart rate was similar, both resting and 15 min recovery heart rates were found significantly higher at hypoxia than at GL. Percentage rate of recovery from submaximal exercise value of heart rate did not show any differences between GL and hypoxic exposure.

The mean systolic blood pressure showed similar rise with exercise, with no significant differences between the values obtained under hypoxia and GL. Recovery systolic blood pressure also showed no differences to altitude conditions. Diastolic blood pressure values virtually showed no change on exercise both under hypoxia and at GL. Also there were no altitude differences in diastolic pressure response at rest, exrercise and recovery.

Oxygen uptake obtained at the last two min of submaximal target heart rate exercise showed significantly ($p < 0.05$) lower mean values under hypoxia (1.347 l/min) than at GL (1.461 l/min).

Table IV presents the heart rate responses of Phase II study conducted on subjects taken to target maximal heart rate exercise at GL and under hypoxia.

Exercise time to reach 85% maximal heart rates was significantly reduced under hypoxia (9.5 min) compared to GL (11.5 min). Also target maximal heart rate was reached significantly earlier under hypoxia (12.8 min) than at GL (15.5 min).

Maximal heart rate remained comparable under both conditions. Resting heart rate was significantly higher under hypoxia. Recovery heart rate from maximal heart rate exercise was found marginally higher under hypoxia. Rate of recovery from maximal heart rate was on the other hand faster under hypoxia, as seen in the significantly higher rate of recovery percentage (85.5%) under hypoxia than that seen at GL (77.4%).

Discussion

This study of treadmill exercise under moderate hypoxia was carried out in normal healthy persons to establish standards for subsequent evaluation of disease and ECG abnormality by this dual stress, i.e., TM exercise under moderate hypoxia. Exposure to moderate hypoxia prior to exercise resulted in ECG changes like significant increase in heart rate, shift of QRS frontal axis to the right and marginal increase in amplitude of P and r waves in V1, V2 as compared to those in resting ECG at ground level. These findings were in agreement to earlier observations[3,4]. However, none of the subjects showed ST-T changes in left ventricular leads (V5, V6) under hypoxia - a finding often described as indicative of latent ischaemic heart disease[5,6].

Table - II Mean electrocardiographic data at rest, at GL and under hypoxia.

	Phase I (n=20)		Phase II (n=20)	
	GL	Hypoxia	GL	Hypoxia
Heart rate(bpm)	69.50	81.40**	67.50	82.90**
P amplitude lead II (mm)	1.62	1.81	1.41	1.56
PR interval (sec)	0.16	0.14	0.14	0.13
QRS frontal axis (deg)	47.30	58.60*	51.40	60.30*
R in V1 (mm)	3.17	3.78	2.14	3.42
R in V2 (mm)	6.40	7.10	5.80	6.40

Table - III Cardiorespiratory parameters at rest and submaximal treadmill exercise at ground level and under hypoxia - Phase I [mean ± (sd)]

	Ground level			Hypoxia		
	At rest	At peak TM exercise	15'after exercise	At rest	At peak TM exercise	15'after exercise
Total time of submaximal exercise (min)		10.3 (1.81)			7.8(1.79)*	
Heart rate (bpm)	69(4.5)	156 (5.2)	89(7.8)	81(6.8)**	156(5.16)	98(7.1)*
Recovery (%)			76.9(3.4)			78.3(2.9)
Systolic BP (mm Hg)	118(5.9)	153(8.6)	120(6.4)	120(4.8)	15(6.9)	118(8.8)
Diastolic BP (mm Hg)	79(7.5)	78(6.8)	79(5.9)	79(7.4)	78(8.1)	78(7.2)
Oxygen consumption (l/min STPD)		1.461(0.246)			1.347(0.209)*	

Table - IV Heart rate responses at rest and treadmill exercise at ground level and under hypoxia - Phase II [mean ± (sd)]

	Ground level			Hypoxia		
	At rest	At peak TM exercise	15'after exercise	At rest	At peak TM exercise	15'after exercise
Total time of exercise (min)						
a) Till submaximal target HR		11.5 (1.4)			9.5 (1.3)*	
b) Till maximal target HR		15.5 (1.8)			12.8 (2.1)*	
Heart rate (bpm)	68 (8.6)	186 (7.8)	94(6.5)	83(7.8)*	184(8.4)	98 (5.8)
Recovery (%)			77.4 (4.5)			85.5(4.8)*

* = p < 0.05 as compared to GL   ** = p < 0.001 as compared to GL

Exercise under hypoxia show proportionate increase in heart rate as at ground level, but the target heart rates (maximal and 85% of the maximal heart rate) are reached at considerable lower work load under hypoxia. Oxygen consumption during exercise is found to be constant for a given work load under hypoxia as at ground level but $VO2_{max}$ shows decline with increase of altitude[7]. Heart rate always remains higher at altitudes even for low and moderate exercise as compared to that at sea level - a constant phenomenon observed by several workers during submaximal and maximal exercises at high altitudes[8,9].

In the present study, target heart rates, both submaximal and maximal, were reached in significantly less time and at lower rate of work load under hypoxia as compared to GL. Also, significantly lower values of oxygen consumption were reached under hypoxia at target submaximal heart rate.

The recovery rate following maximal exercises under moderate hypoxia was found to be faster as compared to the same at ground level. The possible explanation for the faster recovery rate may be a comparatively higher pre-exercise heart rate under moderate hypoxia and more importantly a less duration of exercise to reach the peak target heart rate under hypoxia. Otherwise, the absolute value of recovery heart rate was generally found higher following exercise under hypoxia.

As seen in Table III, blood pressure measurements at rest, peak exercise and recovery did not indicate any significant differences between hypoxia and ground level exposure. However, the observation that a comparable systolic blood pressure was attained under hypoxia and at ground level once the target heart rate (85% of maximal heart rate) was reached is of relevance for the purpose of standardisation of this stress test. Obviously, as compared to ground level condition, on short term exposure to moderate hypoxia a proportionate cardiovascular loading is attained at a shorter duration of TM exercise protocol and standardisation of this dual stress test of TM for exercise in combination with hypoxia, may be made on the basis of the target heart rate itself.

REFERENCES

1. Fortuin NJ, Weiss JL: Exercise stress testing. Circulation 1977; 56:699

2. Bruce RA, Blackmen JR, Jones JW, et al : Exercise testing in normal adult subjects and cardiac patients. Pediatrics 1963; 32:742

3. Akhtar M, Chatterjee PC: Exercise under hypoxia - a stress test for evaluation of cases with ischaemic heart disease for rehabilitation. Aviation Medicine 1983; 27:106

4. Akhtar M, Bandopadhyaya P, Chatterjee PC, et al : Electrocardiographic changes under moderate hypoxia. Indian Heart J 1979; 31:353

5. Milledge JS: Electrocardiographic changes at high altitude. Brit Heart J 1963; 25:291

6. Heath D, Williams DR: Man at High Altitude, Edinburgh, Churchill-Livingstone, 1977; p 165

7. Ernsting J, Sharp GR: Hypoxia and hyperventilation. In : Aviation Medicine, Editor-in-chief: G Dhenin, London, Tri-Med Books, 1978; p 60.

8. Ernsting J: Respiration and anoxia. In Text Book of Aviation Physiology, Editor: JA Gillis, Oxford, Pergamon Press 1965; p 214

9. Pugh GCE, Gill MB, Lahiri S, et al : Muscular exercise at altitude. J Applied Physiol 1964; 19:431