A STUDY OF PHYSICAL WORK CAPACITY OF SEA LEVEL RESIDENTS ON PROLONGED STAY AT HIGH ALTITUDE AND COMPARISON WITH HIGH ALTITUDE NATIVE RESIDENTS

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Summary : Studies have been conducted on 29 young healthy normal residents of sea level on the changes in physical work capacity after prolonged stay of 24 months at an altitude of 4100m and a comparison is made with 20 young native residents of high altitude having identical nutritional compromise and physical training status. Physical work capacity of these subjects have been estimated by recording the cardio respiratory responses and 0_2 transport mechanism during sub-maximal and maximal exercises in the laboratory under controlled conditions and in outdoor performance in running and hill climbing. Endurance work capacity was estimated from all out steeping exercises.

Maximum 0_2 uptake capacity of 46.8 *ml/kg/min* of sea level residents significantly ($P<0.001$) reduced to 34.6 *ml/kg/min* on induction to high altitude of 4100m but gradually improved to 36.6 *ml/kg/min* after 24 months stay at that altitude. The high altitude native residents on the contrary had a significantly ($P<0.001$) higher Vo_2 max of 41.1 *ml/kg/min* which was not significantly different than the sea level residents value at sea level. Timings in out door running performance and hill climbing corroborated the findings of Vo_2 max. Similarly endurance work output in stepping exercise indicated that the native residents of high altitude had much superior capacity and produced 2.5 times more work than the acclimatized low landers even after 24 months stay at 4100m. The increased work capacity of high altitude native residents is attributed to their higher aerobic capacity and cardiovascular efficiency and superior respiratory efficiency, possibly due to genetical adaptations at the tissue level.

Key words : work capacity high altitude acclimatisation adaptation to high altitude

INTRODUCTION

Physical work capacity of sea level residents during sojourn to high altitude has been reported by various workers from different countries (2,4,8,13,19,22,28). However, all these studies pertain to subjects with relatively short term of stay at high altitude. No precise information is available in the literature on the changes that take place in sea level residents due to stay at high altitude over a prolonged period except one by Sen Gupta *et al.* (27). Extensive studies by many workers on high altitude native residents of Andes in South America indicate that these people posses a very high degree of physical work performance capacity (14,18,25), and tolerated successfully the low ambient pressure and could engage themselves in severe physical activity. Similar studies on Himalayan natives have also been carried out (9,15,16,17,24,25,26). All these studies confirmed the superior work capacity of the native residents. The reason for this could be due to adaptational changes at the cellular level.

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This study was undertaken to investigate the changes in some physiological functions associated with work capacity of sea level residents during prolonged stay at high altitude and compare them with permanent high altitude native residents having identical nutritional and physical training status.

MATERIALS AND METHODS

Twentynine young healthy male adults in the age group of 20-30 years were selected at random from a homogeneous population. They had been born and brought up at sea level and had not stayed at high altitude before. These subjects will be referred as low landers. Similarly 20 healthy young permanent high altitude native residents who were born and brought up at altitude varying from 3500 to 4700m and had not been to sea level before, hereafter called high landers, were selected at random from a large sample. Both these group of subjects had similar nutritional and physical training status. The physical characters of the subjects are shown in Table I.

Initial studies of low landers were carried out at Delhi. They were then taken to an altitude of (3500m) by air and studied there. Subsequently they were taken by road to an altitude of 4100m where they were stationed for the next 24 months. They were studied periodically during their stay at that altitude and finally after 24 months of stay at 4100m. In this paper, however, only the results of studies at sea level; within one week of their arrival at 4100m and after 24 months stay at 4100m are presented. The studies on high landers were also done at the same place. The climatic conditions prevailing during the study were recorded at each place.

a) The subjects were given a standard submaximal stepping exercise on a 37.5 cm stool at a frequency of 30 steps/min for 5 min. During the exercise pulmonary ventilation ($\dot{V}E$); O_2 consumption ($\dot{V}O_2$) and heart rate (cf) were recorded by making the subjects breath through a low resistance valve into a Max-Plank KM respirometer. An aliquot of expired sample collected from the respirometer was analysed for Co_2 and O_2 using micro-scholander gas analyser. Heart rate was recorded with an ECG machine. Blood sample for lactic acid estimation was collected from the prewarmed finger tips after the exercise and blood lactate was estimated by Barker and Summerson method (3) as modified by Strom. Pulmonary ventilation and O_2 consumption during 15 min post exercise period were also measured to estimate the aerobic and anaerobic O_2 supply during the effort and the ratio of recovery and exercise ventilation.

b) The subjects were then subjected to a graded maximum exercise on a mechanically braked bicycle ergometer till exhaustion. Pulmonary ventilation, O_2 consumption and heart rate were recorded for each rate of exercise by the method mentioned above. The maximum O_2 uptake capacity ($\dot{V}o_2$ max) of the subjects were determined from the plots and the flattening point was considered as the maximum. Exercise ventilation and heart rate at the maximal exercise have been considered as maximum ventilation (VE max) and max. cardiac frequency (cf max), ventilation equivalent ($\dot{V}E/\dot{V}o_2$) and oxgyen pulse (Vo_2/cf) were also calculated for 1 litre of O_2 consumption from the plottings of various sub maximal exercises.

c) Endurance work capacity of the individuals was estimated by giving endurance stepping exercises at a fixed speed on a 37.5 cm high stool till exhaustion and the time was noted. Besides these laboratory tests, physical work performance capacity of the subjects was also assessed by two out door performance tests:

i) Time in running a distance of 1.6 *km* at maximum speed and

ii) time taken to climb 1500m on a hill having (1 : 3) gradient.

RESULTS

Physical characteristics of the two groups of subjects are shown in Table I. The data indicate that the mean age of the two groups was indentical. However, the high landers were taller and heavier than the low landers. The mean height of the low landers was 166.1 cm and their nude wt. 57.0 *kg* at Delhi was reduced to 54.7 *kg* after 2 years of stay at 4100m, whereas the mean height and nude wiehgt of the high landers were 170.9 cm and 62.5 *kg* respectively. The climatic conditions indoor and outdoor prevailing during various period of study at sea level and at 4100m are shown in Table II and were comparable to seasonal differences.

The physiological responses of low landers in a standard steping exercise on a 37.5 cm stool at sea level as well as at an altitude of 4100m after 2 years stay have been shown in Figs. 1,2, and 3. Similar results of high landers have also been shown in these figures. It will be seen that the pulmonary ventilation for the standard exercise which was 68.2 L at sea level increased significantly to 96.9 L at 4100m, wheras the high landers at 4100m carried out the same work with much less ventilation of 71.2 L which is almost similar to the low landers value at sea level (Fig. 1). The contraction of O_2 debt in the same fixed work was 33.1 *ml* at sea level in low landers but increased to 38.1 *ml/kg* at 4100m whereas the same effort was done at a less O_2 debt (32.0 *ml*) by the high landers at 4100m (Fig. 2). Lactate accumulation in standard exercise followed the similar pattern as in O_2 debt contraction as expected (Fig. 3).

Some of the physiological responses during maximal effort have been shown in Table III. It will be seen that the mean maximum oxygen uptake capacity ($\dot{V}O_2$ max) of low landers which was 46.84 *ml/kg/min* at sea level was reduced to 34.61 *ml/kg/min* on induction to 4100m but improved to 36.62 *ml/kg/min* at 4100m after 2 years of stay at that altitude. The mean $\dot{V}O_2$ max of high landers on the other hand at 4100m was 41.1 *ml/kg/min* which was about 13% higher than the acclimatised low landers. The mean VE

TABLE I: Physical characteristics ot lowlanders and highlanders at sea level and at an altitude of 4100m.

Characteristics	*Lowlanders*			*Highlanders*
	At Delhi	*On induction to high altitude*	*After 2 yrs of stay*	*at 4100m.*
Number	29	29	29	20
Age (yrs)	24.0 ±3.1	24.4 —	26.4 —	26.5 ±5.6
Height (*cm*)	166.1 ±3.6	166.1 ±3.6	166.1 ±3.6	170.9 ±5.2
Body weight (*kg*)	57.0 ±4.4	55.2 ±4.1	54.7 ±4.1	62.5 ±6.7
Surface area (Sq.m)	1.63 ±0.08	1.61 ±0.07	1.60 ±0.07	1.73 ±0.12

± indicates standard deviation

TABLE II: Mean environmental conditions at sea level and at 4100m.

Place	*Period*	*Indoor*		*Outdoor*	
		D.B. (°C)	*W.B.* (°C)	*Max* (°C)	*Min* (°C)
S.L.	Jan	14.50 (Range: 13.33-15.55)	10.0 (Range: 8.33-11.67)	20.10 (Range: 18.89-21.11)	5.94 (Range: 4.44- 7.22)
4100m	June-July	17.28 (Range: 14.44-19.44)	9.17 (Range: 7.78–12.22)	21.4 (Range: 13.89-30.55)	3.78 (Range: —2.22-12.22)

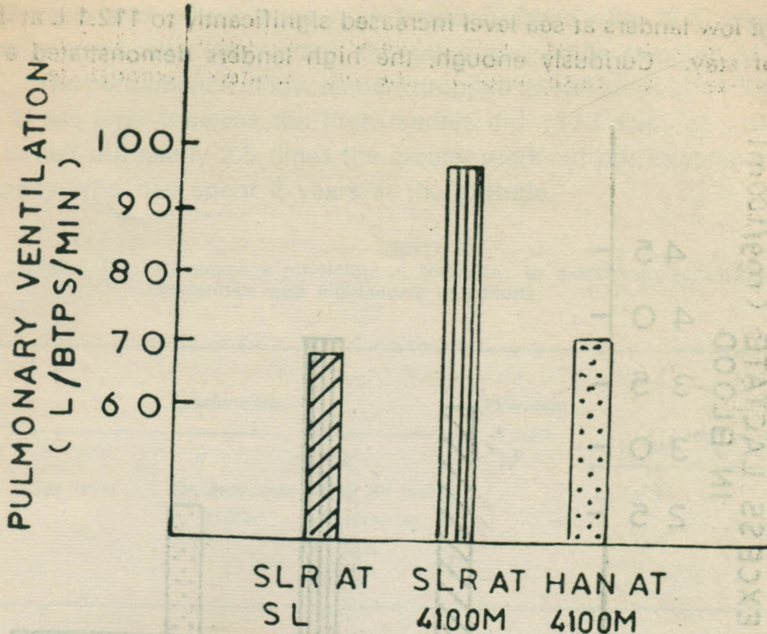

Fig. 1: Pulmonary ventilatory cost in fixed stepping exercise (L.BTPS/min).

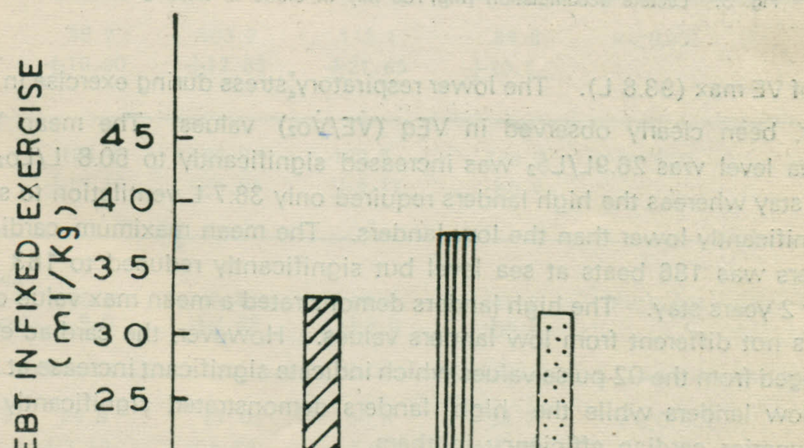

Fig. 2: O_2 debt contracted (*ml/kg*) in fixed work on 37.5 *cm* high stool at 30 steps/min for 4 min.

max of 88.2 L of low landers at sea level increased significantly to 112.1 L at high altitude after 2 years of stay. Curiously enough, the high landers demonstrated a significantly

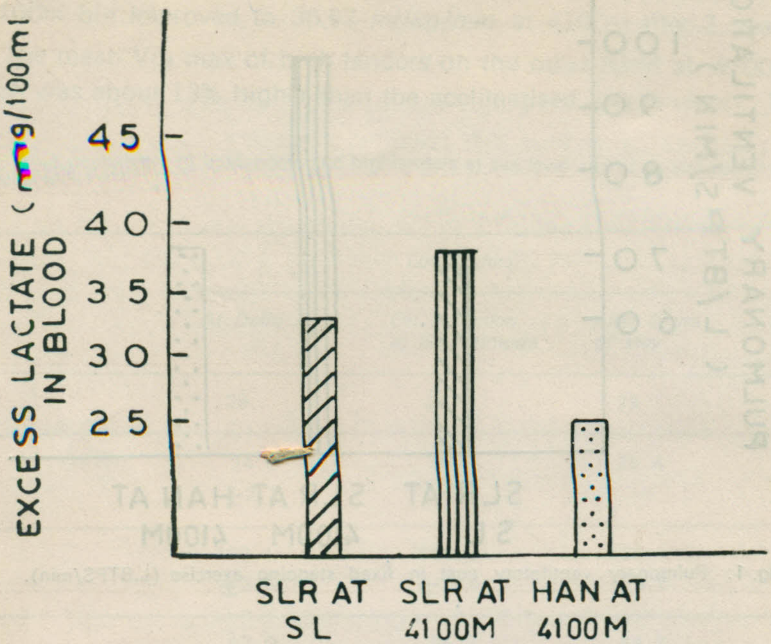

Fig. 3: Lactate accumulation *(mg/*100 *ml)* in blood in fixed a exercise.

lower value of $\dot{V}E$ max (93.8 L). The lower respiratory stress during exercise in high landers has however, been clearly observed in VEq ($\dot{V}E/\dot{V}O_2$) values. The mean V.Eq of low landers at sea level was 26.9L/LO_2 was increased significantly to 50.8 L/LO_2 at 4100m after 2 years stay whereas the high landers required only 38.7 L ventilation to supply 1L 02 which is significantly lower than the low landers. The mean maximum cardiac frequency of low landers was 186 beats at sea level but significantly reduced to 183 beats/min at 4100m, after 2 years stay. The high landers demonstrated a mean max value of 185 beats/ min and was not different from low landers values. However, the cardiac efficiency can be better judged from the 02 pulse values which indicate significant increase at high altitude in case of low landers while the high landers demonstrated significantly lower value indicating superior cardiac efficiency in them.

The physical work performance capacity in endurance step test, 1.6 *km* run and hill climbing ability in both the groups of subjects have been presented in Table IV, It will be seen that in endurance step test done at the rate of 30 steps per min, the total number of steps by low lander at sea level was 1,142 which came down significantly to 648 steps at

4100m after 2 years stay whereas the high lander finished with 1697 steps at the same altitude. Similar trend was observed in the other test while stepping at the rate of 35 steps per min. The performance of low landers dropped to 594 steps at 4100m as compared to 948 steps at sea level whereas the high landers did 1173 steps at 4100m. Thus the high landers turned out nearly 2.5 times the greater work out put as compared to their sea level counterparts who had spent 2 years at the altitude.

TABLE III : Comparative physiological responses to exercise in acclimatized lowlanders and highlanders at altitude.

Physiological parameters	*Lowlanders* I *Sea level*	II *On induction to 4100m*	III *After 24 months stay at 4100m*	*Highlanders of 4100m* IV	*Level of significance* *1 Vs 3*	*3 Vs 4*
$\dot{V}O_2$ max (*ml/kg*/min)	46.84 ±6.47	34.61 ±5.39	36.62 ±11.10	41.12 ±11.10	$P<0.001$	$P<0.05$
$\dot{V}E$ max (L BTPS/min)	88.2 ±10.60	103.2 ±12.80	112.1 ±21.65	93.8 ±20.5	$P<0.001$	$P<0.05$
HR max (beats/min)	186.0 ±13.10	183.0 ±6.04	182.5 ±6.17	185.0 ±5.6	$P<0.02$	NS
Exercise dyspnoea in fixed exercise (37.5cm/30 steps)	45.0 ±9.0	60.4 ±7.65	57.7 ±9.6	42.2 ±8.0	$P<0.001$	$P<0.001$
$\dot{V}E/\dot{V}O_2$ (L BTPS/ LO_2)	26.9 ±3.10	51.06 ±5.88	50.8 ±5.70	38.7 ±4.49	$P<0.001$	$P<0.001$
$HR/\dot{V}O_2$ (beats/ LO_2)	70.7 ±7.00	99.5 ±11.67	89.8 ±5.08	76.0 ±8.02	$P<0.001$	$P<0.0001$

In the 1.6 *km* run, the mean time taken to cover this distance was 6.68 min at sea level but this increased to 8.08 min at 4100m whereas the high landers maintained much higher speed and covered the same distance in much less time 6.78 min which was almost equal to low landers time at sea level. In the hill climbing test also the low landers average time to cover 1500m with 1:3 gradient was 9.17 min whereas the high landers required only 7.55 min to climb the same features.

TABLE IV : Comparative physical work performance of highlanders and lowlanders at altitude.

Tests	*Sea-level residents*		*Highlanders at 4100m*
	At sea level	After 2 years stay at 4100m	
	I	*II*	*III*
Endurance stepping on 37.5 cm high stool –			
@30 steps/min (No.)	1142 ±487.0	648*** ±266.2	1697*** ±718.4
@35 steps/min (No.)	948 ±354.0	594*** ±292.0	1173*** ±599.7
Time in 1.6 *km* run (min)	6.68 ±0.51	8.08*** ±0.72	6.78*** ±0.65
Hill climbing time (min 1500m; 1:3 gradient)	—	9.17 ±1.17	7.55**** ±0.88

±indicates standard deviation

***indicates highly significant ($P<0.001$) changes between I and II; II and III.

DISCUSSION

The capacity for physical work performance is directly related to the efficient O_2 transport mechanism. Thus the max 02 uptake capacity plays the foremost role in physical performance capacity (1). It is a complex measure of a variety of separate physiological functions encompassing the capacity of the heart for pumpnig a maximum volume of blood (11, 12) the O_2 carrying capacity of the blood, the level of oxygenation of the blood in the lungs and the utilisation of oxygen by the active muscle tissues. All investigators (4,10,23 & 20) agree that the max O_2 uptake capacity ($\dot{V}o_2$ max) is reduced on sojourn to altitude. This reduction in aerobic capacity follows a fairly linear pattern. If has been estimated (7) that there is a reduction of 3-3.5% for every 300m ascent above 1500m. The present data fits this regression line satisfactorily.

In comparison to acclimatised low landers, high altitude native residents demonstrated superior oxygen supply mechanism as evidenced by higher $\dot{V}o_2$ max of 41.1 *ml/kg/min* as against 36.62 *ml/kg/min* in the acclimatized-soldiers. High landers also demonstrated better cardio-respiratory efficiency and anaerobic efficiency as shown in figs 1-3. Because of superior cardiorespiratory efficiency leading to higher O_2 transport mechanism, the altitude native residents were able to produce much higher total work output than the acclimatised sea level residents at high altitude. This superiority in physical work capacity of high landers of Andes and Himalayes has been reported by various earlier workers (14, 28,9,15,17,24).

It is not known whether sea level men can adapt fully to high altitude and if so how long it will take to develop the necessary physiological adjustment enabling them to produce work rates similar to the high altitude native residents at altitude. From the present studies it is clear that even after 2 years of stay at 4100m and maintaining a very active schedule of work throughout, the low landers could not produce the same physical work capacity at high altitude as at sea level though they subsequently showed improvement from the initial losses. This finding is in agreement with the observations (28) who studied 10 sea level residents at 4500m altitude and concluded that it is hard to say whether they will ever reach the final physiological state as the adapted man. Extensive studies on acclimatisation process of low lander at great heights for 9 months during 1960-61 in the Himalayas (26,22,23) and for 3 months in the Himalayan School House Expedition (16) concluded that there were many physiological adaptational changes that took place due to continuous stay at high altitude.

Adaptation to high altitude in the native residents demonstrates the highest degree of harmonious integration of body functions attaining a peak condition which is not obtained in new comers even after prolonged exposure for 24 months at those altitudes.

It can thus be concluded from this study that the high altitude native residents possess superior work performance capacity than the low landers acclimatised for 24 months. This might have been possible due to generations of adaptational changes accrueing in them in various system of the body enabling them to overcome the handicap due to the lowered partial pressure of O_2.

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