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THE EFFECT OF BEDREST ON VARIOUS PARAMETERS OF PHYSIOLOGICAL FUNCTION

PART VII. CARDIAC AND VENTILATORY RESPONSE TO THE BICYCLE ERGOMETER TEST

by *D. Cardus, W. A. Spencer, C. Vallbona, and F. B. Vogt*

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

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A study on effects of 14 days bedrest on tolerance to physical work was carried out on six healthy subjects. Tolerance was tested with the bicycle ergometer. Oxygen consumption, CO₂ production, pulmonary ventilation, breaths per minute, frequency of the heart were measured at different work loads, and recovery time of heart rate after cessation of exercise. Results indicate that changes observed after 14 days bedrest in respiratory gas exchange, ventilation and mechanical efficiency were not significant; heart rate at rest and during exercise was significantly higher after 14 days bedrest. Isometric exercises carried out in a second 14-day bedrest period did not completely prevent the observed changes in heart rate.

Author ↑

FOREWORD

This study is a part of a NASA investigation of the effect of bedrest on various parameters of physiological function. It was sponsored by NASA Manned Spacecraft Center under Contract NAS-9-1461, with Dr. Lawrence F. Dietlein, Chief, Space Medicine Branch serving as Technical Monitor.

This study was conducted in the Immobilization Study Unit of the Texas Institute for Rehabilitation and Research, The Texas Medical Center. The authors are affiliated with Baylor University College of Medicine as follows: Dr. Cardus, Departments of Rehabilitation and Physiology; Dr. Spencer, Department of Rehabilitation; Dr. Vallbona, Departments of Rehabilitation, Physiology, and Pediatrics; and Dr. Vogt, Department of Rehabilitation.

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SUMMARY

A study of 14 days bedrest was carried out on six healthy subjects to study the effect of bedrest on the tolerance to physical work as tested by means of the bicycle ergometer test. The parameters measured at different work loads were: O_2 consumption, CO_2 production, pulmonary ventilation, number of breaths per minute, frequency of the heart beat and recovery time of the heart rate after cessation of exercise. The results obtained in this study indicate that the changes observed after 14 days bedrest in respiratory gas exchange, pulmonary ventilation and mechanical efficiency were not significant; the heart rate at rest and the heart rate response to exercise were significantly higher after 14 days bedrest. A program of isometric exercises carried out in a second 14-day bedrest period did not completely prevent the observed changes in heart rate.

INTRODUCTION

The effect of bedrest on the tolerance to physical work was tested in the 14-day experiment (Study II) by means of the bicycle ergometer test which was performed before and after Period 1 (bedrest) by three subjects and before and after Period 2 (bedrest with isometric exercise) by five subjects. The parameters measured at different work loads were: O_2 consumption, CO_2 production, ventilation, number of breaths per minute, frequency of the heart beat, and the recovery time of the heart rate after cessation of exercise.

METHOD

The test was carried out with Lanooy's bicycle ergometer. The design of this instrument is such that variations within a certain range in the rate of pedalling are compensated to result in a constant work load. Before starting the test, the

subject sat on the bicycle for 2 or 3 minutes and during this time electrodes were placed on his chest for the purpose of recording the electrocardiogram, the phonocardiogram and the impedance pneumogram. When the subject appeared to be relaxed, the recording of these variables with a direct-writing Physiograph was initiated. Then the subject was instructed to start to pedal the bicycle at the constant rate of 60 cycles per minute. During the warming-up period of 3 minutes, the subject pedalled the bicycle at a work load of 30 watts. At the end of the third and each successive minute, the work load was increased 10 watts each minute, until a heart rate of approximately 170 was reached. (The setting of the ergometer at this point is called final work load). The heart sounds, the electrocardiogram, and the impedance pneumogram were monitored continuously at rest, during exercise, and during 5 minutes of the recovery period. Samples of expired air were collected with Douglas bags at 40, 80, and 120 watts. The volume of air expired was measured with a wet gas meter and the samples were analyzed for O_2 and CO_2 with the Scholander apparatus. The number of breaths per minute was obtained from the impedance pneumogram.

Measurement of the heart rate recovery time

The recovery time of the heart rate was measured as reported elsewhere.¹ A brief description follows. The electrocardiogram was recorded continuously throughout the test. The average heart rate at rest and the average heart rate during the last minute of exercise were used to calculate the increment (heart rate at exercise minus heart rate at rest). The curve of the instantaneous heart rate obtained during the recovery phase of exercise was fit with a polynomial and the time to recover 37 or 63 percent of the incremented heart rate was calculated. (See Figure 1.) To obtain the curve of the instantaneous heart rate the R-R interval of each complex of the analog recording of the electrocardiogram was digitized with a semi-automatic Benson-Lehner A-D Converter and the data punched into IBM cards. A special program for the IBM 1620 computer was written for the polynomial fit and the calculation of the recovery time.

RESULTS

A. Results obtained before and after bedrest immobilization (Period 1)

The results obtained on the three subjects that were tested before and after Period 1 of Study II (14 days bedrest) are summarized in Tables 1, 2, and 3. These tables contain values for the heart rate at rest, and for ventilation, O_2 consumption, CO_2 production, respiratory quotient, frequency of breathing, and heart rate at 40, 80, and 120 watts. The samples of expired air obtained on subject A.C.L. were not reliable and the results are not reported here.

ANALOG INPUT

RESP.

PHON.

E C G

A-D CONVERTER

COMPUTER → DIGITAL OUTPUT

INST. HEART FREQ.
 $\tau_{0.63}$

GRAPHIC PLOT
(CALCOMP)

INST. HEART FREQ.
 $\tau_{0.63}$

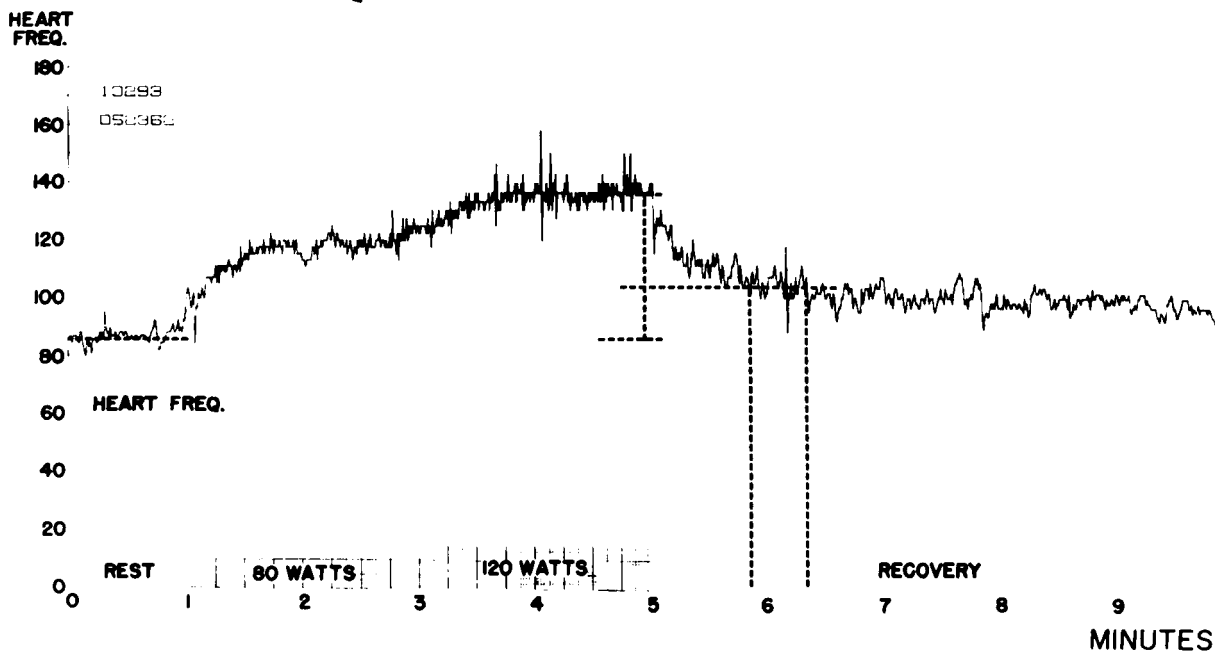


FIGURE 1.

TABLE I

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT A.C.L.
BEFORE AND AFTER PERIOD I OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest	0	-	-	-	-	-	57
Post-bedrest	0	-	-	-	-	-	77
Pre-bedrest	40	0.739	0.560	18.7	0.76	10	72
Post-bedrest	40	-	-	-	-	8	82
Pre-bedrest	80	0.791	0.733	23.3	0.93	10	77
Post-bedrest	80	-	-	-	-	8	92
Pre-bedrest	120	1.224	0.981	28.9	0.80	12	90
Post-bedrest	120	-	-	-	-	12	118

W.L. = Work Load

 $\dot{V}O_2$ = Oxygen Consumption $\dot{V}CO_2$ = CO₂ Elimination

R.Q. = Respiratory Quotient

B.F. = Breath Frequency

H.F. = Heart Frequency

 \dot{V} = Ventilation

TABLE 2

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT D.C.
BEFORE AND AFTER PERIOD 1 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest	0	-	-	-	-	-	81
Post-bedrest	0	-	-	-	-	-	91
Pre-bedrest	40	0.854	0.833	24.6	0.98	23	98
Post-bedrest	40	0.895	0.837	27.4	0.94	28	116
Pre-bedrest	80	1.025	1.006	28.1	0.98	23	113
Post-bedrest	80	1.086	1.037	35.5	0.95	32	131
Pre-bedrest	120	1.399	1.380	41.1	0.99	29	136
Post-bedrest	120	1.498	1.465	50.4	0.98	36	162

W.L. = Work Load
R.Q. = Respiratory Quotient
 $\dot{V}O_2$ = Oxygen Consumption
B.F. = Breath Frequency
 $\dot{V}CO_2$ = CO₂ Elimination
H.F. = Heart Frequency

\dot{V} = Ventilation

TABLE 3

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT T.G.O.
BEFORE AND AFTER PERIOD 1 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest	0	-	-	-	-	-	113
Post-bedrest	0	-	-	-	-	-	118
Pre-bedrest	40	0.710	0.741	23.8	1.04	19	128
Post-bedrest	40	0.741	0.679	20.5	0.92	19	133
Pre-bedrest	80	1.007	0.930	27.9	0.92	19	145
Post-bedrest	80	1.009	0.897	28.7	0.89	23	148
Pre-bedrest	120	1.293	1.265	36.5	0.98	21	161
Post-bedrest	120	1.396	1.234	39.6	0.88	23	174

W.L. = Work Load

R.Q. = Respiratory Quotient

 \dot{V} = Ventilation $\dot{V}O_2$ = Oxygen Consumption

B.F. = Breath Frequency

 $\dot{V}CO_2$ = CO_2 Elimination

H.F. = Heart Frequency

The values for O_2 consumption are lower than those reported in the literature for similar work loads. Our coefficient of regression of the O_2 consumption on work load is consistently lower and this must be attributed to the calibration of the instrument. In the two subjects where comparisons can be established at the three different work levels, the O_2 consumption was always a little higher after bedrest immobilization. The CO_2 eliminated did not show any consistent change. The respiratory quotient was lower after bedrest. The ventilation and frequency of breathing tended to be higher after bedrest.

The heart rate at rest and during work at 40, 80, and 120 watts was consistently higher after the 14-day bedrest in all three subjects.

B. Results obtained before and after bedrest immobilization with isometric exercise (Period 2)

The results obtained before and after the second period are summarized in Tables 4, 5, 6, 7, and 8. The measurements were taken on five subjects before and after 14 days of bedrest with isometric exercise.

There were considerable individual differences in gas exchange and ventilation during the bicycle test, but these differences were not significant (See Table 9).

After the period of bedrest with isometric exercise the resting frequency of the heart was higher than before bedrest. The increment of the frequency of the heart at the three different work levels was smaller than in the first period (bedrest alone). Subject D.C. even showed a lower heart rate after bedrest with isometric exercise.

C. Heart rate recovery time

The 37 percent recovery time of the heart rate was calculated in some of the subjects and the results are tabulated in Table 10. The first figures indicate the time in seconds and the figures in parentheses indicate the work load at which the exercise was stopped.

DISCUSSION

The results of the bicycle ergometer test obtained in the first period can only be compared in two of the three subjects.

The oxygen consumption and CO_2 elimination measured at 40, 80, and 120 watts during the bicycle ergometer test are lower than those reported in the literature for similar work loads.^{2,3} Since this is a constant observation in our laboratory,

TABLE 4

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT A.C.L.
BEFORE AND AFTER PERIOD 2 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest with exercise	0	-	-	-	-	-	56
Post-bedrest with exercise	0	-	-	-	-	-	77
Pre-bedrest with exercise	40	0.682	0.469	14.5	0.69	-	74
Post-bedrest with exercise	40	0.613	0.528	16.0	0.86	14	83
Pre-bedrest with exercise	80	0.832	0.674	18.9	0.81	-	81
Post-bedrest with exercise	80	0.912	0.696	20.0	0.76	12	96
Pre-bedrest with exercise	120	1.220	1.042	29.2	0.85	-	98
Post-bedrest with exercise	120	1.738	1.473	39.9	0.85	14	112

W.L. = Work Load

R.Q. = Respiratory Quotient

 \dot{V} = Ventilation $\dot{V}O_2$ = Oxygen Consumption

B.F. = Breath Frequency

 $\dot{V}CO_2$ = CO₂ Elimination

H.F. = Heart Frequency

TABLE 5

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT D.C.
BEFORE AND AFTER PERIOD 2 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest with exercise	0	-	-	-	-	-	86
Post-bedrest with exercise	0	-	-	-	-	-	92
Pre-bedrest with exercise	40	1.004	0.910	31.0	0.91	30	112
Post-bedrest with exercise	40	0.808	0.749	24.3	0.93	28	109
Pre-bedrest with exercise	80	1.183	1.159	40.0	0.98	35	134
Post-bedrest with exercise	80	0.955	0.911	28.1	0.95	28	128
Pre-bedrest with exercise	120	1.459	1.324	47.2	0.91	36	162
Post-bedrest with exercise	120	1.327	1.270	41.6	0.96	30	156

W.L. = Work Load $\dot{V}O_2$ = Oxygen Consumption $\dot{V}CO_2$ = CO₂ Elimination
R.Q. = Respiratory Quotient B.F. = Breath Frequency H.F. = Heart Frequency
 \dot{V} = Ventilation

TABLE 6

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT C.P.
BEFORE AND AFTER PERIOD 2 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest with exercise	0	-	-	-	-	-	101
Post-bedrest with exercise	0	-	-	-	-	-	102
Pre-bedrest with exercise	40	0.886	0.857	30.0	0.97	24	102
Post-bedrest with exercise	40	0.664	0.549	19.3	0.83	20	105
Pre-bedrest with exercise	80	0.905	0.857	31.7	0.95	27	105
Post-bedrest with exercise	80	0.981	0.812	23.6	0.83	18	116
Pre-bedrest with exercise	120	1.192	1.149	45.5	0.96	28	128
Post-bedrest with exercise	120	1.301	1.244	36.3	0.96	26	130

W.L. = Work Load
R.Q. = Respiratory Quotient
 \dot{V} = Ventilation
 $\dot{V}O_2$ = Oxygen Consumption
B.F. = Breath Frequency
 $\dot{V}CO_2$ = CO₂ Elimination
H.F. = Heart Frequency

TABLE 7

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT M.G.O.
BEFORE AND AFTER PERIOD 2 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m ² .)	$\dot{V}CO_2$ (L./m ² .)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest with exercise	0	-	-	-	-	-	105
Post-bedrest with exercise	0	-	-	-	-	-	107
Pre-bedrest with exercise	40	0.940	0.817	23.9	0.87	18	109
Post-bedrest with exercise	40	0.906	0.758	20.4	0.84	20	108
Pre-bedrest with exercise	80	1.319	0.998	26.6	0.76	20	114
Post-bedrest with exercise	80	1.251	1.006	27.5	0.80	20	125
Pre-bedrest with exercise	120	1.533	1.398	35.3	0.91	20	124
Post-bedrest with exercise	120	1.374	1.098	30.2	0.80	20	132

W.L. = Work Load

R.Q. = Respiratory Quotient

\dot{V} = Ventilation

$\dot{V}O_2$ = Oxygen Consumption

B.F. = Breath Frequency

$\dot{V}CO_2$ = CO₂ Elimination

H.F. = Heart Frequency

TABLE 8

RESULTS OBTAINED WITH THE BICYCLE ERGOMETER TEST ON SUBJECT A.C.I.
BEFORE AND AFTER PERIOD 2 OF STUDY II

	W.L. (Watts)	$\dot{V}O_2$ (L./m.)	$\dot{V}CO_2$ (L./m.)	\dot{V} (L./m.)	R.Q.	B.F. (Breaths/m.)	H.F. (Beats/m.)
Pre-bedrest with exercise	0	-	-	-	-	-	74
Post-bedrest with exercise	0	-	-	-	-	-	76
Pre-bedrest with exercise	40	0.761	0.649	18.6	0.85	12	105
Post-bedrest with exercise	40	0.687	0.684	22.2	1.00	16	111
Pre-bedrest with exercise	80	1.005	0.856	24.5	0.85	16	116
Post-bedrest with exercise	80	0.964	0.786	23.8	0.82	18	121
Pre-bedrest with exercise	120	1.187	0.908	26.2	0.76	18	129
Post-bedrest with exercise	120	1.164	0.874	27.1	0.75	18	138

W.L. = Work Load

R.Q. = Respiratory Quotient

 \dot{V} = Ventilation $\dot{V}O_2$ = Oxygen Consumption

B.F. = Breath Frequency

 $\dot{V}CO_2$ = CO_2 Elimination

H.F. = Heart Frequency

TABLE 9

MEAN VALUES BEFORE AND AFTER BEDREST WITH ISOMETRIC EXERCISE

Variable	n	\bar{x}_1	\bar{x}_2	\bar{d}	S_d	t
$\dot{V}O_2$ (L./m.)	15	1.074	1.043	- 0.031	0.184	0.653
$\dot{V}CO_2$ (L./m.)	15	0.938	0.896	- 0.042	0.181	0.899
R.Q.	15	0.87	0.86	- 0.01	0.276	0.140
\dot{V} (L./m.)	15	29.5	26.7	- 2.9	6.2	1.792
B.F. (Breaths/m.)	12	24	20	- 1.8	4.0	1.570
H.F. (Beats/m.)	15	113	118	+ 5.1	6.3	3.156**

$\dot{V}O_2$ = Oxygen Consumption

\dot{V} = Ventilation

$\dot{V}CO_2$ = Carbon Dioxide Elimination

B.F. = Breathing Frequency

R.Q. = Respiratory Quotient

H.F. = Heart Frequency

** Highly significant.

TABLE 10

T_{0.37} VALUES OF HEART FREQUENCY RECOVERY CURVE
(STUDY II)

Subject	Pre-Period 1	Post-Period 1	Pre-Period 2	Post-Period 2
A.C.L.	4.6 (200)	7.8 (180)	14.8 (220)	13.7 (220)
D.C.	13.4 (170)	7.8 (120)	11.9 (120)	11.7 (140)
C.P.	-	-	4.9 (160)	4.4 (160)
A.C.I.	-	-	8.9 (180)	9.2 (160)
T.G.O.	14.6 (160)	10.6 (140)	-	-
M.G.O.	-	-	5.9 (200)	2.5 (150)

Pre-Period 1 = Pre -Bedrest

Post-Period 1 = Post-Bedrest

Pre-Period 2 = Pre- Bedrest with isometric exercise

Post-Period 2 = Post-Bedrest with isometric exercise

First figure indicates seconds. Figures in parentheses indicate work load (watts) at which exercise was stopped.

one must conclude that this is due to the calibration of the bicycle ergometer. The oxygen and CO₂ values obtained after the 14-day bedrest were a little higher than those obtained before the experiment. These differences are within the error of the measurement and for this reason are believed not to be significant. The respiratory quotient was always lower after immobilization in the first period. The subjects probably hyperventilated when they were tested before immobilization. The ventilation values obtained at the different work loads were also lower for similar work loads than those reported in the literature and this again indicates that the calibration of our bicycle ergometer has a smaller slope. The oxygen utilization (ratio $\dot{V}O_2/\dot{V}$) before Period 1 was lower than before Period 2, but there was no difference in the values obtained before and after bedrest immobilization in both periods. The fact that it was greater before Period 2 as compared to Period 1 indicates also that there was a relative hyperventilation when the subjects were submitted to the bicycle test for the first time.

As indicated in Table 9 the differences observed when comparing the results obtained before and after bedrest with isometric exercise were not significantly different for O₂ consumption, CO₂ elimination, respiratory quotient, ventilation per minute, and frequency of breathing.

A consistent finding in these experiments was a higher heart rate after bedrest immobilization. The average increase of the heart rate at rest in the first period (bedrest alone) was 11.6 beats per minute, whereas the average increase in the second period (bedrest with isometric exercise) was 6.4 beats per minute. Table 9 indicates that the increase of the heart rate at work observed after bedrest immobilization with isometric exercise was significant. This increment of the work heart rate was, however, smaller than that observed during the bicycle test of the first period (bedrest alone). These findings agree with those of Taylor, et al.^{4,5}, who in an experiment carried out on six healthy individuals, 20 to 23 years old, submitted to bedrest from 3 to 4 weeks, found a decrease of 17 percent of the volume of the heart; a decrease in the maximal oxygen intake of 13 to 22 percent in the two subjects on whom this measurement was made; an increase of the resting heart rate of 0.5 beat per minute per day bedrest; and an increase of the heart rate during exercise. No change was found in the mechanical efficiency of these individuals after immobilization and this seems to be also the case in our study. Similar observations were made by Birkhead et al.⁶ and Deitrick et al.⁷ The latter observed an average increase of 4 beats per minute of the resting pulse rate and no significant changes in ventilation at rest.

Comparisons of values obtained before and after Period 1 and Period 2 are only possible on the two subjects (A.C.L. and D.C.) who were tested in all of these circumstances. After Period 1 (bedrest alone) subject A.C.L., an athlete, went back into field track training. In comparing the heart rate values obtained before and after the two periods, it can be observed that after the ambulatory recess

of 14 days, subject A.C.L. recovered his heart rate at rest and partly his heart rate at work and that the program of isometric exercises had no evident effect on the heart rate at rest and at work of this subject.

The same type of analysis with the results obtained on subject D.C. shows that, after the 14-day ambulatory recess, this subject had not recovered the heart rate at rest nor the heart rate at work. In contrast to subject A.C.L., the heart rate at work of subject D.C. after bedrest immobilization with isometric exercise was lower than before bedrest immobilization with isometric exercise.

Subject A.C.L. was in permanent training to keep himself in good physical condition. Subject D.C. was a man with sedentary habits. This difference of interest in their physical condition may explain the "deconditioning" effect of bedrest immobilization on subject A.C.L. and the "training" effect of isometric exercises on subject D.C.

The heart rate recovery times (summarized in Table 10) are difficult to interpret because the recovery time varies with the amount of work performed as well as the final work load reached by the individual. Since both of these quantities varied from one subject to another and in the same subject in the two periods, and we do not have yet normal values and correction factors for final and total work load; our comments here must be necessarily very conservative. The final work loads after bedrest were lower than before bedrest. In those cases where the $T_{0.37}$ was greater after bedrest in spite of the final work load being lower, the interpretation is that there was a prolongation of the recovery time. In those cases in which the final work load was lower and the $T_{0.37}$ was also lower, one cannot draw any conclusion. The results obtained in Period 1 seem to indicate that the recovery time was prolonged in subject A.C.L. The results obtained in Period 2 when the subjects were submitted to bedrest with isometric exercises seem to be the same before and after immobilization, except for subject A.C.L. who had a prolonged $T_{0.37}$ after bedrest immobilization.

CONCLUSION

1. The results obtained in this study seem to indicate that there were no changes in gas exchange, ventilation and mechanical efficiency before and after bedrest in Period 1 (bedrest alone) and Period 2 (bedrest with isometric exercises).
2. The resting heart rate was always higher after bedrest in Period 1 and Period 2.
3. The heart rate at the three different work loads (40, 80, and 120 watts) was higher after bedrest immobilization in both periods.

4. The recovery time after Period 1 (bedrest alone) was probably longer than normal. The recovery times measured before and after bedrest with isometric exercise (Period 2) seemed to be the same for all the subjects except subject A.C.I., but the small number of observations does not warrant any firm statement in this regard.
5. These findings lead to the conclusion that the most prominent effect of bedrest was an increase of the heart rate at rest and an increase of the heart rate during exercise. If this is interpreted as "cardiovascular deconditioning" this "deconditioning" was partially prevented by the isometric exercises.

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