Psychobiologic Effects of Water-Immersion-Induced Hypodynamics

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OF THE many biomedical problems that man will encounter in eventual space flight, prolonged weightlessness is the most difficult to evaluate. 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 floating type of existence. That component of muscular tone previously required to maintain, for instance, the erect posture in a one-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 less than during similar activity under normal gravitational conditions. This effect will be apparent whether man remains strapped to a seat during his space journey or is allowed to move freely about the cabin. To move an object or one's self (slowly) across the cabin will require only relatively slight muscular efforts to overcome inertial effects. As a consequence, muscular hypotonicity or even atrophy can be expected to occur. Certain cardiovascular changes may also result due to lack of normal hydrostatic pressure of the blood column as well as due to the lack of normal muscular support. Such changes may demonstrate the adaptability of the human organism to any environmental situation; however, in the case of the astronaut, such adaptations are undesirable in that they may deprive him of the biodynamic potential to survive gravitational reentry stresses.

At the present time, a weightless condition of less than one minute's duration can be obtained by the use of aircraft flying a Keplerian trajectory. For simulation of prolonged zero-gravity other techniques must be employed. Water immersion offers one approach which approximates some of the effects of weightlessness, particularly with respect to the musculoskeletal system. Normal gravitational influences are still present on the body; however, as in the zero-gravity state, there is a marked decrease in the amount of muscular effort required for almost all activities. Man is then in a state of "Hypodynamics." This area of research is new to the field of Space Medicine. The study of hypodynamics deals with the metabolic and functional responses of the body to a 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 adaptive changes.

The physiologic responses to prolonged muscular inactivity have been studied by Taylor, Henschel, Brozek and Keys.[8] These investigators found a marked deterioration in the cardiovascular response to posture changes after a three-to-four week period of bed rest as measured pulse rate and blood pressure changes in tilt-table experiences. The resting pulse rate was higher than it was before and during an exercise test, while the "normal" working pulse rate was surpassed by 40 beats per minute with workload held constant.

Deitrick, Whedon and Shorr[2] extended their studies of four normal, healthy men to include metabolic responses to prolonged muscular inactivity. In addition to cardiovascular deteriora-

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tion, they were able to demonstrate marked increases in nitrogen excretion. The calcium content of the urine was doubled during the fourth and fifth weeks on immobilization. Also noted was increased excretion of phosphorus, sulfur, sodium and potassium. A significant decrease in muscle mass and muscle strength was accompanied by a definite lowering of creatinine tolerance.

In previous studies[1,4] we investigated normal young men before and after two-week periods of absolute bed rest and found remarkable functional deterioration. Compensation of the cardiovascular system to positional changes as measured by the tilt-table was markedly impaired. Treadmill studies showed up to 30 per cent decrease in the respiratory and cardiovascular adaptability to provide a maximum of aerobic oxygen supply during work.

The present study involves the use of water immersion to approximate the hypodynamic effect of weightlessness. Supported by water, normal weight sensation is altered and movement is effortless. A pilot experiment of two day's duration was followed by another experiment extended to a maximum time of tolerance. Medical considerations required termination after seven days of continuous immersion.

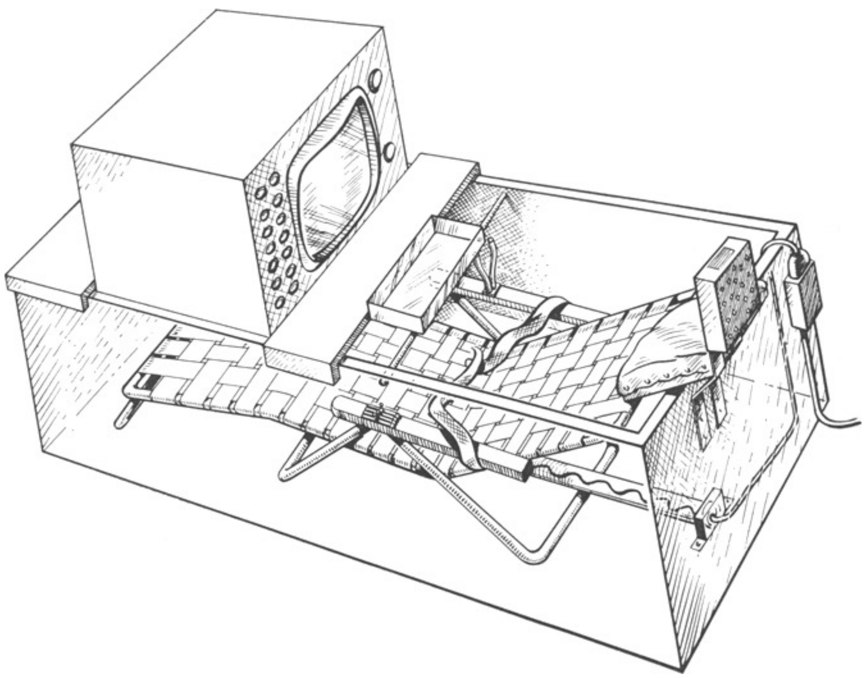

Fig. 1. View of tank and subject's console.

MATERIALS AND METHODS

A tank was constructed of sufficient size to allow immersion of the subject in a semireclining position. A form-fitting couch was installed in the tank to insure a stable position from which the subject could perform various manipulative tasks. The experimental setup is depicted in Figure 1. An automatic heating device maintained the water temperature at 33.5 degrees Centigrade. The subject, clad in a rubber suit of conventional SCUBA design, was immersed in the water up to his neck with his head supported by a padded rest. The remainder of the body was supported by the water in accordance with Archimedes' principle. The resultant specific gravity of the subject was very close to 1.0, and under these conditions movements of the trunk and extremities were effortless.

The subject's diet for a continuous five-week period was Sustagen, a powder containing all the necessary nutritional and caloric requirements. Mixed with water, it is taken in the manner of a milkshake. In addition to being low residue, this type of diet minimized the food preparation and feeding problem. Due to its constant known composition, accurate intake values of the various components of the diet were recorded as a necessary requirement for the metabolic evaluations. These metabolic studies included the determination of urinary and serum calcium, phosphorus, sodium, potassium, chlorides, corticosteroids, urinary catecholamines, total urinary nitrogen, total serum protein, serum protein electrophoretic pattern and serum transaminase. Hematologic data included complete blood count, sedimentation rate and hematocrit. Blood volume was determined by the Evans Blue dye technique. In addition to this type of assessment, there were functional studies before and after the seven-day water immersion. These included tests of orthostatic tolerance on the tilt-table, work capacity on the treadmill, centrifuge profiles and in-flight testing of G-tolerance, and electrocardiographic tracings, blood pressure, pulse rate, ventilatory volumes, metabolic rate, oral temperatures, and electroencephalographic tracings (for monitoring sleep) were obtained at regular intervals.

To evaluate sleep characteristics, two different kinds of EEG data were obtained: (1) standard clinical records for the pre-immersion and post-recovery periods, and (2) records monitoring sleep while immersed. The standard clinical EEG's were conventional runs with natural sleep, hyperventilation and photic stimulation. The pre-immersion record was made on the day before the week in the tank and the control record was made one week after leaving the tank. Conventional arrangements of eight leads on both monopolar and bipolar runs were recorded, using needle electrodes. Records for studying sleep during immersion were obtained in the regular sleep period scheduled from 0400 to 0800 hours each day. Sleep states were measured on a sampling basis, with six fifteen-minute runs spaced out through the four-hour block. This schedule was subject to modification during each sleep period, some recording times being extended when significant changes in sleep could be observed. Only one arrangement of leads was used for the immersion records. It consisted of a bipolar run with eight leads consisting of frontal, central, parietal and temporal, using disc electrodes with bentonite paste.

Changes in psychomotor proficiency were assessed in two ways: (1) three one-hour sessions on complex performance in a simulated systems task, and (2) simpler perceptual-motor tasks performed during immersion. The apparatus used to assess complex performance in a simulated systems task was the Complex Behavior Simulator, a systems simulator developed at the School of Aviation Medicine.[6] This device consists of an assembly of sub-tasks requiring performances ranging from simple functions such as pushing a button when a light flashes to more complex behavior such as decoding multiple signals and integrating them into a single response. Performance on this simulator immediately after the seven-day immersion period and ten days after was compared to baseline values obtained just prior to the hypodynamic period. The apparatus used to assess proficiency changes during immersion contained three separate elements consisting of a binary matching sub-task, a simple vigilance task and a multiple vigilance sub-task. These tasks were operated by microswitches which, in turn, were activated by a combination of four finger-operated slide controls located on the left arm rest and two hand-operated levers located on the right, as seen in Figure 1. During immersion, the subject performed the tasks continuously for two four-hour work periods each day.

Diet and activity were thus controlled, monitored and tested over a five-week period, includ-

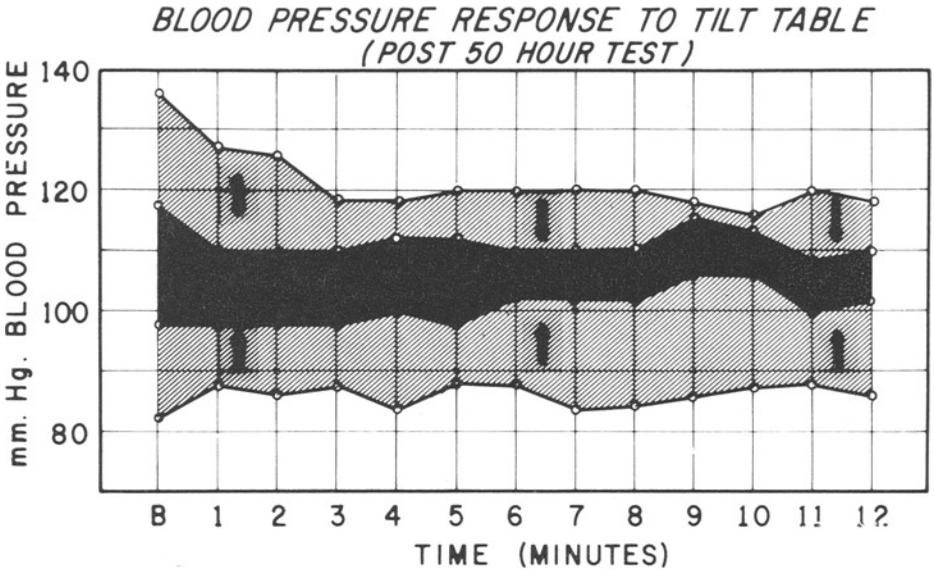

Fig. 2. Blood pressure response to tilt-table testing after the fifty-hour immersion period, demonstrating the decrease from control systolic pressures (top line) and increase over control dystolic pressures (bottom line).

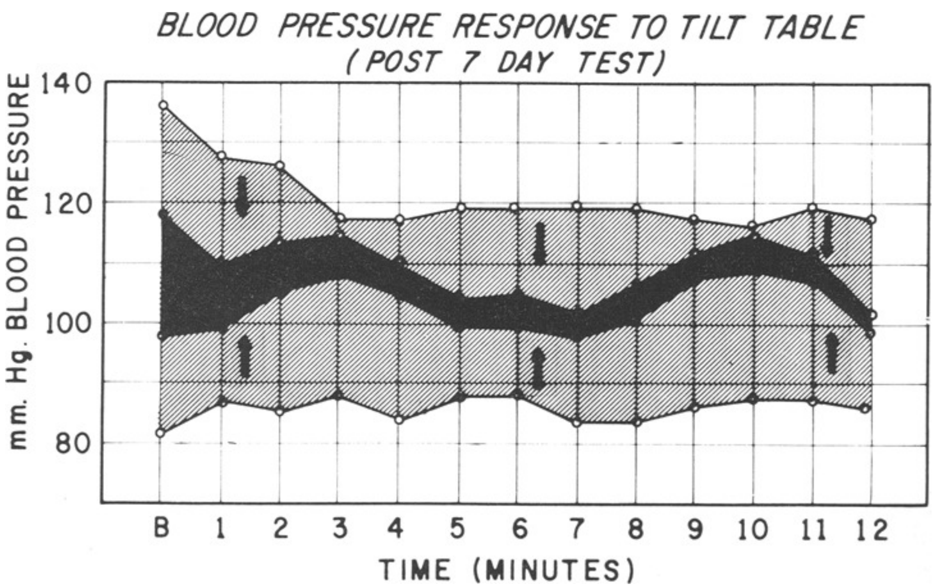

Fig. 3. Blood pressure response to tilt-table testing after the seven-day immersion period, demonstrating the decrease from control systolic pressures (top line) and increase over control dystolic pressures (bottom line).

ing the pilot experiment of fifty hours for equipment checkout and the actual seven-day immersion experiment. During the latter experiment, the subject left the tank only for periods of about thirty minutes each day for the purpose of skin hygiene, defecation, blood drawing, changing underwear and securing ECG electrodes.

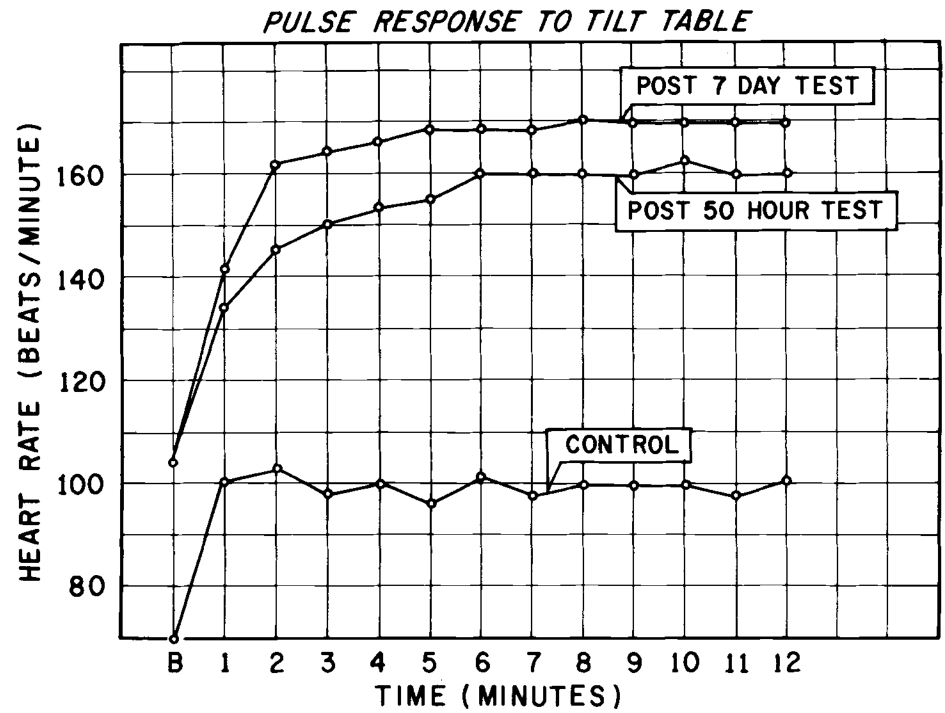

Fig. 4. Heart rate response to tilt table. Baseline rate (B) is obtained while the table is horizontal. The other rates are obtained with the table tilted to 90 degrees.

RESULTS

General observations:—Blood pressure recordings made three times daily revealed that although the pulse pressure stayed relatively constant, a gradual decrease in both systolic and diastolic pressure occurred. The heart rate varied between 68 to 82 beats per minute with no diurnal variations evident. The respiratory rate remained relatively constant at 14 per minute. There were no drastic changes of the metabolic rate related either to diurnal variations or the work-rest periods. During the immersion in the pre-experimental phase, the dietary intake had been in the range of 2,700 calories. The average daily caloric output was determined to be approximately 1,900 calories, accordingly the dietary intake was held at this same level. Oral temperatures ranged from 97 to 98 degrees Fahrenheit. A review of the lead II electrocardiographic tracings which were done twice daily throughout the seven-day hypodynamic experiment showed a gradual decrease in the amplitude of the T-waves. This change was most apparent on the fifth test day at which time a plateauing of the T waves was evident with a slight tendency towards notching. By the sixth and seventh days, however, the T-wave amplitude increased somewhat to approximate the initial levels.

Work capacity:—A comparison of the pre-immersion and post-immersion response to gradually increased exercise indicated a remarkable

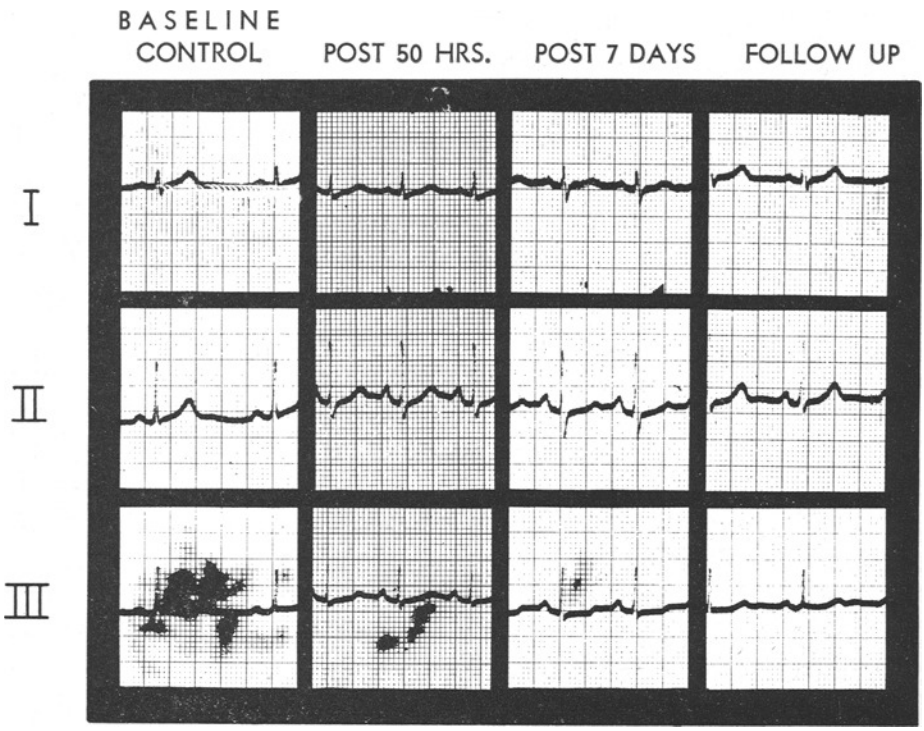

Fig. 5.

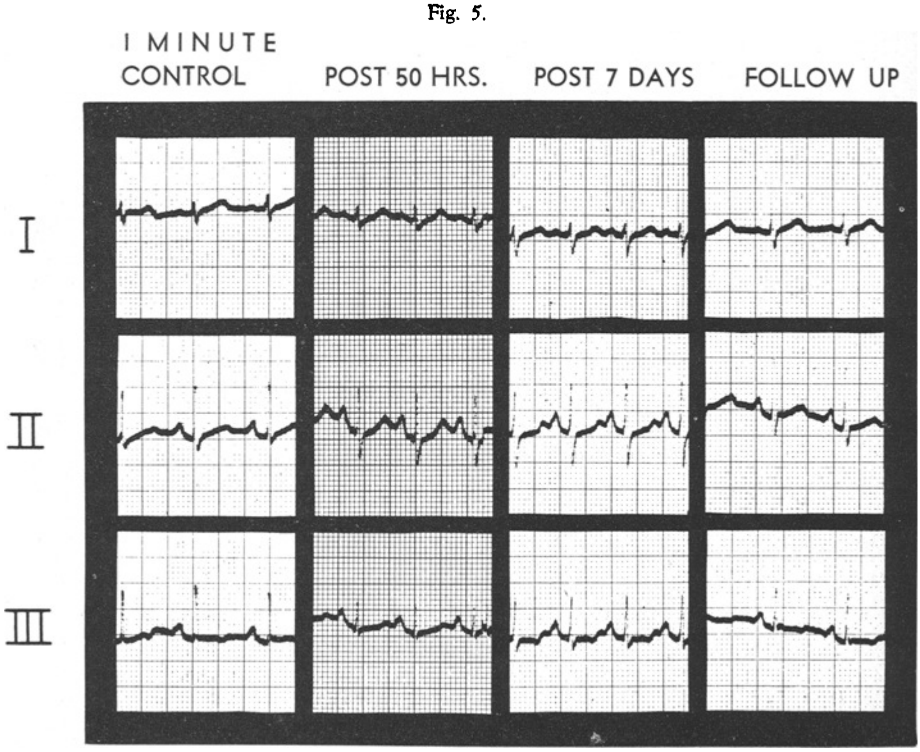

Fig. 6.

Fig. 5 through Fig. 8. ECG leads I, II, and III obtained during the tilt-table testing at baseline (horizontal) and while tilted to 90 degrees at the first, sixth and twelfth minutes. The follow-up

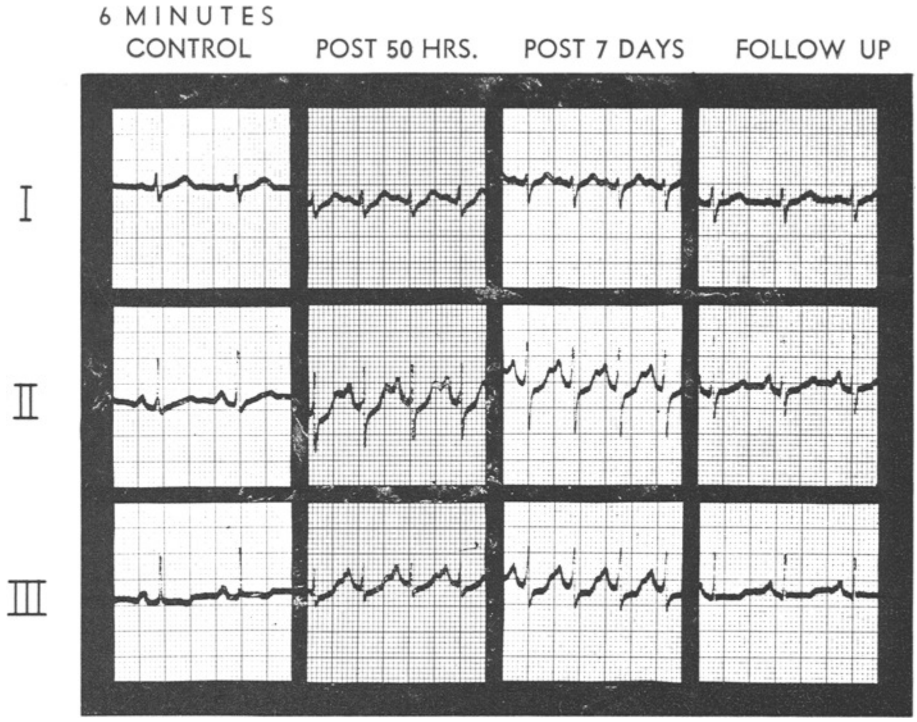

Fig. 7.

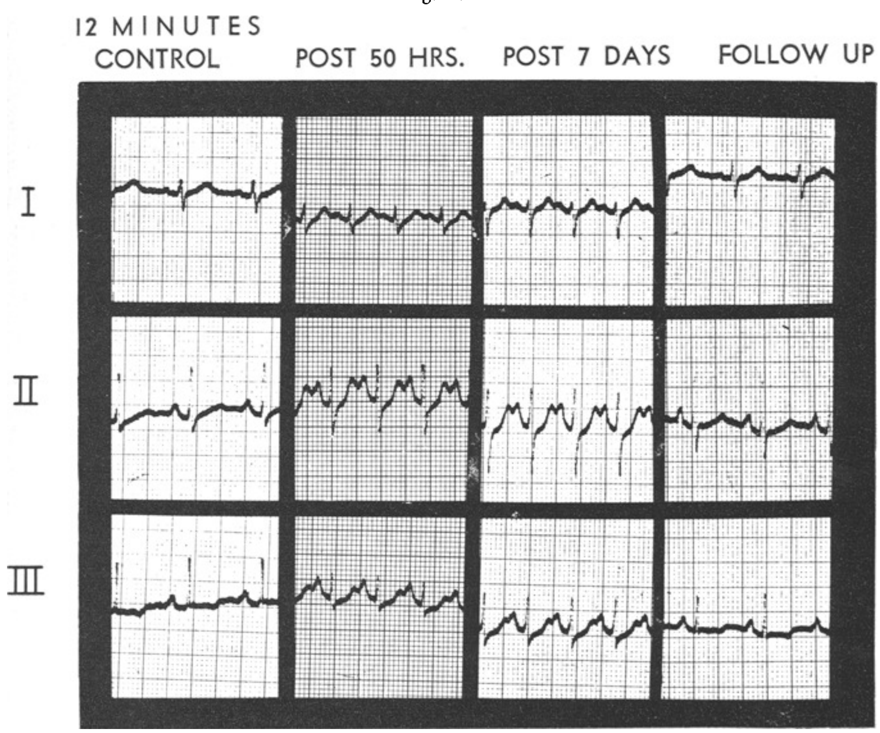

Fig. 8.

test was done ten days after completion of the seven-day hypodynamic period. The heart rate changes, axis shifts and ST, P and T wave changes are well demonstrated.

decrease of functional adaptability. Maximal oxygen intake attained during the control tests on the treadmill was 36.5 ml./kg./min., while after the fifty-hour pilot study, it was 30 ml./kg./min. and only 23.5 ml./kg./min. after the seven-day immersion period. This functional deterioration was revealed by cardiorespiratory patterns typical for physical fatigue: a higher heart rate and reduced pulse pressure at identical work intensities, and by increased frequency and higher minute volumes of ventilation.

Orthostatic tolerance:—Blood pressures during the tilt-table studies after both the fifty-hour and the seventh day are shown in Figures 2 and 3. In both instances a decrease in systolic and an increase in diastolic pressures (resulting in a marked decrease of the pulse pressure) were observed. During the control tests on the tilt-table, pulse pressures remained in the area of 35 mm. Hg throughout a twelve-minute period at 90 degrees; however, after the fifty-hour pilot study, pulse pressures were decreased to 10 to 12 mm. Hg and after seven days of immersion, the pulse pressure amplitudes ranged between 4 to 6 mm. Hg in this same position. No syncope occurred during these tests. Following both the fifty-hour and the seven-day hypodynamic runs, tilting to 90 degrees produced a marked pallor of the skin accompanied by a gradually increasing cyanosis. This was not seen during the control studies.

Pulse rate response to the tilt-table tests is shown in Figure 4. The pulse rate changed (after tilting from a horizontal to a vertical position) from 70 to 100 beats per minute during the control tests, from 104 to 160 beats per minute following the fifty-hour immersion, and from 104 to 170 beats per minute following the seven-day study. Resting pulse rate in the supine position on the tilt-table increased from 70 to 104 beats per minute as a consequence of the hypodynamic state induced during water immersion.

Electrocardiographic response to tilt-table tests are shown in Figures 5 to 8. Standard ECG leads I, II, and III, during supine position and the first, sixth, and twelfth minute with the subject tilted to 90 degrees, showed the following changes:

1. Control ECG showed orthostatic T-wave changes consisting of decreased amplitude, flattening and inversion occurring as a normal variation in a certain percentage of normal healthy people.
2. Following the fifty-hour and the seven-day water immersion experiments, tachycardia, increased amplitude of the P-waves and junctional ST occurred. There were no significant T-wave changes from baseline values. The tendency of the T-waves to decrease in amplitude as noted in the control ECG was no longer apparent. The accentuation of the S-wave reflected a shift of the QRS axis so that the terminal electrical events were directed more toward the right shoulder. The above findings were more prominent following the seven-day test. However, the changes occurring after only fifty hours of immersion were also quite dramatic.
3. Follow-up ECG studies showed a return to normal after ten days.

G-Tolerance:—The elapsed time between removal from the water tank and the G-tolerance tests was eleven hours. This time delay was caused by the post-immersion tests and by the subsequent transportation in jet aircraft to the centrifuge test facilities. G-tolerance to both rapid onset of rotation (ROR) and gradual onset of rotation (GOR) were obtained.[3]

Heart rate responses obtained during the centrifuge runs indicated greater cardiovascular stress post-test, however, the G-tolerance as measured by blackout threshold alone was unchanged. Presumably this indicated that mean arterial pressure and sufficient supply of blood to the brain and eyes were still maintained. Subjectively, after the seven-day hypodynamic experiment, G stresses were much more severe, producing greater sensations of pressure, much more discomfort and incapacity, and marked nausea.

Hematologic Findings:—The results of the hematologic evaluations before, during and after the seven-day experiment are presented in Table I. Sedimentation rates and white blood cell differentials also were done. These showed no significant changes from control values. As can be seen from the table, the WBC values increased steadily during the test to more than double the control level. The hematocrit showed a maximum increase in the third day to a value of 57. This was confirmed by two repeat tests. At this time, scleral injection and a dusky red color of the face gave clinical evidence of a plethoric condition. Generalized pruritus was also maximal at this time. However, by the beginning of the fourth day this condition diminished markedly. Pruritus became less tense, and the face and sclera assumed a more natural appearance. The hematocrit at this time was 49. Changes in the red blood cell count paralleled the changes in the hematocrit.

Biochemical Findings:—Total daily urinary nitrogen excretion before and during the hypodynamic seven-day period were determined by the Micro-Kjeldahl technique and are shown in Figure 9. The marked elevation in urinary nitrogen excretion on the first three immersion days corresponded closely to the polyuria noted during this same time. (See Figure 10 for twenty-four-hour urine volumes). Approximately 45 gm. of nitrogen were eliminated during this seventy-two-hour period. During the entire seven days, a total of 66 gm. of nitrogen were eliminated. Control values averaged at 2.3 gm. daily.

TABLE I. HEMATOLOGIC STUDIES

	RBC	WBC	HCT
CONTROL I	5,390,000	7,250	47
CONTROL II	5,220,000	6,850	44
CONTROL III	5,510,000	6,900	48
DAY 2	5,660,000	9,100	49
DAY 3	6,090,000	9,200	57(56,57)
DAY 4	—	10,550	49
DAY 5	5,220,000	11,200	49
DAY 7	—	15,650	53
FOLLOWUP	—	8,250	44

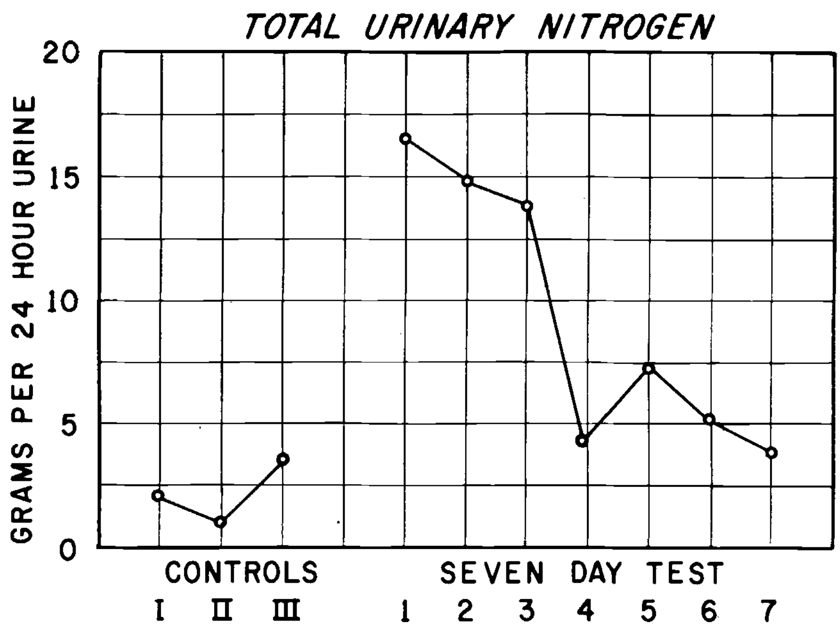

Fig. 9. Total urinary nitrogen excretion during the seven-day hypodynamic period are compared to the control values, demonstrating the marked nitrogen output during the first three days.

Urine volumes for each twenty-four-hour period are shown in Figure 10. Starting about four hours after entering the tank for the seven-day run, there was marked polyuria accompanied by a demanding polydipsia. This persisted for about seventy-two hours and then decreased abruptly. During this phase of water loss the mucous membranes, lips and throat were dry. The clinical evidence of plethora and the increased hematocrit during this time period have already been mentioned.

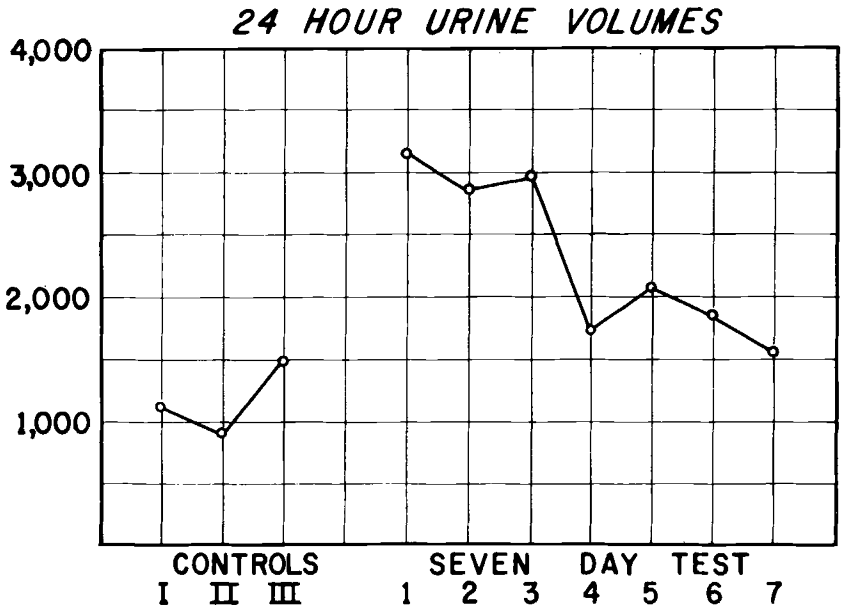

Fig. 10. Twenty-four hour urine volumes, demonstrating the polyuria which was most marked during the initial three days.

TABLE II. BIOCHEMICAL ANALYSIS OF SERUM SAMPLES

	meq/l				mg %		
	Na	K	Ca	Cl	UREA	GLUCOSE	PO_4
CONTROL (AVERAGE OF THREE VALUES)	141.4	3.7	5.3	102.3	18.6	70	3.1
DAY 1	142.0	4.1	5.5	101.6	18.0	70.8	3.5
DAY 2	141.6	3.9	5.5	102.1	20.0	69.8	4.8
DAY 3	142.6	4.1	5.5	102.8	20.6	63.0	4.6
DAY 5	143.2	3.7	5.4	105.2	20.4	58.0	5.7
DAY 7	142.2	3.5	5.5	101.1	19.5	60.0	4.0

Urinary catecholamine studies indicated that epinephrine values, expressed in gamma per hour, showed an initial elevation, then a gradual decline to control level. Norepinephrine values, also expressed in gamma per hour, showed a rather marked elevation on the second day, and then also a gradual return to control level.

Plasma-free 17-hydroxycorticosteroid studies indicate that throughout the seven-day immersion period, the values were consistently elevated over the control values, while urine total 17 OH corticosteroid determinations showed no significant changes from baseline levels and apparently did not parallel the serum values.

The results of serum determinations of Na, K, Cl, Ca, PO_4, urea and glucose are presented in Table II. In each case, three control determinations have been averaged to obtain a baseline value. With the exception of PO_4, the various biochemical constituents remained remarkably constant throughout the seven-day water immersion test. The PO_4 values increased considerably from a control value of 3.0 mg. per cent to a maximum value of 5.7 mg. per cent on the fifth day.

The results of the urinary determinations of

Na, K, Ca, Cl and PO_4 were expressed as meg./24 hours and are presented in Table III. The dietary composition throughout the entire four-week control period and during the seven-day test period was constant; however, the actual quantity of the diet was 2,700 Calories daily during the former and 1,900 Calories daily during the latter period. Despite a 30 per cent decrease in intake, urinary output of Ca and PO_4 showed no significant departure from control figures. This could be interpreted as an indication that liberation of available Ca salts from skeletal sources was occurring due to disuse changes, thus contributing to the total urine output. However, the metabolism of these substances is extremely complex and further investigation is necessary before definitive interpretations can be made. Na and Cl were very similar in their changes during the test period. They showed a rather marked initial outpouring followed by a decrease to below control values on the fourth day and a terminal elevation to control values or greater.

SGO-T determinations throughout the test period showed no significant variation from control values.

Immunochemical Analysis of Serum Samples:—Samples were analyzed for total protein, increases or decreases in a reliable nonspecific stress indicator associated with mucoprotein, and changes in the concentrations of albumin, gamma globulin, beta globulin, and alpha glycoproteins. A combination of immunodiffusion and paper electrophoretic methods was used. Statistically significant results at 0.05 level were as follows:

1. A progressive increase in total protein (base 7.11) to a high of 7.82 gm. per cent at seven days.
2. A marked increase in the concentration of serum albumin beginning at twenty-four hours through forty-eight hours, decreasing sharply to base-line at the seventy-two-hour level.
3. A marked increase in gamma globulin concentration beginning at forty-eight hours through seventy-two hours, then returning precipitously to the normal range for the remainder of the samples.
4. A decrease in the A/G ratio at forty-eight hours to 1.64 from a base-line of 2.18.

TABLE III. BIOCHEMICAL ANALYSIS OF URINE SAMPLES

	(meq/24hrs) Na	K	Ca	Cl	PO_4
CONTROL (AVERAGE OF THREE VALUES)	251.7	81.1	10.8	74.9	49.2
DAY 1	549.5	83.1	11.8	137.1	35.1
DAY 2	345.0	79.4	7.8	77.6	45.1
DAY 3	221.6	103.6	12.9	55.1	61.7
DAY 4	175.7	80.6	7.5	39.2	51.1
DAY 5	131.1	70.6	8.7	43.6	42.3
DAY 6	192.3	74.3	10.4	50.1	45.4
DAY 7	307.5	40.7	10.9	66.7	39.3

Several calibrated reagents were used without success in an attempt to detect concentration increases in a substance associated with mucoprotein. Such increases have been reliable indicators of other aerospace stresses, such as irradiation, long-term altitude chamber exposure and serological imbalances. The results were not so extreme as to suggest harmful experimental conditions, and indicated that the experimental conditions for this subject were not markedly stressing.

X-Ray Studies:—Radiographic studies which were done include PA of the carpals and PA and lateral of the tarsals for evidence of bony demineralization. These films were taken before, immediately after, and one week after the seven-day period of water immersion. In reviewing these films, significant bony change could not be demonstrated.

Psychomotor Performance:—There was a significant decrement in performance proficiency related to the hypodynamic state. These findings are covered in detail in another paper.[5] Briefly, an analysis of the response times of performance during immersion revealed a significant but small increase on each successive day, indicating a gradual decrease in psychomotor effectiveness. Observations of the subject's performance on the Complex Systems

Simulator immediately after the seven-day hypodynamic period demonstrated gross disruption of psychomotor effectiveness. During the first forty-five minutes after coming out of the tank, the subject was obviously almost nonfunctional. Initially, the subject's performance was characterized by marked disorganization of the psychomotor response pattern with each response clearly fractionated into three segments: detection of the signal, selection of the response, and execution. Detection was accompanied by an exaggerated startle response to signals having high attention value and execution was characterized by gross spatial errors.

Sleep Studies:—Sleep in the hypodynamic environment was monitored by means of electroencephalographic recordings and evaluated with pre- and post-immersion control recordings. This part of the study is reported elsewhere.[7] An analysis of these EEG records reveals several important findings. First, the total amount of actual sleep each day was considerably less than the allotted four hours. In general, after the second day the subject slept very little during the fourth hour. Second, the range of sleep states became progressively smaller on each successive day. Third, the amount of variability in relative depth or quality of the sleep state showed a progressive reduction across days, with improved stability in sleep states during the middle portion of the sleep periods during the latter days. There was a progressive adjustment of sleep to the hypodynamic environment during the week, and the most characteristic sleep state during the latter period was one falling between drowsiness and light sleep. On the average, it appears that the subject spent on the order of 120 to 130 minutes in some sort of sleep state each day. Most of the sleep during this period was of a very light to dozing nature from which the subject could be easily aroused. Only rarely did deep sleep occur similar to the control and follow-up sleep records. Yet all evidence indicated that the amount of sleep obtained was entirely adequate under these hypodynamic conditions. The subject remained normally alert at all times during the seven-day experiment and presented no indication that a sleep deficit was accumulating. Following the experiment, the subject immediately went back to his normal sleep pattern of seven to eight hours daily.

DISCUSSION

The results of this study provide evidence that the debilitating effects of a prolonged hypodynamic state are extraordinary, especially with respect to the cardiovascular system. The experiment was essentially an extension of previous bed-rest studies except that the hypodynamic state induced by water immersion was more severe and produced earlier and greater debilitating changes. There is every reason to anticipate that a true weightless condition may produce similar or even more pronounced effects.

Concerning the experimental design, there are obvious sources of bias which must be taken into consideration in the interpretation of the results, aside from its exploratory nature. Allowance must be given to the possible influences of the water pressure on the immersed body of the subject, and to the alteration of normal thermoregulatory dynamics by the elimination of evaporative cooling.

It should be stressed that while the subject was immersed, few of the debilitating effects were apparent. Blood pressure, pulse rate, temperature, and respiration showed no significant departures from normal values. It was only upon removal from the support of the water, and return to a normal gravitational sensation that muscular tone and strength were seriously affected.

A marked deterioration in the mechanisms necessary for adequate circulation in the erect posture was shown by tilt-table testing. A great reduction of the work capacity measured on the treadmill reflects a pronounced decrease in cardiorespiratory adaptability. Centrifuge determination of G-tolerance following the hypodynamic state similarly revealed much greater cardiovascular stress.

In addition to these debilitating changes of a functional nature, interesting metabolic changes occurred. At the present, no definite explanation can be given for the progressive increase in white blood cell count, the rather large increases in total urinary nitrogen, the elevation in hematocrit, or for the immunochemical responses. More experimental work is necessary to substantiate and clarify these results.

Although the psychomotor performance showed a slight, but significant, progressive decrease during the seven-day water immersion, this might only reflect altered states of motivation. There was little reason to expect a major performance decrement during the hypodynamic state, where the over-all functional effectiveness of the subject exhibited so few changes. The real proficiency problem for a man in space flight lies in the gross debility which may result from prolonged hypodynamic conditions. The essential finding of this study was the generalized incapacitation of man upon return to normal 1 G sensation. The sudden impact of returning gravitational forces not only affected physical fitness but also psychomotor effectiveness for a complex systems task. Such reaction to increased G-forces after a longer period of weightlessness might become crucial for the astronaut as he experiences the re-entry phase.

The information obtained concerning sleep was completely unexpected. Evidence indicates that the reduced amount of sleep appeared entirely adequate for the existing conditions. The broader implications of these results may have major theoretic importance. They suggest a specific biologic purpose for sleep. How can we account for the fact that the subject, on less than a third of the normal amount of sleep (and most of it drowsiness or light sleep), gave every indication of having had all the sleep he needed? His sleep during immersion represents a marked deviation from his normal sleep habits, yet there were no observable or subjective signs of sleep deprivation.

Under normal gravitational conditions, a significant portion of the total amount of energy expended each day is for work done while compensating for gravitational influences. This involves more or less continuous neuromuscular activity which stops only when we stop counteracting gravity in a relative way, as, for example, when we go to bed. It can be postulated that this involves some progressive accumulation of fatigue—some neuromuscular "debt."

In the hypodynamic state, during immersion, there is no need to counteract G-forces. Nor will it be present in the weightless state. Therefore, the magnitude of the neuromuscular "debt" will be greatly reduced, and the duration of the recovery period required will be reduced. In effect then, the duration of sleep needed to maintain normal efficiency will be reduced. The results of this aspect of the study lead to the premise that the biological function of sleep is to provide a period with minimal requirements for counteracting gravity so that recovery from the neuromuscular "debt" accumulating in the active man can take place. Now, sleep is obviously more complicated than this hypothesis suggests, and our hypothesis deals only with the biological purpose, but it would appear that this may be the bedrock of the function of sleep.

If further investigation into this hypodynamic area corroborates these findings concerning sleep, it may mean that the sleep demands of the orbiting astronaut will be significantly reduced. Information of this nature is essential for space operations.

SUMMARY

Utilizing a technique involving whole-body immersion in water, a hypodynamic environment was produced in which the normal weight sensations were removed and movement was effortless. This experiment was conducted with one subject for a seven-day period during which time extensive biologic data were collected.

There are definite indications that pronounced functional impairment results from prolonged exposure to hypodynamic conditions. There is

a marked decrease in the need for sleep, and sleep characteristics observed in this quasi-weightless environment permit us to hypothesize a specific biological function for sleep, suggesting that it provides a period of recovery from the neuromuscular "debt" accumulated by man in counteracting the effects of gravity. Following the period of immersion, marked changes of cardiovascular reflexes and diminished muscular tone were apparent. Hematologic investigations and extensive biochemical studies on blood and urine show some interesting changes, and there is a gross disruption of psychomotor effectiveness. In general, this study suggests that during prolonged space flight under true weightless conditions the organism may attain a critical state of deconditioning which will seriously attenuate his tolerance for re-entry stresses and the normal gravitational environment. Investigation into this area must continue in an effort to further assess these effects, and then to develop appropriate protective devices or techniques.

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Kinsey's Heritage

After a few uncertain years following the death of Dr. Alfred C. Kinsey in 1956, the Institute for Sex Research at Indiana University in Bloomington is in the midst of vigorous activity. Nate Haseltine, *Washington Post* and *Times-Herald* science writer, recently visited the Institute and reports that the staff is engaged in an intensive study of some 600 convicted sex offenders. A book on pregnancy, birth, and abortion has been published. The Institute's collection of material continues to expand and includes 23,000 books, between 30,000 and 40,000 art prints, 18,000 case histories, and films on mammalian sexual behavior as well as lewd movies produced during the past generation. To the University's maintenance support, the National Institute of Mental Health has added $350,000 in grants since 1957.—*Modern Medicine*, March, 1961.