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Symptoms Resulting from Prolonged Immersion In Water: The Problem of Zero G Asthenia

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IT IS GENERALLY agreed that, prior to actual experience, less will be known concerning the effects of prolonged exposure to zero G* than about the effects of any other stress man is likely to encounter in space flight. We do know some of the effects of very short exposure. However, certain of these findings must be accepted with reservation because of the complications introduced by the experimental procedures used.[1,6,25,26] Animals have been exposed to zero G for prolonged periods of time, up to ten days in the case of the Russian dog Laika.[18] In general, the findings suggest that this state was tolerated very well, but the data obtained were necessarily few, and most animals were not recovered. Moreover, the extrapolation of the findings to man are severely limited.[4,7,10,13,24]

Water immersion has been used to simulate zero G, and reliable observers state that the feeling of "floating" under the two conditions is similar. The simulation derives from the fact that the relative densities of the human body and water are nearly the same, which almost abolishes the "contact forces" and the internal deformations due to them. Thus, if the subject is passive, many sensory receptors which normally are strongly stimulated are now weakly stimulated although if the subject moves, inertial forces are generated due to the resistance of the water. During immersion the body is still acted upon by "field forces" due to the relative densities of different parts of the body. The simulation is therefore not only partial but is also complicated by the fact that the body is surrounded by water rather than by air. On the other hand, the necessary confinement during immersion simulates, to a degree, the confinement in small vehicles aloft.

Water immersion has been used as part of the experimental procedure in widely different studies some of which, by design or not, have application to space travel.[2,8,11] These include studies dealing with spatial orientation, particularly with reference to the role of the otolith apparatus.[15,17,19] Water immersion has been used in studies of sensory deprivation. Lilly[20] has emphasized the high level of relaxation during immersion under favorable conditions and the equivalence of this relaxation to sleep.

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Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the views or the endorsement of the Navy Department.

*This could be due, theoretically, to the absence of the acceleration of gravity, or, practically, to the circumstance in which either the acceleration of gravity does not produce a force as in free fall in a vacuum, or when the acceleration of gravity is exactly counterbalanced by an inertial acceleration.

Graveline's experiment[28] represents the most clear-cut attempt to extrapolate the observations during submersion to weightlessness in space flight. Graveline remained under water most of the time for seven days in a small tank containing 400 gallons of warm water. The most remarkable subjective symptoms were sleeplessness and weakness. Objectively, the muscles became softer and smaller, and certain metabolic alterations were reported.

The primary purpose of the present investigation was to study the effects of reduced muscular activity under conditions simulating to a degree the subgravity or zero G state. This was done with the full realization of the limited character of the simulation and the great care necessary in applying the findings to man in space flight.

PROCEDURE

Subjects and Method.—The subjects used in this experiment were four naval enlisted men assigned to the U. S. Naval School of Aviation Medicine with a primary duty of acting as subjects in research projects. They had participated in various experiments in progress during their assignment to the School and for this they received hazardous duty pay. Each man had a complete physical examination before the present experiment began. Three of the four subjects completed the experiment, but the fourth had to be taken off the schedule because he had an ear infection which failed to respond satisfactorily to treatment.

The experiment began with a series of preliminary tests for each pair of subjects. They then entered the U. S. Naval Hospital, Pensacola, at which place the experimental room was located. The next morning they were given the final preliminary series of tests immediately after which they were placed on a daily schedule, as follows:

6:00 A.M.- 6:15 A.M.	Subjects awakened
6:15 A.M.- 7:00 A.M.	Toilet, breakfast, et cetera
7:00 A.M.-11:00 A.M.	In tank
11:00 A.M.-12:30 P.M.	In bed, lunch
12:30 P.M.- 3:30 P.M.	In tank
3:30 P.M.- 5:30 P.M.	Daily tests in bed (Subjects B and C), supper, reading
5:30 P.M.- 8:30 P.M.	In tank
8:30 P.M.-10:30 P.M.	In bed, television, reading

This schedule maintained the subjects in the tanks for a ten-hour period each day. The remainder of the time they were in bed except for brief intervals to go to the toilet, to get in and out of the tanks, and to take the scheduled tests. Two subjects (B and C) were given certain tests during the two-week experimental schedule. The third subject (R) was tested only before and after the two-week period; this change was made to minimize further the amount of muscular activity.

The subjects were not permitted to walk and were moved in a wheel chair from the tanks to bed and to the toilet. They were assisted from the tanks and dried by a hospital corpsman. Regular hospital meals were served to them in bed. Any type of muscular activity was discouraged except that required for getting out of the tanks or into bed, for eating, smoking, eliminative functions, and for the daily tests. Visitors were permitted during regular hospital visiting hours, and radio and television were available throughout their waking hours. Every attempt was made to avoid the effects of sensory deprivation and the associated stresses which have been reported recently.[14,20] At least one person was with the subjects at all hours. During the daytime, three to four persons were available to feed the subjects, attend to their wants, and assist with the tests as necessary. During the night, a corpsman and a flight surgeon were with them. A detailed log of the activities of the subjects was maintained throughout the testing period.

The chief objective of the experimental procedure was to reduce contact forces for the longest period feasible, and the chief problem was to keep the subject comfortable and contented. The two tanks used to immerse the subjects were essentially half cylinders, 110 inches by 58 inches (Fig. 1). This made it possible to have a fluid depth of 31 inches with approximately 742 gallons of physiological saline solution. A net was strung in the tank 18 inches from the bottom to about 3 feet from the head end. At this point it sloped upward

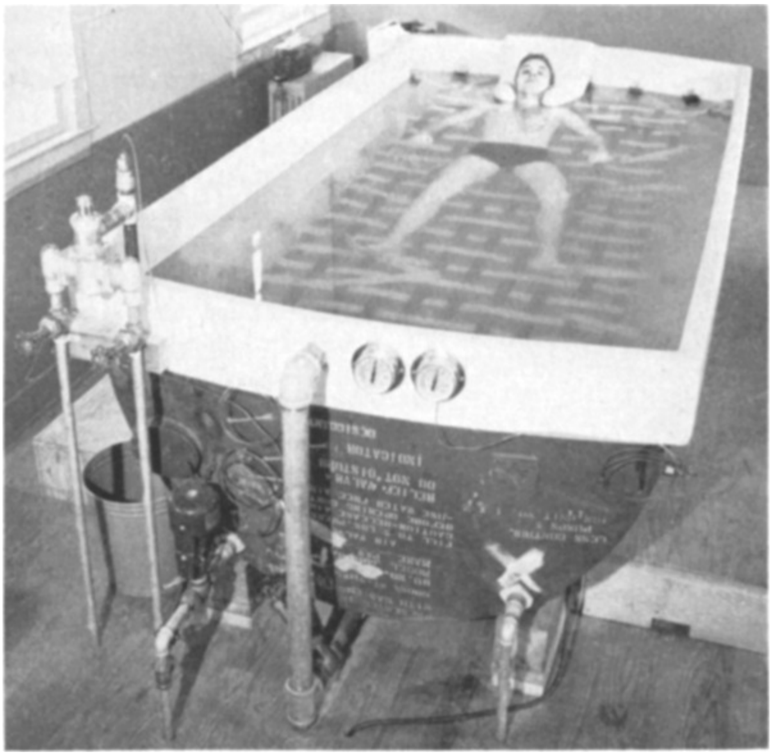

Fig. 1. Subject immersed in tank.

1 foot to provide slight support for the subject's head and shoulders. The net was made of 1¾-inch webbing placed 3 inches apart in both directions. This allowed 12 to 15 inches in which to float the subject below the level of the overflow drain pipe. The head and neck of the subject were supported on a sponge rubber pillow encased in a plastic case. This was found to be very flexible and comfortable since it was possible for the subject's head and neck to mold into the pillow and be supported by the buoyancy of the sponge rubber. The net effect was for the subject's feet, buttocks, and shoulders to touch the net lightly and for his head, including the ears, to be clear of the water.

There were two temperature controls to maintain the water at the proper temperature. The first of these was a water mixing valve** which controlled the temperature of the water as it entered the tank. This temperature was normally set between 92° and 94° F., depending on the subject's preference. The second temperature control was a thermostat† which controlled the water circulation in hot water tubes running the length of the bottom of the tank. Checks of water temperature were also made routinely by a Powers Dial Thermometer and a floating thermometer which were used to insure a uniform temperature throughout the tank. This proved to be a minor problem, however, in spite of the fact that manual control was

**Hydroguard Water Mixing Valve, N-45 (Max. temp. 115° F.), Model S-1, Powers Regulator Company, Skokie, Illinois.

†No. 11 Regulator (temp. range 60°-120° F.), Model T 5376A, Powers Regulator Company.

required occasionally. The general effect of the tank was to float the subject comfortably in the warm saline solution. He barely touched the net with his shoulders and buttocks, and his feet rested lightly on the net. His arms either floated in the water or were hooked under the webbing, if he preferred this.

Tests:—A series of tests of muscular strength and co-ordination and physiological function were given. Some of these were used only before and after immersion whereas some were given periodically during the period of immersion. Five tests of muscular strength and co-ordination were used: (1) *The strength of grip* was measured by a Stoelting Company Hand Dynamometer with the subject in bed. He exerted a single maximum pressure which was read to the nearest kilogram. (2) *Body sway* was measured by a modified Rhomberg Test. The test was made for sixty seconds on both feet and thirty seconds on each foot. Performance ratings and a time score for the three parts of the test were obtained. (3) *Hand steadiness* was measured with the Whipple Steadiness Test. This consists of a metal plate with nine holes of different sizes drilled in its face. The subject's task is to hold a metal stylus in each hole for fifteen seconds without touching the sides. Tests were made using the subject's preferred hand, and his score was the time he made contact with the side of the metal plate. (4) *Leg ergograph*: The subject was supine on the test table. A strap was buckled around his right foot and connected to the ergograph with the scale set at zero. The subject placed his hands, palms down, on the table and on command exerted a single lift of his leg extended upward. Prolonged straining was not permitted, and the subject was instructed to lower his leg within two seconds if he had not already done so. Three trials were taken with the right leg with thirty seconds between trials. The test was then repeated with the left leg. The score for each trial was the maximum pull during the trial to the nearest pound, and the mean of the three trials was the score for each leg. (5) A test of *exercise tolerance* was given with the subject at a slow run on a treadmill which was set at 7 mph. and at an 8.6° grade. The test was begun with the subject standing on the side of the device with the belt running at 7 mph; then he grasped the handhold and stepped onto the belt, releasing his grip as soon as he could maintain his balance. He was timed for a single trial with a stop watch, the trial ending when he could not maintain the pace and stepped off. A second stop watch was started immediately upon his failure to maintain the pace; the subject was placed on a test table, and electrocardiograph leads were attached. Pulse rate determinations were made from the electrocardiogram. Rates were counted from one minute after failure to one and one-half minutes, from two to two and one-half minutes, and from four to four and one-half minutes. The following determinations were also made: two times the sum of the counts of the pulse for the three thirty-second intervals, the duration of the exercise in seconds, and an index of physical performance on the test from a nomograph.[3] The index was equal to the duration of exercise times 100 divided by two times the sum of the heart beats during the three thirty-second intervals.

The following physiological tests were also carried out. A *tilt* table was actuated by a hydraulic pump which required six to twelve seconds to tilt the subject up and four to six seconds to tilt him down. On the side of the table was an arm rest attached in such a position so that when the subject was upright, the arm used for blood-pressure determinations was horizontal at the level of the heart. The subject was helped onto the tilt table, and his feet placed against the footboard so that the weight was borne chiefly through the long bones of the legs with a minimum of muscular effort. He was instructed to relax, refrain from moving, and to keep his eyes open. He was placed immediately in the horizontal position for a minimum of fifteen minutes or until the blood pressure and pulse became stabilized. Blood pressure measurements were begun eight minutes after the subject was placed in the horizontal position and taken every two minutes until he was tilted. A fifteen-second standard Lead 2 of the electrocardiogram also was taken every two minutes during this interval. When all of the equipment was in readiness and the readings stabilized, the subject was tilted passively with head up to an angle of 77° from the horizontal. He was held in this 77° tilt position for a maximum of fifteen minutes or until he showed symptoms of real peripheral circulatory insufficiency or imminent collapse. Arbitrary criteria were used to define imminent collapse, but an attempt was made to keep the subject from fainting. He was then returned to horizontal, and observations were made for five minutes. The subject was carefully observed throughout the whole procedure and was questioned regarding his symptoms after the final electrocardiogram. The following measurements were made:

A standard *electrocardiogram* was taken fifteen seconds before the subject was tilted and was continued for two and one-half minutes. Thereafter, a fifteen-second electrocardiogram (Lead 2) was taken every minute beginning three minutes after the tilt and every minute throughout the tilt. Similar measurements were made for five minutes after the subject was returned to the horizontal. Electrocardiographic tracings of three leads were made as a terminal test. Measurements of the *blood pressure* were made immediately following tilt and at one-minute intervals which began one minute after tilt and ended five minutes after the subject was returned to the horizontal position. The *heart rate* was obtained from the electrocardiogram. The number of *eosinophils* in the peripheral blood was determined before, after, and every other day during the period the subjects were immersed in the tanks. A blood sample was obtained from the finger approximately three hours after breakfast. The smear was prepared with Wright's stain, and at least 1,000 white cells were counted. Before and after their immersion, the blood *serum cholesterol* level also was determined, using the method of Kingsley and Schaffert,[16] and the *protein bound iodine* level (PBI) was measured, using the method of Zak and his associates.[27]

RESULTS

Before the experiment began there was some concern about the subjects being able to remain in the tank for a prolonged period each day. This concern was held in spite of the fact that the authors had been in the tank for preliminary test periods up to four hours. It had some justification because, at first, the subjects reported difficulty in adjusting themselves to the experimental regime and, in particular, they had difficulty getting comfortable in the water. However, after the first four or five days, they adjusted to the routine and voiced a minimum number of complaints. Two of the subjects slept a great deal of the time while they were in the tanks. It is estimated that one subject (R) slept as much as five hours during daytime in the tank and approximately eight hours at night in addition, after he became adjusted to the situation. All of the subjects who completed the experiment slept well at night (eight to nine hours) in spite of the rest and sleep during the day.

The data obtained from these three subjects could not be combined for statistical treatment since the procedure was not identical for them. However, an examination of the performance of the subjects makes it possible to draw some inferences regarding the significance of such a regime on their muscular activity.

Hand Steadiness:—The raw data for the tests using the four smaller holes of the Whipple Steadiness Test for the right hand are presented in Table I. The scores for the remaining trials were not included because they were either zero or very near zero throughout the series. The data for the left hand are not included since they do not show significant differences from the right hand. It will be noted that two

TABLE I. STEADINESS TEST FOR THREE SUBJECTS SHOWING THE TIME IN 0.1 SECOND (Subject Made Contact with Side of Test Holes*)

Right Hand

Date	Subject B				Subject C			
	6	7	8	9	6	7	8	9
Pre-Tests								
7/30/58	7	12	42	95	12	16	46	65
7/31/58	11	36	39	67	5	18	38	82
8/ 1/58	6	17	52	56	15	33	47	96
8/ 4/58	8	9	46	40	23	26	54	85
Mean	8.0	18 5	44.8	64.5	13.8	23.3	46.3	82.0
Tests During Period in Tank								
8/ 5/58	4	5	9	52	4	10	30	57
8/ 7/58	4	8	20	69	3	4	10	54
8/ 9/58	3	7	25	52	6	7	22	57
8/11/58	4	6	33	88	1	5	31	46
8/13/58	10	22	54	75	4	11	27	83
8/15/58	0	4	11	19	6	4	40	60
8/17/58	0	6	15	50	7	8	29	52
8/18/58	0	2	21	36	8	11	29	70
Mean	3 1	7.5	23.5	55.1	4.9	7.5	27.3	60.5
Post-Tests								
8/19/58	1	3	23	67	5	7	6	48
8/20/58	1	3	17	59	2	9	28	27
8/21/58	2	5	13	52	1	15	27	58
Mean	1.3	3.7	17.7	59.3	2.7	10.3	20.3	44.3

Date	Subject R			
	6	7	8	9
Pre-Tests				
8/12/58	2	0	6	31
8/13/58	2	3	12	35
8/14/58	2	2	10	55
8/15/58	2	2	3	5
8/18/58	0	1	7	28
Mean	1.6	1.6	7.6	30.8
(No tests during period in tank)				
Post-Tests				
9/ 2/58	5	2	7	24
9/ 3/58	1	3	20	27
9/ 4/58	0	14	17	23
9/ 5/58	2	7	29	23
Mean	2.0	6.5	18.3	24.3

*Tests on August 4 were made before subjects B and C entered the tank for the first time, while those on August 18 were made after the final period in the tank but before any exercise was permitted.

subjects (B and C) were given the test every other day during the period they were in the tank. The third subject (R) was given only preliminary and post-tests. Since there appeared to be no systematic change throughout the three intervals shown in the tables, means were computed to obtain a representative measure for each of these periods. The data show substantial variability for all three subjects and a trend toward improvement throughout the experiment in the case of subjects B and C. Subject R showed a trend toward a small decrement after being taken out of the tank. However, one point seems to be very clear from these data. There were certainly no pronounced decrements in steadiness as measured by this particular test. This is true whether the comparison is made between mean scores or between individual scores at the beginning or end of the three periods. The data then support the notion that there is no substantial decrement in steadiness during such an experimental procedure.

Strength of Grip—The data for the strength of grip (Table II) are the means of three trials on each test day. This test was given on alternate days for subjects B and C while only preliminary and post-tests were given to subject R. Inspection of the data indicated no systematic changes throughout the test intervals, and means were therefore computed to obtain a representative measure for each period. Again, the results show substantial variability for each individual and between individuals. No systematic change related to the time spent in the water is evident. Comparison of the mean scores for the different periods shows minor variations throughout. The first trial after the subjects were released from the regime in the tanks (August 18) when compared with the mean of the preliminary trials for the different hands shows five out of six measurements greater following the period in the tanks. Similarly, a comparison of the final preliminary trial with the final experimental trial (August 18) shows four with an increase and two with a decrement. None of these differences exceeds 6 kilograms. In addition, no systematic decrement was evident in the data for the two subjects who were tested throughout the period they spent in the tank. On the contrary, slight improvement appeared to be present (Table II). These data unequivocally show no evidence in this performance of decrement that appears to be related to the time they spent in the tank.

is associated with a reduction in muscular activity of the sort involved here.

Body Sway:—All three subjects received the maximum score for all trials while standing on both feet, *i.e.*, they stood without moving their feet the full sixty seconds, and body sway was rated as minimum. Similarly all three subjects stood on first the right foot and then the left foot for the full thirty-second test period without putting the foot down for all trials. Ratings of sway showed some change throughout the series, but it was not consistent for any subject. One subject (R) showed a minimum sway on the final preliminary test and a maximum sway during the first test after being released from the schedule in the tank. The other two subjects showed a slight increase in sway for one foot and no change for the other. In general, these results would suggest some small decrement in co-ordination on this test although this can be said only with serious reservation, and certainly no marked decrement occurred.

TABLE II. STRENGTH OF GRIP FOR RIGHT AND LEFT HANDS AS MEASURED IN KILOGRAMS*

Date	Subject B		Subject C		Date	Subject R	
	RT	LT	RT	LT		RT	LT
Pre-Tests					*Pre-Tests*		
7/30/58	47.0	49.3	35.0	37.3	8/12/58	45.0	44.3
7/31/58	45.0	47.3	42.0	38.3	8/13/58	45.3	41.7
8/ 1/58	46.3	44.7	37.3	35.3	8/14/58	46.3	43.7
8/ 4/58	49.3	50.0	35.7	35.7	8/15/58	38.7	39.0
					8/18/58	47.0	43.3
Mean	46.7	47.8	37.5	36.7	Mean	44.7	42.4
Tests During Period in Tank					(No tests during period in tank)		
8/ 4/58	46.7	48.3	37.3	35.3			
8/ 6/58	48.3	49.0	40.3	37.7			
8/ 8/58	47.3	48.3	35.3	34.0			
8/10/58	44.3	46.0	39.0	34.0			
8/12/58	46.7	48.0	41.0	32.0			
8/14/58	46.3	49.7	43.3	40.3			
8/16/58	44.3	44.2	44.0	40.6			
8/18/58	49.0	52.0	40.7	36.3			
Mean	46.6	48.2	40.1	36.3			
Post-Tests					*Post-Tests*		
8/19/58	52.3	53.0	37.7	32.0	9/ 2/58	46.7	44.7
8/20/58	54.0	50.0	40.7	36.0	9/ 3/58	42.3	33.3
8/21/58	54.0	51.0	39.0	40.3	9/ 4/58	40.7	34.0
					9/ 5/58	43.3	40.7
Mean	53.4	51.3	39.1	36.1	Mean	43.3	38.2

*Each figure is the mean of three trials on the day indicated. Tests on August 4 were made before subjects B and C entered the tank, while those on August 18 were made after the final period in the tank but before any exercise was permitted.

Leg Ergograph:—Data from the leg ergograph are summarized in Table III. Since again no systematic changes were evident throughout the series of tests, mean scores for each series are presented for the preliminary test, the test during the period the subjects were in the tank, and for the post-test. No systematic statistical analysis appears justified; nevertheless, the data show unequivocally that there are no consistent decrements in performance as measured by this test. This is true in comparing preliminary trials with both the trials while the subjects were in the tank and with the final experimental trials. Comparisons of the scores just before subjects B and C were released from the schedule in the tank and the initial trials after they had been up and about the ward show the same negative results. These data further support the notion that little change in muscular strength

Treadmill:—The results obtained from the tests on the treadmill again support the notion that no substantial change in muscular performances resulted from the regime in the tank (Table IV). However, it is interesting to note that all three subjects showed a decrement in the physical performance index between the final preliminary test and the first test following the schedule in the tank. The decrement was great only for one subject (R). Two of the subjects (C and R) also showed a substantial decrement in running time, comparing the final preliminary test and the first post-test. On the other hand, one subject (B) showed a slight increase in running time. He showed little change in the remaining trials.

TABLE III. DATA IN POUNDS FOR STRENGTH OF PULL FOR RIGHT AND LEFT LEGS*

Date	Subject B		Subject C		Date	Subject R	
	RT	LT	RT	LT		RT	LT
Pre-Tests					*Pre-Tests*		
7/30/58	16.0	20.3	19.3	19.7	8/12/58	27.3	30.0
7/31/58	15.7	17.7	31.0	26.0	8/13/58	27.0	30.3
8/ 1/58	18.7	19.0	25.0	19.0	8/14/58	31.3	30.3
8/ 4/58	21.7	23.0	21.3	20.0	8/15/58	30.3	31.7
					8/18/58	33.3	32.0
Mean	18.0	20.0	24.2	21.2	Mean	29.8	26.0
Tests During Period in Tank							
8/ 5/58	23.3	20.7	24.3	18.7			
8/ 7/58	21.3	21.3	22.7	22.7			
8/ 9/58	21.7	21.3	23.7	21.3			
8/11/58	20.0	17.3	19.7	17.7	(No tests during period in tank)		
8/13/58	22.3	20.7	18.7	19.0			
8/15/58	23.0	19.3	21.0	23.0			
8/17/58	25.3	25.0	29.7	29.7			
8/18/58	23.7	21.3	26.0	22.3			
Mean	22.6	20.9	23.2	21.8			
Post-Tests					*Post-Tests*		
8/19/58	23.0	23.0	22.7	21.7	9/ 2/58	31.0	31.3
8/20/58	21.7	24.3	22.0	20.7	9/ 3/58	23.3	23.7
8/21/58	25.0	21.3	21.7	21.0	9/ 4/58	24.3	23.0
					9/ 5/58	25.3	25.3
Mean	23.3	22.9	22.1	21.1	Mean	30.9	25.8

*Each figure is the mean of three trials on the day indicated. Tests on August 4 were made before subjects B and C entered the tank, while those on August 18 were made after the final period in the tank but before any exercise was permitted.

TABLE IV. TREADMILL PERFORMANCE OF THE THREE SUBJECTS TAKEN BEFORE AND AFTER THE PERIOD IN THE TANK*

Date	Subject B		Subject C		Date	Subject R	
	Running Time in Seconds	Index	Running Time in Seconds	Index		Running Time in Seconds	Index
Pre-Tests					*Pre-Tests*		
7/30/58	64	15.0	81	21.0	8/12/58	79	23.0
8/ 1/58	59	15.5	74	21.5	8/14/58	131	36.5
					8/15/58	127	34.0
Post-Tests					*Post-Tests*		
8/18/58	62	13.0	58	15.0	9/ 2/58	100	24.0
8/19/58	64	14.0	80	20.0	9/ 3/58	95	25.0
8/20/58	60	15.0	83	21.0	9/ 4/58	97	27.0
8/21/58	62	17.0	90	22.0	9/ 5/58	88	25.0

*The time score is the actual running time each day, and the index is a measure of physical performance.

Tilt Table:—All three subjects were tested on the tilt table before and after immersion in the tank, and two of them were tested on alternate days throughout the experimental period. Although there was much individual variation, all three subjects completed the full fifteen-minute control tests prior to immersion in the tank and all showed marked deterioration as a result of the experimental procedure. Subject R who was tested only during the control and recovery stages exhibited the most profound effects. During the initial control period prior to immersion when he was tilted upright for fifteen minutes, he exhibited little change in systolic blood pressure, a moderate rise in diastolic pressure, and an increase in heart rate from 52 to 80 beats per minute (Fig. 2). When he was questioned following the tests, he reported no subjective complaints, and there were no objective signs of peripheral circulatory collapse. On the other hand, on the day he was taken out of the tank after the two-week experimental period immediately after he was tilted up, there was a sharp rise in pulse, a marked drop in systolic blood pressure, and it became necessary to terminate the tilt shortly after the five minute measurements were obtained; at this point the pulse at the wrist and the blood pressure were unobtainable. On the second day of the recovery period it was necessary to terminate the tilt at six minutes, but on the third day his response was very similar to that obtained during the initial control period.

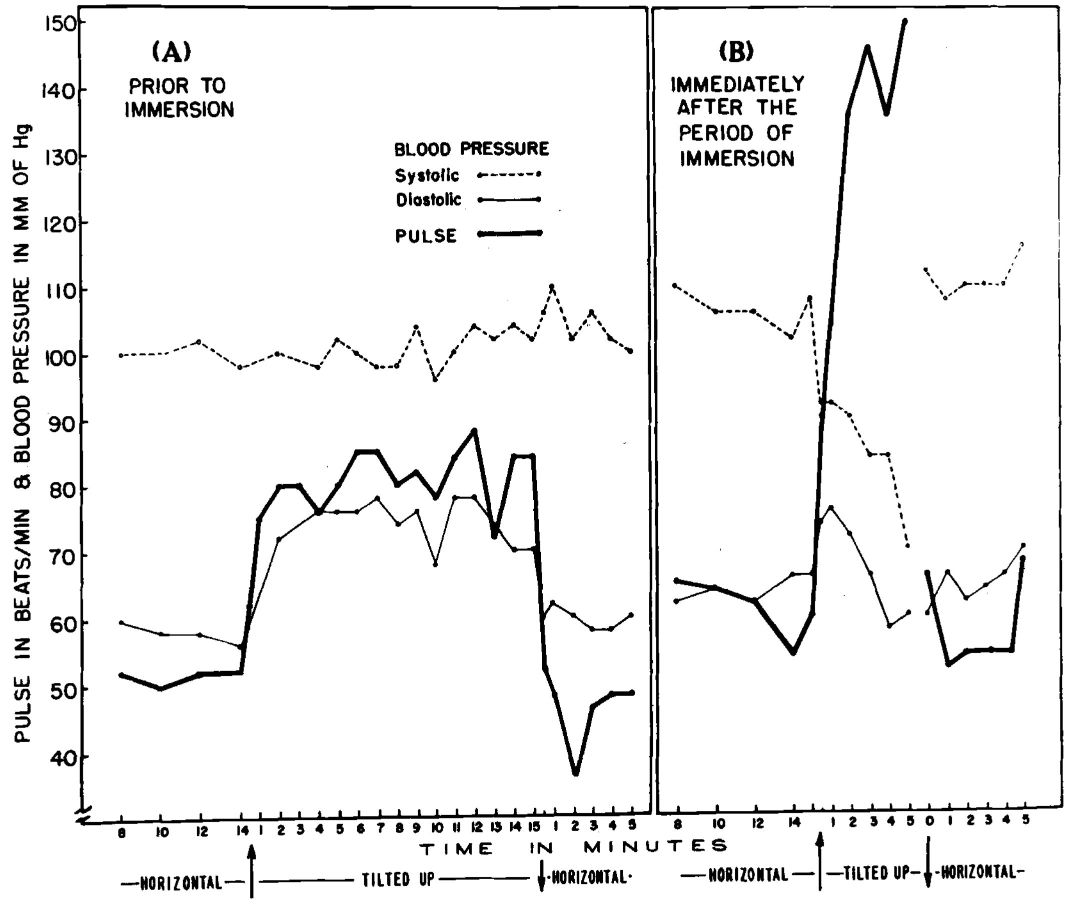

Fig. 2. Blood pressure and pulse rate before and immediately following the period of immersion.

On the fourth day of recovery, his response was not essentially different from the control period. Subject B showed little change in systolic and diastolic blood pressure and a moderate rise in heart rate during the control tilt test. However, after one day's exposure in the tank he exhibited a substantial fall in his systolic blood pressure during the tilt and an increase in his pulse rate of approximately fifty. These unfavorable signs became progressively worse throughout the tests taken during the days of immersion, but on no occasion did he have any complaints other than slight dizziness and fatigue after assuming the upright position. He was able to complete all of the fifteen-minute test periods without being returned to the horizontal position. The third subject (C) exhibited a relatively poor response to tilting even during the control period. On the second day after immersion the only significant change was a greater increase in heart rate which doubled when he was tilted upright. On the sixth, eighth, and twelfth experimental days it was necessary to terminate the tilt because of inability to obtain the pulse at the wrist and to obtain the blood pressure. In no instance did the subject collapse although he exhibited evidence of impending peripheral circulatory failure.

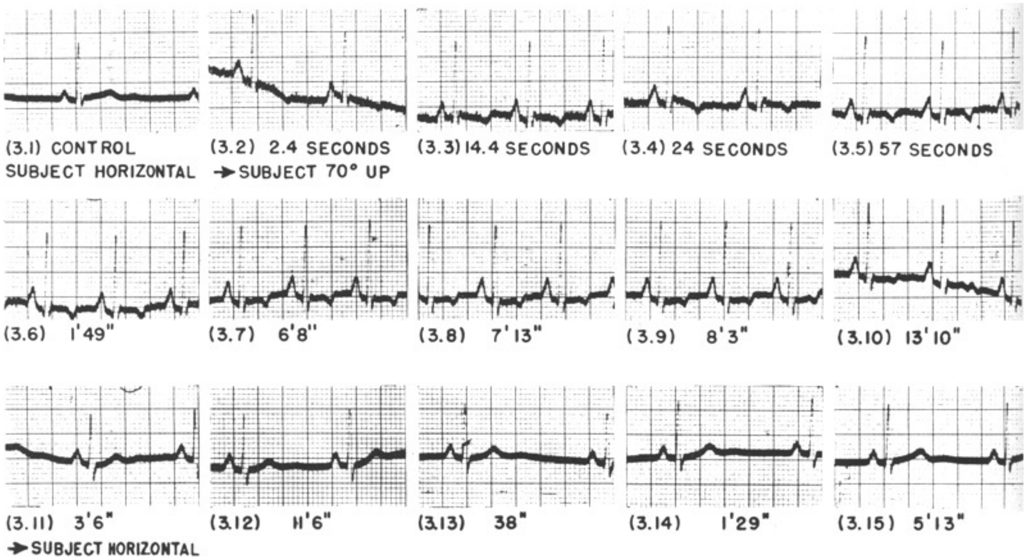

Fig. 3. Serial electrocardiograms (Lead 2) obtained from Subject C shortly after emerging from tank at end of second day. Note progressive alteration in P, T, and level of S-T with changes in posture.

The electrocardiographic tracings shown in Figure 3 were obtained from subject C shortly after emerging from the tank at the end of the second experimental day. The heart rate increases to twice its initial value after tilt-up and there is slight compensatory slowing on return to the horizontal. The increase in amplitude of P and inversion of T occurred very soon after tilt-up, but the slight depression of S-T segments and their return occurred more gradually.

*Blood Analyses.**—There was a striking increase in the level of protein bound iodine (PBI) following immersion (Table V), and the PBI returned to normal shortly after the period of immersion was terminated. This increase came as a surprise but can no doubt be explained by the fact that the salt used to provide

*We are grateful to Mr. James Colehour for carrying out these analyses.

the normal saline solution contained 0.01 per cent potassium iodide. Because of the comparatively much lower concentration of potassium iodide in the blood, there was a transfer so as to increase the protein bound iodine level.

The values for the 0-12 lipoprotein fraction and the serum cholesterol were higher in all three subjects immediately after immersion compared with the control ones (Table V). It would be difficult to explain these increased values on the basis of a change of diet, although during the experimental periods the subjects were provided with a diet containing more protein and less fat than they ordinarily received. The explanation may be related to the activity of the subjects. The activity was lowest, of course, during the period of immersion and higher after the subjects got out of the tank, at which time they had a strong desire to exercise. This explanation is in line with the findings of Rakestraw[22] who demonstrated a lowering of blood cholesterol levels with exercise.

TABLE V. RESULTS OF BLOOD ANALYSIS

Subject	Date	Condition	Body Weight	AI	O-12	Cholesterol	PBI
B	7/31/58	Before immersion	153	70	385	174	6.0
	8/18/58	Immediately after immersion	146½	87	433	259	7.2
	9/10/58	23 days after immersion		58	345	196	6.1
C	7/31/58	Before immersion	151	42	258	172	5.1
	8/18/58	Immediately after immersion	144½	42	334	179	6.7
	9/ 2/58	15 days after immersion		35	218	133	4.8
R	8/18/58	Before immersion	132	44	284	182	4.2
	9/ 2/58	Immediately after immersion	130½	58	403	190	6.0
	9/10/58	8 days after immersion		35	283	156	5.7

There was a marked variation in the number of eosinophils in the peripheral blood throughout the test period for all three subjects (Table V). For two of the subjects these variations appeared to bear no systematic relationship to the period of immersion in the tanks. However, subject C had a regular decrease in eosinophil count throughout the test period until he was released from the daily immersion in the tanks. Following this there was a sharp increase to the original eosinophil level. The implications of this finding for subject C are not clear since he exhibited less evidence of stress than subject B.

DISCUSSION

Some of the findings deserve further discussion; namely, (1) observations on sleep habits, (2) the subjective symptoms associated with simulated zero G, (3) muscular strength, (4) orthostatic hypotension, and (5) the problem of zero G asthenia.

Sleep:—The importance of being able to sleep at will under monotonous conditions exemplified in this experiment can hardly be overestimated. This may be illustrated by comparing two subjects and their behavior during the experiment. Subject B was originally judged to be a stable, well-poised individual and easily able to withstand the rigorous demands of this experimental situation. However, he was slow to adjust, complained of being uncomfortable, was irritable, and only under some pressure from himself and the experimenters was he able to complete the two-week immersion period. He slept little during the day and averaged seven and three-fourth hours at night. He occupied his waking hours watching television, listening to the radio, talking, reading, and smoking. On the other hand, subject R appeared to be emotionally more labile than B, much more physically active, and less likely to complete the experiment. Yet he adjusted quickly to the situation and even liked certain aspects of it. He deliberately spent about five hours a day in either light sleep or a somnolent state. In other words, when there was little activity to interest him, he simply went to sleep and thus was able to avoid boredom. This in no way interfered with his eight hours of sleep at night. It would appear that a crucial difference in the abilities of these two subjects to adapt to immersion was simply the amount of time they spent sleeping while in the water. This points up not only the individual differences in this regard but also the need for selection devices for or indoctrination with respect to sleep for persons in confining tasks where sleep is possible. In this connection, it has been reported that men on long submarine cruises typically slept most of the hours when not on duty. At first glance these observations may appear to be in conflict with the findings of Lilly[20] and Graveline[28] who reported that they required less sleep during immersion. It should be noted, however, that there were marked differences in their methods and, in particular, motivation was very different since they themselves acted as the subjects. In any event, our results do point out that immersion is not necessarily incompatible with a normal amount of sleep.

Subjective Symptomatology:—The most interesting subjective finding was the desire of the subjects to maintain contact with the webbing or edge of the tank. This applied particularly to the arms which tended to float free unless the hands were slipped between the mesh of the webbing. Although we did not make systematic daily observations, the subjects at the end of the two-week period still held their hands under the webbing, indicating little adaptation in this respect. Probably the same would be true of the zero G state; at least floating under water most nearly resembles the experience under zero G and raises the question whether one would quickly learn to adapt to the unusual situation. The positive thigmotropism of lower animals and the "contact comfort" reported by Harlow[12] in young monkeys may be relevant to this problem.

The reports of the three subjects revealed marked discrepancies between their subjective symptoms and their performance on the tests of muscular strength. All three subjects complained of weakness in varying degrees and all expressed surprise when they learned how well they had done on the muscular performance tests. The specific factors which contributed to these results in this particular case cannot be unequivocally determined from this experiment, but it would appear likely that at least three factors were involved. First, a false impression of weakness may have been created, in part at least, by the symptoms associated with the change from a recumbent to an upright position. All of the subjects reported symptoms similar to those associated with postural hypotension, and these may have been interpreted as an indication of general weakness. Second, it is possible that the relatively high temperature of the water which contributed to relaxation and enervation was interpreted by the subjects as general bodily weakness. Third, it may be that the subjects were influenced by the widely held view that one becomes weak when he reduces his muscular effort and spends much time in bed.

Muscular Strength:—We were surprised that muscular strength was fully maintained and that endurance, as measured on the treadmill, was reduced in only two of the subjects inasmuch as earlier studies of immobilization of healthy subjects in plaster casts had reported decrements in several tests.[5] The only strenuous muscular effort exerted by the subjects during the immersion period was made in carrying out the ergographic tests (two subjects) since they were assisted in and out of the tanks and were transported by wheelchair. Movements of the legs were minimal, but the arms were used. At all events, these muscular movements were far less than would be experienced under zero G conditions even if the persons were confined to a seat or couch. However, under zero G certain "antigravity" muscles might not be called into play.

In this connection, the experimental findings of Mueller and Hettinger[21] which emphasize the importance of daily muscular training are particularly noteworthy and are in general supported by the experiment of Rose and his group.[23] The former investigators found that muscular exercise constitutes a training stimulus if it exceeds one-third the maximum potential, and they suggested that this may be regarded as a threshold value. They also pointed out that it takes far less than one-third the maximum potential to prevent atrophy and that the range between the threshold for training and threshold for atrophy may be termed the range-of-indifference. This range-of-indifference tends to vary with variations in muscular activity. The great significance of the strength of stimulus is shown by the fact that daily exercise, where the strength of stimulus exceeds one-third the normal potential, will lead to an increase in muscular strength even though the total daily activity of the muscles may be reduced. With regard to the temporal aspects of training, Mueller and Hettinger demonstrated that daily muscular training which leads to a rapid increase in strength will show an equally rapid decline on cessation of exercise. However, a high muscular potential (50 to 80 per cent over the initial strength) could be maintained or even slightly increased by once-a-week maximum contraction, but there is a reduction in strength if the exercise is limited to once every three weeks. It is interesting that in experiments wherein muscular potential was slowly increased by once-a-week training exercises, there was an even slower decline on cessation of exercise. In other words, muscular strength was much better maintained by slow versus rapid development. It may very well be that the small amount of muscular activity involved in getting in and out of the water, moving in bed, et cetera was sufficient to meet the required criteria of exercise indicated by Mueller and Hettinger.

Postural Hypotension:—It is noteworthy that, while muscular strength was little affected by the experimental procedure, there was an early and significant decrease in circulatory adaptation to the upright position. It must be remembered that immersion in warm water leads to peripheral vasodilation which increases the tendency toward postural hypotension.[9] Under zero G conditions this factor would normally not be present. That recovery involved something more than abolition of the peripheral vasodilation is shown by the period of time required. The two subjects who were tested every other day throughout the immersion period showed a rapid loss in adaptation to change in posture. After one day in the tank subject B, who showed the best tolerance before the experiment began, exhibited a striking loss in adaptation to change from the recumbent to the upright position. The two subjects (B and C) tested throughout the immersion period showed a rapid decline in tolerance with increasing length of immersion. At the end of the two-week period all three subjects were showing striking decreases in tolerance to change in position, but all three soon recovered from this loss. Whether these rapid changes in adaptation are to be regarded as beneficial or harmful depends upon one's point of view. In terms of quick adaptation to change in environmental conditions, the responses were excellent. On the other hand, if these changes are judged by the ability of the individual to retain good postural adaptation under changing conditions, the response was poor.

It would be reasonable to expect that persons living in a zero gravity environment would experience profound changes in the endovascular reflex responses. Without artificial support, they would be poorly equipped to withstand the effects of acceleration, particularly the sudden effects to which they might be subjected on reentry into the earth's gravitational field. It is easy to speculate about, but difficult to be sure of, the long-term effects of the alterations in the endovascular reflexes resulting from exposure to zero gravity. Nothing in our past experience has furnished us with the powers to adapt to this state. Certainly the possibility must be kept in mind that there will be serious disorders in the partition of fluids between the endovascular and extravascular spaces, between the cardiovascular and cerebral fluid systems, and in changes in the heart muscle as a result of the decreased work of the heart. These are among the problems which would be avoided by the creation of an artificial gravitational field.

Zero G Asthenia:—Zero G asthenia is a term which might appropriately be used in describing the fatigue and weakness incidental to prolonged exposure to the subgravity or zero-gravity state. The asthenia resulting from physical inactivity under otherwise normal living conditions, such as prolonged bed rest, is well recognized, and on *a priori* grounds it is reasonable to believe that if the need to counteract the effects of gravity were removed, muscular weakness and even degeneration might ensue unless adequate measures were instituted to prevent it. The tendency toward asthenia would be ever-present, and adequate countermeasures might be difficult to devise and carry out. This difficulty would center around the maintenance of muscular strength, not in the case of muscles such as the flexors and extensor of the arms which can be readily tensed, but in the case of muscles which support our weight but are not otherwise required for ordinary bodily movements. However, if the proper exercises were devised, only a very brief time would be required to maintain their normal strength. However, a further consequence of muscular inactivity is osteoporosis, and the minimal amount of exercise to prevent loss of muscular strength might be insufficient to prevent osteoporosis.

SUMMARY

The principal objective of this study was to evaluate changes in fitness of subjects while the effects of G on the body were reduced. Three healthy young men were floated in tanks of physiologic saline solution for ten hours a day for two weeks. When they were not immersed, they remained in bed, and great care was taken to minimize both muscular activity and sensory deprivation.

In general, it was found that, after an initial period of adjustment, the principal stress was of a psychological nature and that individual differences were striking. Subject B, regarded as having the most stable personality, became irritable and had difficulty completing the experiment while R, regarded as the least stable, rather enjoyed the experience and was ready to continue "indefinitely." The third subject reacted more nearly like B than R. The most obvious explanation of these differences was in the comparative ability to enter a somnolent state or actually fall asleep. R could, seemingly at will, spend many hours during the day either asleep or nearly asleep, and that in no way interfered with his sleeping at night. B, on the contrary, remained relatively alert during the daytime despite his desire to "escape" the tedium by sleeping.

None of the subjects showed a significant decrease in muscular strength. Two showed a slight decrease in exercise tolerance as measured on the treadmill, and one did not. All of the subjects complained of "weakness" which contrasted sharply with the results of strength and endurance tests. The tendency to orthostatic hypotension increased during the experimental period. This appeared four hours after immersion, and peripheral vasodilation was undoubtedly the most important factor responsible for this early change. Later on, it was necessary to terminate the tilt-table test in order to prevent collapse. The fact that at least two days were required, after immersion, for the increased tendency toward postural hypotension to disappear suggests that factors in addition to peripheral vasodilation were involved.

Several additional observations were made. The subjects showed a strong desire to avoid "postural uncertainty"; the hands were thrust through the mesh of the webbing to keep the arms from "floating free." The serum cholesterol and 0-12 lipoprotein fraction rose during the immersion period. One subject exhibited a progressive decrease in number of circulating

eosinophils, and two did not. The rise in value of protein-bound iodine during the period of immersion was considered an artifact caused by the use of iodized salt in the water.

Three technical points deserve mention in connection with the procedure. The use of webbing in the tank ensured the maintenance of a comfortable posture and also satisfied the desire to maintain contact with a fixed element in the environment. The use of an adjustable floating headrest prevented discomfort in the neck muscles. Imbibition of water by the thick skin of the hands and feet, which was prominent at first, lessened over a period of days.

The implications of these findings for the zero G state must be drawn with caution because of the limitations of the simulation of zero G. However, it would appear that muscular strength will not be lost soon, but during prolonged exposure, exercise of *all* muscles will be necessary. The feeling of weakness or asthenia may be a prominent complaint but will not be a reliable indicator of muscular fitness. With regard to cardiovascular responses, tolerance to positive G can be expected to be rapidly and significantly reduced long before muscular fitness is impaired. The feeling of "floating" which may be initially pleasant, may give way to unpleasantness and a strong desire to maintain pressure contact with the environment.

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