Physiologic Effects of a Hypodynamic Environment: Short-Term Studies

CAPT. DUANE E. GRAVELINE and
CAPT. GEORGE W. BARNARD, USAF (MC)

HAVING EVOLVED in the normal gravitational field of the Earth, man will find that the muscular efforts, consciously or subconsciously needed in normal life, will be markedly reduced in a weightless existence. Muscular tone previously required to maintain, for instance, the erect posture in a 1-G environment will be diminished considerably. Although a certain amount of energy will be expended in manipulating controls and overcoming inertial effects, the energy expenditure will be much less than similar activity under normal gravitational conditions.

The study of Hypodynamics deals with the metabolic and functional responses of the body to this state of relative muscular inactivity, first by assessing qualitatively and quantitatively these responses, then by evaluating various preventive measures designed to protect the body against these debilitating adaptative changes.

The present study involves the use of water immersion to approximate some of the hypodynamic effects of weightlessness. Supported by water, normal weight sensation is altered and movement is relatively effortless. That component of muscular activity previously used to compensate for one gravity is no longer actively utilized. Previous research in this area has evaluated on one subject the effects of similarly induced hypodynamic periods of two and seven days duration.[1] Marked debility was apparent after both time periods upon emersion from the hypodynamic environment and return to a normal gravitational situation. It is now timely and important to try to establish how long this type of environment can be tolerated before significant deconditioning occurs.

In this study, four subjects have been evaluated after six, twelve and twenty-four hours of water immersion induced hypodynamics. Functional studies obtained on these subjects include tilt table and heat chamber tests as well as the responses to headward acceleration. Pertinent psychomotor tests and evaluations of muscle strength also were done.

METHODS

A tank was constructed of such a size as to allow immersion of a subject in a semireclining position. Installation of a form-fitting couch insured a stable position to which the subject, if he so desired, could attach himself using a seat belt. The water temperature was maintained at a constant temperature of 33.5 degrees C. The subject, clad in a rubber suit of conventional SCUBA design and wearing a modified partial pressure type helmet, was completely immersed in the water to a depth of approximately 18 inches. A pressure regulator was installed in the outflow line of the helmet air and was adjusted so that respiration was optimally balanced. With the resultant specific gravity of the subject being very close to one, movements of the trunk and extremities were relatively effortless. Modifications in the suit and helmet permitted *ad lib* liquid intake and continuous urine collection.

Four healthy male subjects were used ranging in age from twenty-three to thirty-three years and in state of physical conditioning from a very well conditioned athlete (Subject 1, mile time was four minutes, thirty-two seconds) to

From the Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio.

a sedentary mildly obese type with slight to no participation in strenuous sports (Subject 4).

Functional studies before and after the six, twelve and twenty-four-hour periods of water immersion included heat tolerance, response to headward acceleration and orthostatic tolerance studies. Heat tolerance was assessed using the heat chamber at 71.1 degrees C., 10 mm. Hg vapor pressure water for one hour or until a critical pulse rate of 150 beats per minute was reached. Measures of orthostatic tolerance were obtained using the tilt table with a 90 degree tilt for twelve minutes. During this time, a standard three-lead electrocardiogram was obtained and blood pressure values were recorded at minute intervals. Psychomotor measures consisted of a stylus-in-hole type of task done under varying degrees of headward acceleration. The accelerative profile during these performance runs began with 1 radial g for one minute, then immediately to 1.5 radial g for one minute, et cetera, up to 3 g. During this time the subject was responding to a randomly administered signal light by inserting a metal stylus into a metal receptacle located on the control panel at arm's length. In this manner both response times at each g level and error signal (contact with sides of the receptacle) were obtained to allow some estimate of arm strength and coordination under dynamic conditions. During all centrifuge runs, continuous electrocardiographic values were obtained. In addition to the performance profile, a blackout run was made on each subject using 0.1 g per second rate of onset and response to center light as the end point.

In order to objectively assess any changes that might occur in the contractile strength of selected muscle groups, a series of seven strength tests were administered during the course of this investigation. The tests were grip strength, hip extension, hip flexion, trunk extension, neck extension, knee extension, and knee flexion. These tests include the main anti-gravity groups of muscles. The S.A.M. (School of Aviation Medicine) Complex Coordinator also was used as an indicator of over-all neuromuscular coordination. Additional studies included complete blood count, hematocrit values, urine volume and urine specific gravity determinations.

The sequence of administration of the various tests upon emersion was as follows: 5 cc. of blood were drawn, followed by the tilt-table test, then by the centrifuge, heat chamber and muscle strength measures and finally by the S.A.M. Complex Coordination test. This sequence remained the same throughout this study.

RESULTS

Cardiovascular System.—The pulse rate responses to tilt-table testing are shown in Figures 1-4. Even following the six-hour run, a considerable increase in pulse rate reflecting altered response to orthostasis is apparent in all four subjects. The tachycardia is progressively more severe following the longer hypodynamic runs and is quite marked after the twenty-four-hour experiments.

The blood pressure responses of the four subjects to tilt-table testing are shown in Figures 5-8. The decreases in pulse pressure secondary to decreases in the systolic level and/or increases in the diastolic level are readily apparent even after the six-hour studies. Following the twenty-four-hour runs, these are quite extreme, with pulse pressures in the range of 2-6 mm. Hg. The standard clinical auscultatory technique of blood pressure determination was used throughout this study. Following the twenty-four-hour run, Subject 1 experienced syncope at the tenth minute of the tilt-table test with a pulse rate of 184 and blood pressure of 98/96.

These pulse rate and blood pressure responses reflect significant alteration in those cardiovascular reflexes necessary for adequate circulation in the erect posture.

Although it is apparent that all subjects show the same general pattern of response, individual differences are noted especially with regard to Subject 3. This individual does not participate in strenuous sports or in programmed exercises but is of a hyperkinetic nature and has what appears to be a physiologic bradycardia reflecting considerable vagotonia. The

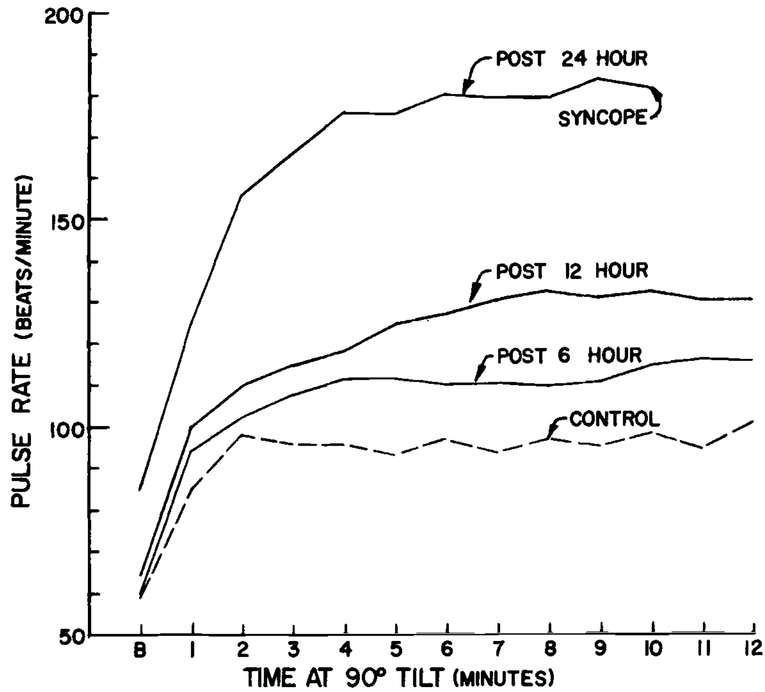

Fig. 1. *Subject 1:* Pulse rate response to tilt table testing. Baseline rate B is obtained while the table is horizontal, before being tilted to 90 degrees.

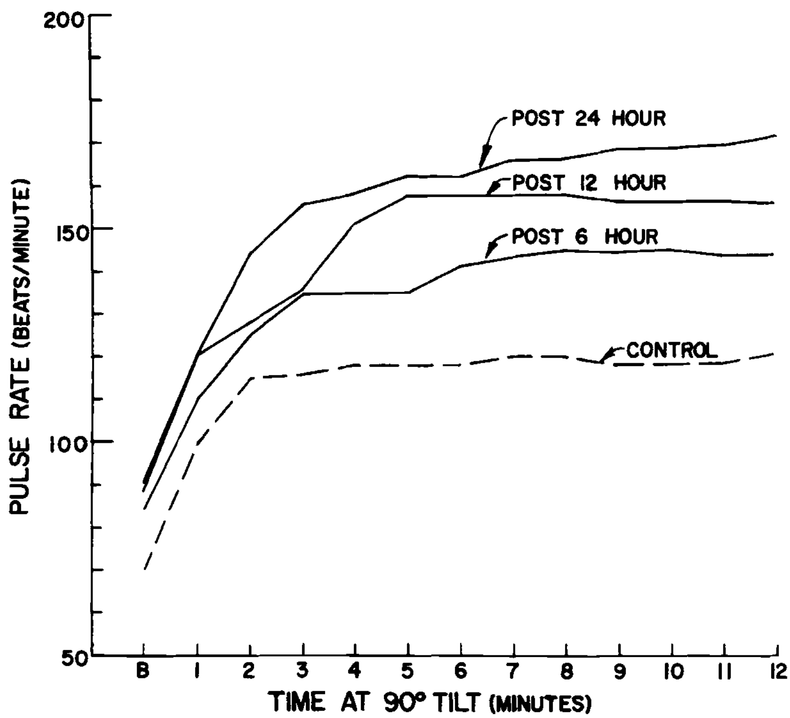

Fig. 2. *Subject 2:* Pulse rate response to tilt table testing. Baseline rate B is obtained while the table is horizontal, before being tilted to 90 degrees.

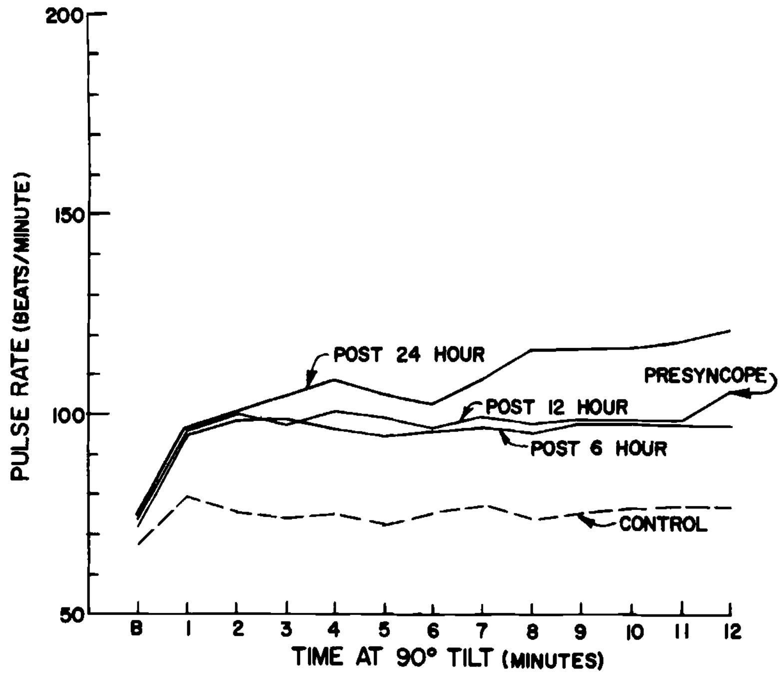

Fig. 3. *Subject 3:* Pulse rate response to tilt table testing. Baseline rate B is obtained while the table is horizontal, before being tilted to 90 degrees.

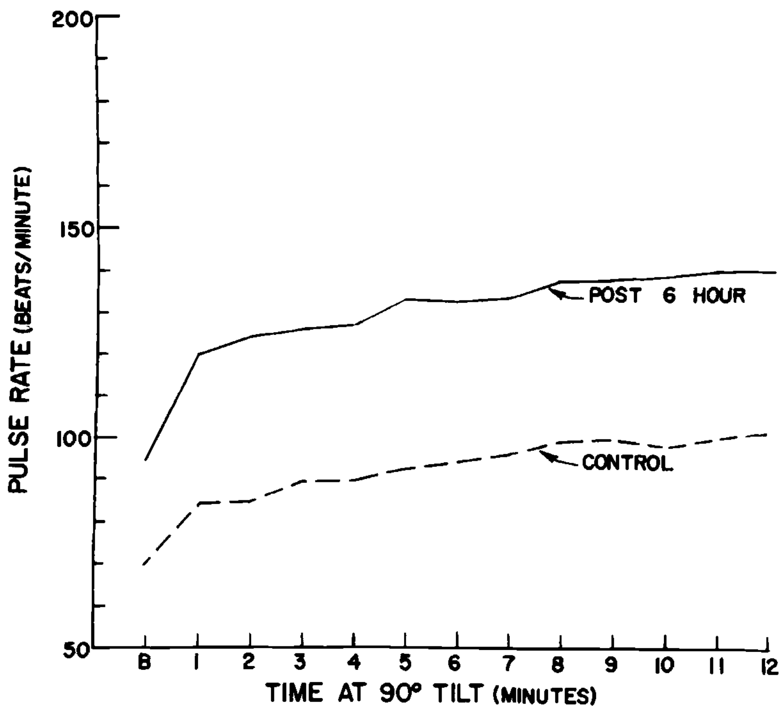

Fig. 4. *Subject 4:* Pulse rate response to tilt table testing. Baseline rate B is obtained while the table is horizontal, before being tilted to 90 degrees.

control cardiovascular stress tests in this subject induced unusually small heart rate increases. Assuming cardiac output is maintained, it must be primarily through increasing stroke volume with less input from heart rate increases than is seen in the other more typical subjects.

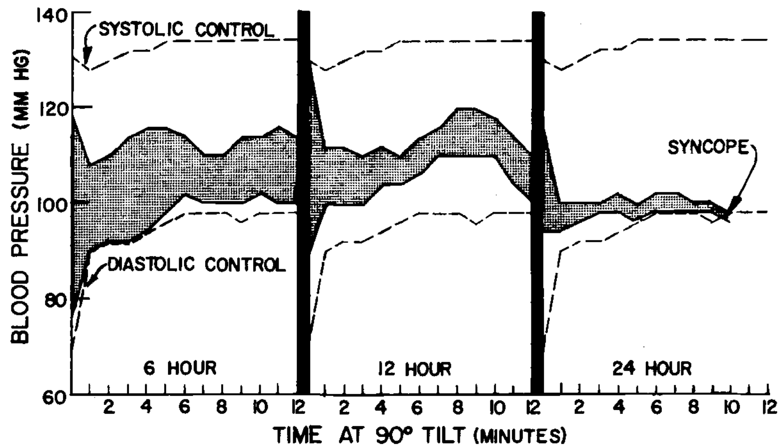

Fig. 5. *Subject 1:* Blood pressure response to tilt table testing demonstrating the decrease from control systolic pressures (top dotted line) and/or increase over control diastolic pressures (bottom dotted line).

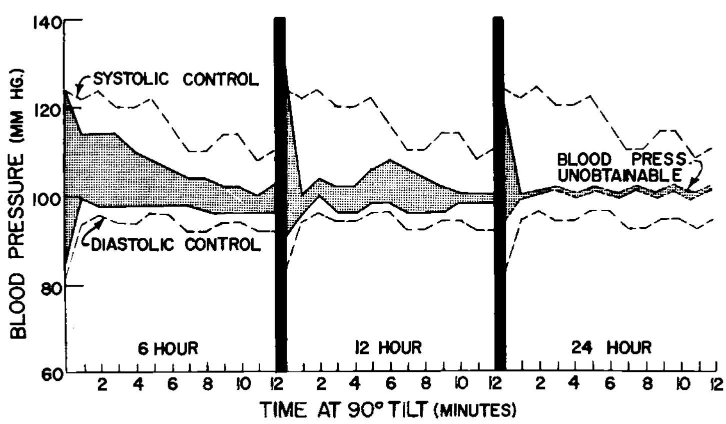

Fig. 6. *Subject 2:* Blood pressure response to tilt table testing demonstrating the decrease from control systolic pressures (top dotted line) and/or increase over control diastolic pressures (bottom dotted line).

The pulse rate responses to heat chamber tests are shown in Figures 9-12. A rate of 150 beats per minute was chosen as the critical cutoff at which point the run would be terminated. Prior to the hypodynamic deconditioning, all subjects found the fifty to sixty-minute control runs readily tolerable with moderate pulse rate increases. Heat intolerance expressed as greater pulse rate responses to the same heat stress was evident in all subjects after the six-hour studies and became progressively more marked with the twelve and twenty-four-hour runs.

Table I records the pulse rate response to headward acceleration. These rates were taken from a modified Lead II ECG which monitors each subject continuously during centrifugation. It is evident that after hypodynamic deconditioning, the pulse rate response to the higher g loads is much greater than control values. This altered response is apparent even after the six-hour studies and reflects decreased capacity for adequate cardiovascular support during accelerative stress.

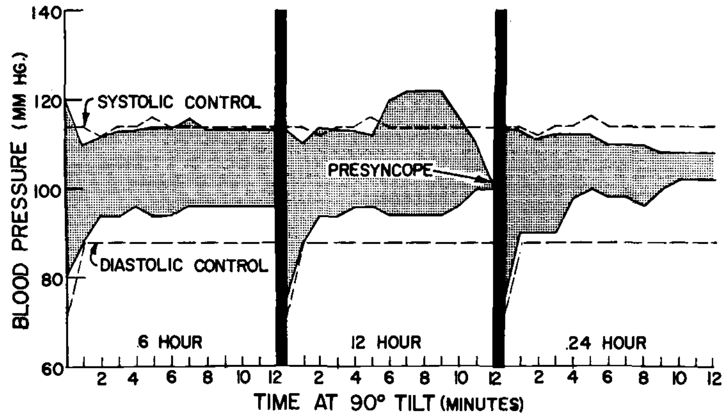

Fig. 7. *Subject 3:* Blood pressure response to tilt table testing demonstrating the decrease from control systolic pressures (top dotted line) and/or increase over control diastolic pressures (bottom dotted line).

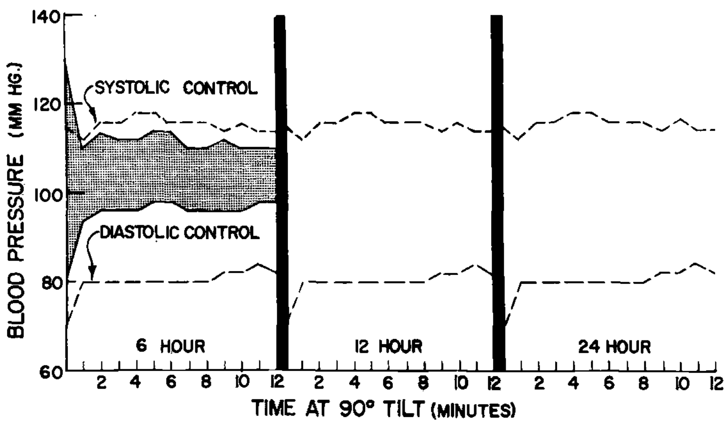

Fig. 8. *Subject 4:* Blood pressure response to tilt table testing demonstrating the decrease from control systolic pressures (top dotted line) and/or increase over control diastolic pressures (bottom dotted line).

The blackout point of each subject during headward acceleration showed no significant change from control run values despite the presence of marked cardiovascular deterioration as evidenced by other more sensitive tests. Apparently blackout point alone is a fairly gross indicator of cardiovascular capability and from the results it may be inferred only that central arterial pressure was maintained. It must be remembered that approximately thirty-five minutes elapsed from emersion until centrifugation actually took place. During this time the subject was undergoing tilt table testing. Recent research into the Hypodynamic area at Johnsville Naval Development Center indicated that immediate centrifugation after similar time periods of water immersion did significantly decrease the blackout point.

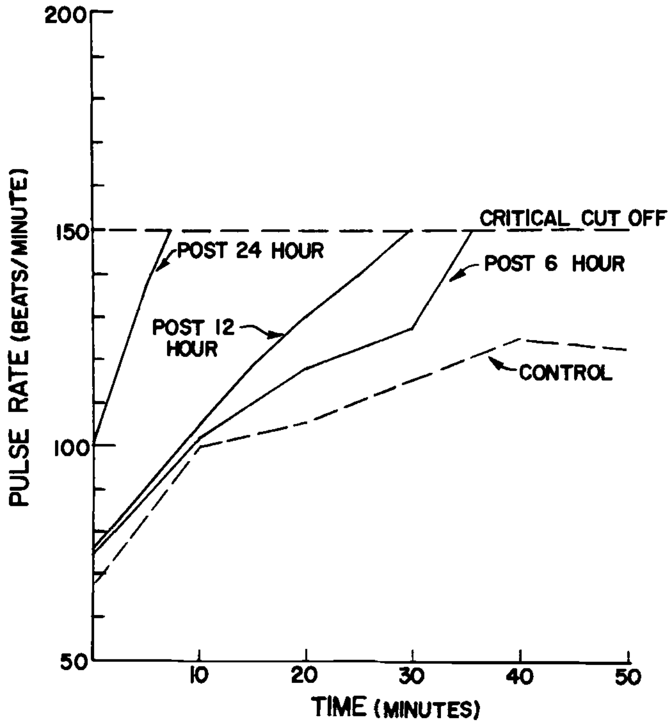

Fig. 9. *Subject 1:* Pulse rate response to heat chamber testing demonstrating the progressively increased rates over control rates (dotted line) for the same heat stress.

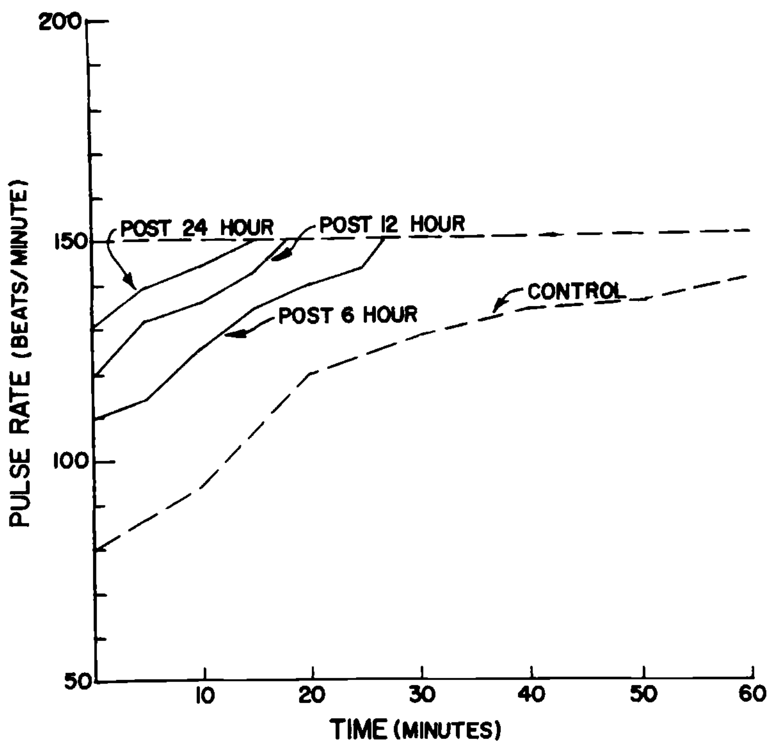

Fig. 10. *Subject 2:* Pulse rate response to heat chamber testing demonstrating the progressively increased rates over control rates (dotted line) for the same heat stress.

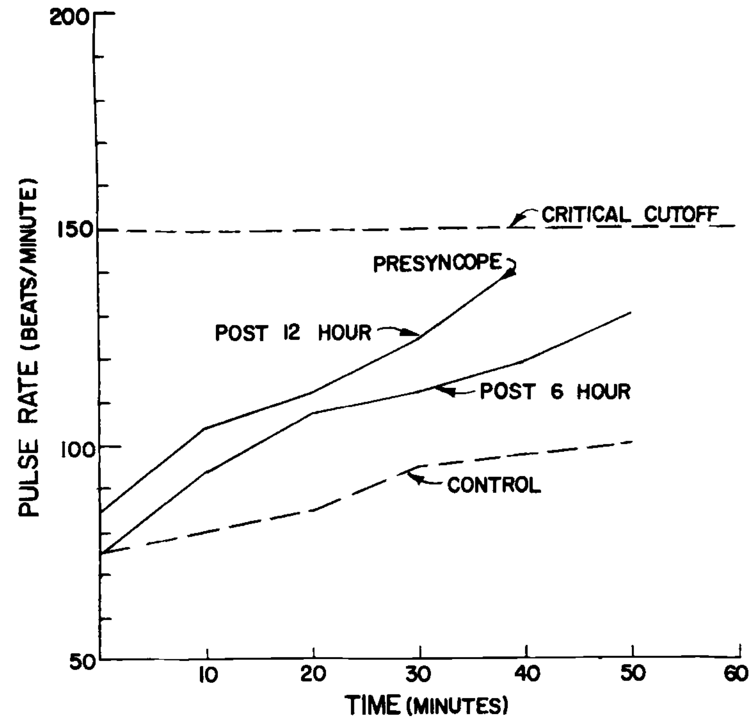

Fig. 11. *Subject 3:* Pulse rate response to heat chamber testing demonstrating the progressively increased rates over control rates (dotted line) for the same heat stress.

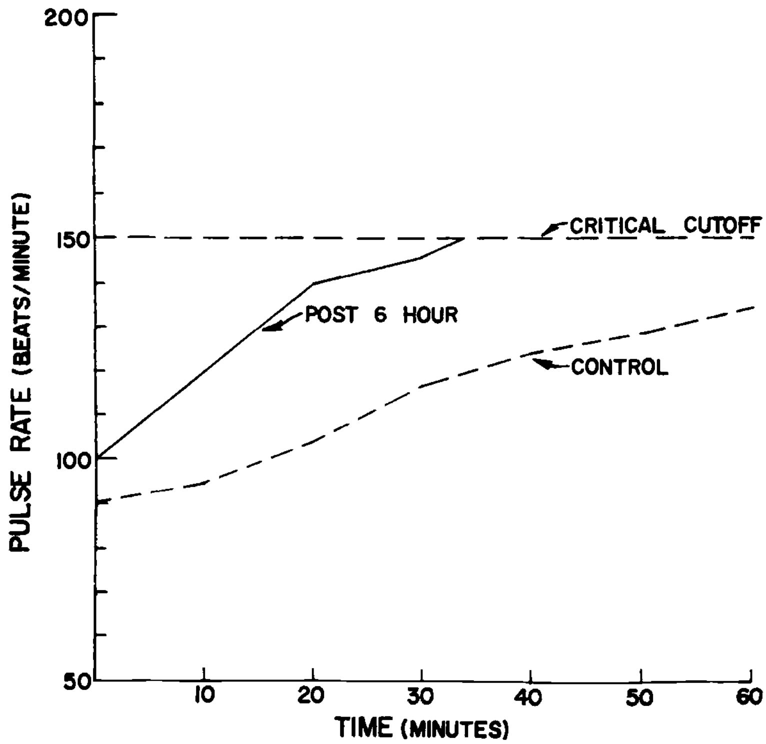

Fig. 12. *Subject 4:* Pulse rate response to heat chamber testing demonstrating the progressively increased rates over control rates (dotted line) for the same heat stress.

The electrocardiographic changes noted on Subjects 2 and 4 upon emersion after just six hours of hypodynamic deconditioning are shown in Figure 13. These were recorded during the twelfth minute of tilt table testing and have been included to demonstrate rather interesting changes which are of a transient nature and of no apparent clinical significance. In addition to orthostatic T wave changes, shifts in the QRS loop with the terminal electrical events directed more toward the right, and accentuation of the P waves which were noted in all subjects, Subjects 2 and 4 demonstrated ST segment depression. Although these are of an obvious junctional nature in some leads, in others (such as lead III) the configuration is that of a plateau type depression which easily could be misinterpreted.

TABLE I. PULSE RATE RESPONSE TO HEADWARD ACCELERATION AFTER THE SIX, TWELVE AND TWENTY-FOUR-HOUR STUDIES

Subject	Constant g Runs					Blackout Runs	
	1 g	1.5 g	2.0 g	2.5 g	3.0 g	2 g	4 g
I control av.	113	87	100	105	105	136	154
post 6 hr.	96	88	108	116	132	104	152
post 12 hr.	112	108	124	144	160	136	168
post 24 hr.	112	112	116	156	164	120	152
II control av.	108	108	117	125	140	136	168
post 6 hr.	-	-	-	-	-	126	150
post 12 hr.	108	116	124	148	176	128	152
post 24 hr.	116	132	148	173	184	128	154
III control av.	96	96	96	106	112	112	137
post 6 hr.	98	112	112	120	152	132	161
post 12 hr.	110	110	112	134	152	121	144
post 24 hr.	-	-	-	-	-	-	-
IV control av.	96	96	96	112	116	120	152
post 6 hr.	111	112	120	134	154	134	158
post 12 hr.	-	-	-	-	-	-	-
post 24 hr.	-	-	-	-	-	-	-

Neuromuscular System. — Although it was hypothesized that no significant changes in muscular strength would be revealed owing to the relatively short periods of decreased muscular activity, slight trends were evident. For both Subject 1 and 2 the results of the strength tests showed a progressive decrease in strength of some of the muscle groups as the duration of the water immersion periods increased; however, these changes were not statistically significant. Significant decrements in muscular ability may be revealed after longer exposures to a hypodynamic state.

The S.A.M. Complex Coordination tester was used to evaluate the over-all neuromuscular coordination of the subjects. It is a light-matching task utilizing a control stick and rudder pedals so that simultaneous use of both upper and lower extremities is required to match the roll, pitch and yaw lights. No evidence of significantly altered general coordination could be demonstrated by this test even after the twenty-four-hour runs. The capability for neuromuscular performance of this type was maintained throughout the time periods used in this study, despite other evidences of general debility.

The more dynamic test of neuromuscular coordination, the "stylus in hole" task designed to evaluate upper extremity strength and coordination under gradually increasing g loads, showed only slight changes from control values. These small increases in response times and all subjects were in the control range. Following the twenty-four-hour runs, the hematocrits of all subjects were increased considerably with Subject 1 rising to 53 and Subject 2, to 55

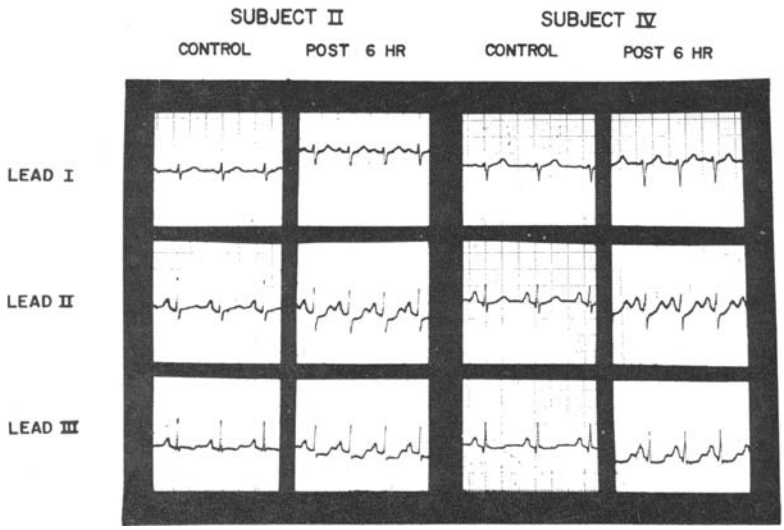

Fig. 13. Electrocardiographic changes recorded during the tenth minute of tilt table testing demonstrating the sinus tachycardia, alteration in the QRS axis, increased amplitude of the P waves, T wave changes and ST segment depression.

error signals noted on the high g loads especially after the twenty-four-hour runs, although apparent in all subjects, were not of a sufficient degree to be significant. In general, the results of this test indicate that minimal, if any, performance decrement for this type of task resulted following the hypodynamic periods used.

Hematologic Findings.—The red blood count and hematocrit showed considerable departure from control values in a response pattern similar for all four subjects. The blood drawn immediately upon emersion from the six-hour runs showed significant decrease in these values. For example, Subject 1 with control hematocrits of 44, 44 and 45 decreased to 37 with parallel red blood cell changes. Subject 2 decreased from a control range of 47, 47 and 48 to 39 with parallel RBC changes. Following the twelve-hour runs, the hematocrits and RBCs of with parallel RBC changes. In general, the blood picture of all subjects was that of an early hemodilution progressing to a terminal hemoconcentration.

Urinary Findings.—All subjects had low specific gravity polyuria during the various water immersion periods; however, pronounced diurnal variation was evident. The experiment was designed so that all runs terminated at 0800 hours so that all functional testing was given at the same time of day. The six-hour runs, therefore, began at 0200 hours; the twelve, at 2000 hours the previous day and the twenty-four hours, at 0800 the previous day. The urine output of all subjects during the nocturnal six-hour runs was quite small, in the range of 300-600 cc. with specific gravities of 1.003-1.007. Yet the outputs of these same subjects during the diurnal six-hour periods were large, in the range of 1000-1400 cc., with specific gravities of 1.001-1.003. This unexpected association with the normal diurnal variation in urine output was consistent for all subjects.

DISCUSSION

The results of this study demonstrate that even relatively short exposures to a hypodynamic environment of this type result in significant deconditioning. Evidence of cardiovascular deterioration readily apparent after the six-hour tests became progressively more severe with longer exposure.

The physiologic adaptive processes leading to the observed deteriorative changes occur early. It would be of interest to evaluate even shorter time periods than the six-hour runs used in this study to determine the earliest point at which these debilitating changes can be demonstrated. After the initial phase, the rate of change slows, becoming more gradual. The cardiovascular changes observed in this study after the twenty-four-hour tests were comparable in degree to those resulting from the seven-day experiment done earlier.[4]

If the obvious inferences of this type of hypodynamic deconditioning can be extended to the zero gravity environment, then man must be adequately protected even in orbital flights of only a few hours' duration. The unprotected astronaut will adapt to the new set of environmental demands and it is man's capacity for such adaptation which will compromise his biodynamic potential for re-entry stresses.

Unusual urinary and hematologic changes occurred. Because respiration was balanced to a very narrow range from optimal to a few millimeters Hg positive pressure, it may be assumed that negative pressure breathing was not a casual factor. That the diuresis is somehow a function of ambient water pressure does not adequately explain the diurnal variation. More study is needed to clarify these areas.

SUMMARY

By a technique involving complete immersion in water, a hypodynamic situation was produced in which normal weight sensations were altered and movement was relatively effortless. Four subjects were evaluated after six, twelve and twenty-four hours of this environment. Tilt table, centrifuge and heat chamber studies demonstrated significant cardiovascular deterioration even after the six-hour runs, becoming progressively more severe with the twelve and twenty-four-hour experiments. Pertinent psychomotor evaluations, anthropometric measures and urine and blood studies also were done. The results of this study indicate that the cardiovascular adaptation to a hypodynamic environment of this type occurs early and the deterioration from even a six-hour exposure is readily apparent.

REFERENCE

1. GRAVELINE, D. E., BALKE, B., MCKENZIE, R. E. and HARTMAN, B.: Psychobiologic effects of water-immersion-induced hypodynamics. *Aerospace Med.*, 32:387, 1961.

Scientific Reports

About 50 per cent of scientific reports available for world distribution appear first in English, according to National Science Foundation. Russian and German publications, both steadily increasing, claim 16 per cent and 12 per cent, respectively, of first publications. Ten per cent of reports are published first in Japanese, less than 5 per cent in French and less than 1 per cent in Chinese.—*AMA News*, June 24, 1961.