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**ATTEMPTED ACCLIMATIZATION BY  
VIGOROUS EXERCISE DURING PERIODIC  
EXPOSURES TO SIMULATED ALTITUDE**

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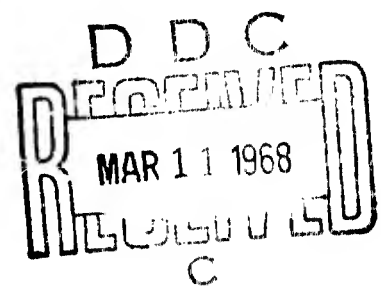
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## FOREWORD

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This technical report has been reviewed and is approved.

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## ABSTRACT

Acclimatization to altitude by means of periodic short-term chamber exposures could have military and athletic application by preparing unacclimatized subjects for endurance performance at altitude. Three unconditioned men were trained daily by endurance running for 3 weeks at ground level. Following control measurements, they exercised strenuously on a treadmill 2 hours daily for 17 days in a chamber at a simulated altitude of 2300 meters. Responses were evaluated by: symptoms; maximal work performance (as measured by the duration of exercise-to-tolerance); maximal heart rate; duration of breath-holding; production of lactate and excess lactate; maximal expiratory minute volume and oxygen consumption. During the initial periods of exercise at altitude, maximal work performance fell significantly from control levels (average 23%) with striking symptoms of exhaustion; breath-holding duration fell 13%; the production of excess lactate rose significantly in two subjects. Over the remainder of the altitude exposures, exercise performance and breath-holding duration increased to near control levels while fatigue was much less noticeable. Daily maximal heart rates varied greatly. There was no significant change in maximal oxygen consumption during exercise at altitude, but expiratory minute volume rose slightly. During the period of altitude exposures, symptoms common with chronic exposures (malaise, Cheyne-Stokes respiration, rheumatic complaints) were often noted both in the chamber and at work and at home. Identical exercise at ground level for 2 days following the chamber tests showed remarkable increases in maximal work performance and duration of breath-holding and a significant increase in maximal heart rate, along with feelings of well-being and vigor. These data suggest that some degree of acclimatization may have been accomplished, but improved exercise performance may be attributable in part to improved physical conditioning. The later "supernormal" performances raise the possibility of using this technique for the training of endurance athletes.

## SECTION I

### INTRODUCTION

Acclimatization to altitude is still a poorly understood phenomenon involving changes in plasma and red cell volume and complex cardiorespiratory and metabolic adaptations. The achievement of a degree of acclimatization permitting competitive exercise performance usually requires residence at altitude (or its chamber simulation) for several weeks. This investigation was undertaken to attempt acclimatization by carrying out vigorous exercise during short-term exposures to simulated altitude for 17 days. The military and athletic applications in preparing unacclimatized subjects for endurance performance at altitude are obvious.

## SECTION II

### METHODS

Three healthy, young, unconditioned and unacclimatized, male volunteer subjects were chosen from the personnel of the research laboratory; their physical characteristics are presented in table I. Prior to the experiment itself each subject carried out a strenuous conditioning program involving distance running for 3 weeks; treadmill exercise was used frequently, and during the last week of the program was the major means of exercise. During the last few days an exercise regimen similar to that of the experiment was carried out. At the completion of this program, we thought that the subjects had achieved good but not maximal conditioning.

The 20-man Shaw-Estes High Altitude Chamber Complex of the Chamber Facility Operations Branch of the Aerospace Medical Research Laboratories was used for the experiments that were carried out for 2 hours daily, between 1000 and 1600 hours. Chamber decompression to a simulated altitude of 2300 meters (575 mmHg) was reached over a period of approximately 5 minutes, and, following the 2-hour exposures, repressurization was accomplished at a similar rate. Chamber temperature was monitored daily and remained between 25 and 28 C. An altitude of 2300 meters was chosen because: vigorous exercise is possible at this altitude, military maneuvers and athletic performances with unacclimatized subjects at similar levels have been of interest and concern, and daily, short-term exposures to this pressure present minimal physical complications. Altitude at the laboratory is 260 meters.

TABLE I

PHYSICAL CHARACTERISTICS OF THE SUBJECTS AND THE TREADMILL SETTINGS FOR THEIR  
PRELIMINARY AND TOLERANCE RUNS

SUBJECT	AGE (YRS)	WEIGHT (Kg)	BODY SURFACE AREA (METER <sup>2</sup> )	TREADMILL SETTINGS			
				PRELIMINARY RUN		TOLERANCE RUN	
				METERS/SECOND	% GRADE	METERS/SECOND	% GRADE
E.S.	30	67.3	1.73	2.3	10.0	2.7	12.5
R.M.	28	95.0	2.16	2.3	0	2.7	5.0
S.S.	27	69.2	1.90	2.7	5.0	3.2	7.5

Exercise was carried out on a special treadmill, offering graded inclinations up to 40% and speeds up to 6.8 m/sec, and consisted of two regimens. Three preliminary periods of 9 minutes each of submaximal exercise were separated by rest intervals of 21 minutes; the degree of exercise was chosen for each subject after conditioning to provide repeated fatigue but not exhaustion. The severity of a final "tolerance run" was chosen to exhaust each subject in approximately 3 to 4 minutes.

The response to exercise and the estimation of acclimatization were evaluated by means of the following daily tests: (1) duration of the tolerance run: exercise was discontinued by the subject at the point of exhaustion and not at any arbitrary heart rate level, (2) maximum heart rate, measured from the electrocardiogram recorded at the end of the tolerance run, (3) duration of breath-holding, measured 15 minutes after the completion of the third preliminary run, (4) symptoms and clinical signs in the altitude chamber and during usual activities outside of the chamber. Daily values for the first three of these factors for each subject were averaged for days 1-3, 9-11, and 15-17 during simulated altitude, and for the 2 days at ground level following these exposures (recovery); these average values represent the early, middle, and later periods of exercise at altitude, and the changes during the recovery period (table II and fig. 1).

On the day prior to the beginning of the exercise at altitude (control day), on the second, tenth and seventeenth day of exercise at altitude, and on the second day after the return to ground level, the following measurements were also made: (1) maximal expiratory minute volume (L/min (BTPS)), and oxygen consumption (L/min), measured during the last 30 seconds of the tolerance runs: (2) blood lactate (8) and pyruvate (9) from venous samples drawn before chamber evacuation and immediately following the tolerance run. Excess lactate was calculated by Huckabee's method (10). It is important that these determinations were made from peripheral venous blood samples and cannot be compared with values determined from arterial samples.

The experimental plan for a typical test day at altitude was as follows. Each subject arrived at the chamber having abstained from food for 2 hours. Following venipuncture for the determination of lactate and pyruvate, and the securing of electrocardiographic leads, the chamber was evacuated to 575 mmHg over a period of 5 minutes, and the first subject began his first 9-minute preliminary run. One minute after he completed this run, the next subject started running. Fifteen minutes after the completion of the third preliminary run, the duration of breath holding was measured, and shortly thereafter the tolerance run was carried out. During the last 30 seconds of each tolerance run, expired air was

collected in a Douglas bag through low-resistance mouthpiece, valve, and connecting tubing, and the electrocardiogram was recorded. Immediately following the completion of this run, a venous blood sample was obtained for lactate and pyruvate determinations. After the completion of the last tolerance run and blood sampling, chamber pressure was restored.

### SECTION III

#### RESULTS

During the first 4 to 5 days of exercise at subatmospheric pressure, each subject noticed extreme fatigue during the preliminary runs (subjects SS and RM could not complete a few of these runs), and early exhaustion with the tolerance runs. With repeated exposures, fatigue gradually lessened and symptoms of exhaustion were less severe and prolonged. Exercise at ground level during recovery after these exposures was completed with great ease and few symptoms of fatigue, and subjects enjoyed a remarkable feeling of well-being and even exhilaration. Throughout the first several days at 2300 m, malaise and rheumatic complaints (ankle and knee aching especially) were common. Cheyne-Stokes respiration, similar to the pattern described by Luft (in the review by Lange and Hecht) (13), was noted in each subject during occasional brief naps during altitude exposures, and one subject was found to exhibit a similar respiratory pattern during sleep at home throughout this period. Subject RM developed intractable insomnia, and SS noted frequent dreams and one nocturnal bout of extrasystoles during this period. "Irritability" was occasionally noticed by observers in two of the subjects during the first several days of exercise at 2300 m.

A subsiding respiratory infection may have affected the control (prealtitude exposure) values for subject RM. SS could not exercise on days 4-6 because of ankle pain; his maximal expiratory minute volume and oxygen consumption were not obtained (for technical reasons) on day 10 during altitude exposures.

Exercise performance, as measured by the duration of the tolerance runs, fell strikingly during the first 3 days of exercise at 2300m (table 2, fig. 1), and improved significantly in two of the subjects by the time of the 9-11 day and 15-17 day series of tests. The duration of tolerance runs following the return to an altitude of 260 m rose to extraordinary levels, exceeding control values by 100%. The higher of the individual maximal heart rates during the two recovery runs for these subjects reach 205, 210 and 192; these are the highest heart rates ever recorded in these subjects. There was no obvious relationship between the heart rate and the duration of exercise, except during the recovery runs.

EFFECTS OF EXERCISE-AT-ALTITUDE IN THREE PHYSICALLY CONDITIONED SUBJECTS

	DURATION OF TOLERANCE RUN (SECONDS)	MAXIMUM HEART RATE (BEATS/MIN)	DURATION OF BREATH HOLDING (SECONDS)	LACTATE RISE (mM/L)	EXCESS LACTATE (mM/L)	EXPIRATORY MINUTE VOLUME (L/min, BTPS)	OXYGEN CONSUMPTION (L/min.)
<u>E.S.</u>							
CONTROL	240	184	65	7.6	6.7	115.4	3.12
1-3*	170	183	49	6.8	5.7	119.9	3.04
9-11†	192	170	62	7.9	7.5	126.4	3.10
15-17‡	232	179	57	7.9	6.1	128.8	2.49
Rec.§	473	195	93	7.5	6.4	102.7	2.69
<u>R.M.</u>							
CONTROL	210	185	78	6.1	2.5	151.8	3.65
1-3	165	180	75	6.3	5.0	158.3	3.33
9-11	158	180	64	5.6	4.9	168.3	4.06
15-17	160	178	79	6.7	5.0	144.4	3.89
Rec.	445	200	102	6.8	5.0	154.2	3.90
<u>S.S.</u>							
CONTROL	135	180	68	5.3	2.4	161.6	3.72
1-3	115	187	58	7.2	6.5	165.6	3.23
9-11	155	188	59	7.6	6.1	164.2	3.50
15-17	160	190	61	6.7	5.9	- 0	- 0
Rec.	273	186	87	6.5	5.7	155.6	3.93

LEGEND

- \* Average values for the first 3 days of altitude exposure;
- † Average values for ninth through eleventh day;
- ‡ Average values for last 3 days;
- § Average values for 2 days at ground level following altitude exposures;
- ⊙ Sample lost.

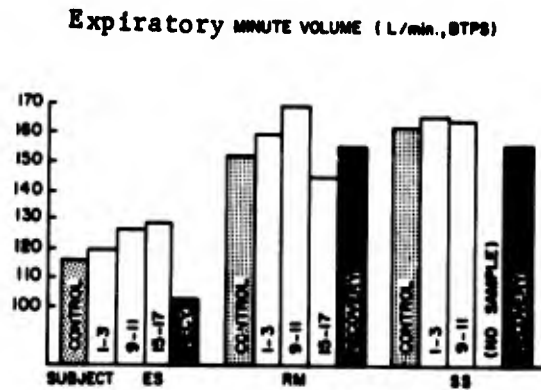
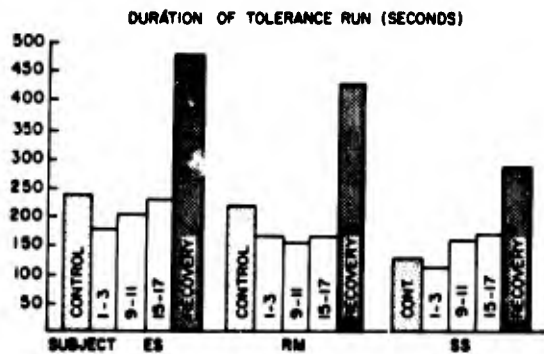
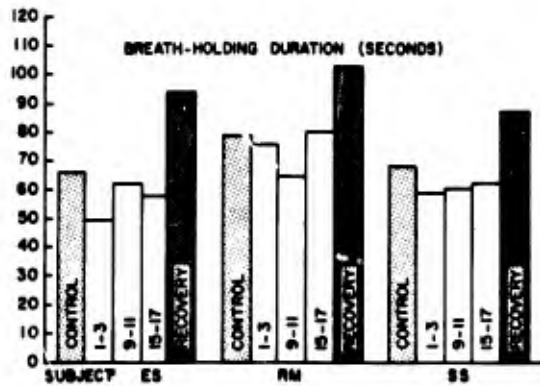
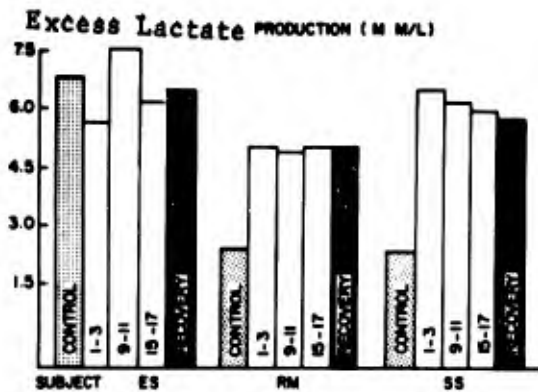


Figure 1

REPRESENTATIVE MEASUREMENT PERIODS DURING THREE WEEKS OF EXERCISE

LEGEND

Each group of five bars depicts values for a single subject. Cross-hatched bars represent control values; the three unshaded bars represent average values during the early, middle and final periods of exercise at simulated altitude; stippled bars represent the values during recovery after the altitude exposures.

Breath-holding duration decreased in each subject during the first several days at altitude, then varied widely until the return to ground level when each subject achieved his maximal duration of breath-holding (30-50% above control values). Maximal expiratory minute volume rose and remained elevated (but for one test) throughout the period at altitude, while maximal oxygen consumption fell initially and changed inconsistently thereafter. Lactate production during exercise was similar before, during, and after the altitude exposure, while excess lactate rose in two subjects during exercise at 2600 m and during the recovery tests.

#### SECTION IV

#### DISCUSSION

Attempts to achieve altitude acclimatization in animals and human subjects by intermittent exposures to simulated altitude have been few and unsuccessful (1-3) except for the study by Scholtz v Merényi et al, which showed a 1 - 2 kilometer increase in altitude tolerance after twice weekly 1-hour exposures to a simulated altitude of 5000 m for 3 weeks (17). Exercise was not carried out in any of these studies. It seemed of interest to re-study this problem using vigorous exercise during the periods of altitude exposures because: (1) strenuous exercise accelerates natural acclimatization to altitude (12) and to heat (15, 18); (2) when altitude acclimatization has once been achieved, it can be maintained satisfactorily by intermittent chamber exposures (as little as 1.5 hours, 6 days a week) (1, 15); (3) it was necessary to preserve the conditioned state in order to use exercise performance as a measure of acclimatization.

The degree of acclimatization achieved in the present study is uncertain. The improvement in performance during exercise at 2300 m may be attributed to acclimatization, but may also represent, in part at least, improved conditioning of incompletely conditioned subjects. However, during exercise at ground level following the altitude exposures, each subject performed with much greater ease and less final fatigue while doubling the duration of his tolerance run. To discriminate clearly between acclimatization and continued conditioning, it may be necessary to carry out a complex series of experiments using more highly conditioned subjects, prolonging the duration of the daily exposures, the number of days of the stress, or elevating the simulated chamber altitude, or both.

As Balke (4) and Kellogg (12) showed, exercise performance was very much impaired during the first few days of the exposures at subatmospheric pressure, and there was no significant improvement in performance over the first week to 10 days in the chamber, even though there was a very significant improvement in symptoms during exercise. Exercise during the last few days of the 17 days of altitude exposure proved easier subjectively, and work performance, as measured by the duration of the tolerance runs, increased.

However, there were no significant changes in maximum heart rate during these tolerance runs nor in the duration of breath-holding.

During this series of intermittent altitude exposures, a variety of symptoms was noted by the subjects when not in the chamber, which are familiar symptoms during prolonged, constant altitude exposures. One subject developed severe, nightly insomnia while another noted frequent dreaming, both rare symptoms for these men. Cheyne-Stokes respiration was noted in all subjects during brief naps in the altitude chamber, and one subject's wife frequently observed him to exhibit this pattern during sleep at home. During the first several days of exercise at altitude, malaise was noted by each subject, and exercise caused a much greater degree of fatigue that was much more prolonged than with exercise at ground level. One subject, a physician, was awakened from sleep on one occasion with very frequent extrasystoles which persisted for 5 minutes; these had never been noted before. Each subject noted rheumatic complaints, particularly ankle or knee aching, or both, for a few days shortly after the beginning of the series of altitude exposures; in two of the subjects these symptoms persisted even when outside the chamber, and one subject was unable to exercise for 3 days on this account.

During the last several days of the altitude exposures, each of these symptoms had disappeared, but for the insomnia, which left only after the completion of the altitude exposures. Mild, transient coughing was occasionally noted after exercise at sub-atmospheric pressures, and one subject developed a persisting cough for 2 to 3 minutes on one occasion, but there were no clinical signs of pulmonary edema on physical examination.

A significant decrease in the duration of breath-holding has been proposed as a useful index of acclimatization (16). In the present study, breath-holding duration fell uniformly with the initial exposures to altitude, then varied widely, tending to rise to control levels over the remainder of the period at altitude, unlike the usual pattern during acclimatization. The greatest change in this test for all three subjects was noted after the return to ground level, when each reached a level 30-50% greater than prealtitude control values.

Preexercise lactate and pyruvate samples were obtained before chamber evacuation, not just before the final tolerance run, so that changes in lactate and pyruvate values actually represent the cumulative effects of altitude exposure, the three preliminary periods of exercise, and the exercise to exhaustion. The rises in venous lactate levels following exercise at 2300 m are similar to those at ground level, but the calculated excess lactate production, possibly a more accurate estimate of anaerobic metabolism (10 and 11), rose to much higher levels during exercise at altitude, when the duration of exercise and thus the work levels were usually lower; this does not support Balke's conclusion that mild hypoxia (exercise at 2300 m) does not affect oxygen debt capacity (7).

Of greatest interest was the "supernormal" exercise performance of each of the three subjects following return to ground level. This improved performance seems beyond that which could be expected by continued conditioning, and is similar to Balke's finding in conditioned athletes after 10 days of exercise at 2300 m (6, 7). It is not clear whether this improved exercise performance is sustained for more than a few days after return to ground level. The possible use of such conditioning by endurance athletes warrants further evaluation.

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## 13. ABSTRACT

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14.

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