# Physiologic Changes Observed in Human Subjects During Zero G Simulation by Immersion In Water Up to Neck Level

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EVER SINCE man has contemplated space flight, his imagination has been captured by the physical condition of zero G. Since the zero G state cannot be generated on earth, the multitudinous theories and concepts of life under zero G conditions have multiplied and will continue to grow and to concern the imaginations of both the scientific and lay populations. Short term zero G states have been simulated in high speed jet aircraft by flight through a Keplerian trajectory. These flights, to date, have lasted not more than a minute. Some experiments have been conducted in which animals have been subjected to zero G as the inhabitants of test rockets which were fired into ballistic trajectories and, in a few cases, into orbital flight about the earth. Physiological data and psychomotor performance on the response of animals to these conditions is unfortunately limited. Investigators utilizing animals in rocket-propelled vehicles will continue to contribute information on the effects of zero G but it will be only after man himself has experienced zero G of the duration of orbital flight that the scientific world and lay community will receive factual information on the effects of this physical state upon the human organism. For some time to come, the difficulty of producing prolonged periods of weightlessness should cause its several presumed analogues to be of interest. At this time, the physiological effects of the prolonged zero G state on man are not known and, since these effects may be such as to cause a serious decrement in physiological and/or psychomotor function, it is important to gain as much scientific insight into these conditions as possible before human beings are exposed to their effects in orbital space flight.

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## REVIEW OF THE LITERATURE

The possible effects of zero G were postulated by Gauer and Haber[5] as early as 1946. These authors theorized that there would be no serious impairment of respiration or circulation but that susceptibility to collapse due to loss of pressoreceptor tonus, similar to that observed in patients who have been confined to bed for long periods of time, might be observed. They also theorized that, due to the absence of gravitational effects on motor control and loss of the labyrinthine reflexes, there might be a disturbance or alteration of autonomic nervous system function, which they termed "kinetosis." This disturbance might be expected to affect the autonomic nervous system so as to produce weakness or the even more severe sensation of succumbence which might result in absolute incapacity. This situation is similar to the severe debility which many of us have experienced in severe seasickness.

More recently, Clark and Hardy[4] have summarized the effects of the gravity free state based upon data available up to 1959 and predicted the possible physiological and psychological effects. These authors divided the effects of weightlessness into two major factors: (1) static and (2) dynamic. The static factors are those which would result from the loss of the structural distortion due to the weight of the tissues. This effect includes the fact that there is no pressure gradient in fluids due to depth and that frictional contact forces due to gravity are also absent. The dynamic factors are those which result in loss of gravitational effects upon displacement. In this category, they listed such physiological effects as the loss of convection and stratification of separate bodies due to density and energy differences and the fact that liquids and solids will tend to randomize their position in the presence of other distorting forces so as to intermix. Another effect of the dynamic aspects produces a physical situation not known to "earthlings" in that the momentum of bodies placed in motion will be more significant than the inertial forces, which is the reverse of the situation at 1 G.

Despite the many implied effects of zero G, there is a surprisingly small amount of experimental data available for use in analyzing the physiological and psychological effects. Gerathewohl studied the ability of the human to carry out fine psychomotor movements during the zero G state and reported that the control of the skeletal muscles, for an arm-pointing task in the zero G state, is rapidly learned.[7] This conclusion is based upon the performance of subjects who did pencil-pointing tests while subjected to simulated zero G conditions in a jet aircraft flown through Keplerian trajectories for approximately 30 seconds. The subjects were asked to point a pencil at a small target and their learning curve was evaluated. The test was conducted with the eyes open so that the task was under visual control. It seems unlikely that the learning rate would have been so rapid had the subjects been blindfolded as they were in similar experiments reported by von Beckh.[11]

The difficulty in accurate proprioceptive movement in water has been reported by Beckman[2] who observed that subjects who were attempting to escape from a flooded aircraft cockpit with their vision blurred by bubbles were unable to find escape devices which had been easily found when they were blindfolded in air.

The buoyant effect of water has been compared to the zero G condition.[10] Graveline et al,[9] utilized water buoyancy in designing a comprehensive physiological investigation in which the buoyant effects of water immersion upon the body were used to create a hypodynamic situation in simulation of the zero G condition. These authors carried out extensive physiological measurements upon the senior author who was immersed in water up to neck level for a period of seven days. The subject was permitted to emerge from the tank briefly for one period each day for the purpose of body hygiene. The subject reclined on a supporting couch and carried out a series of psychomotor tasks during the test period. He wore a standard underwater swim suit and the temperature of the bath was controlled at 33.5° C (92.3° F). The subject was placed on a commercially prepared high protein diet for several weeks prior to the start of the experiment so as to control the nutritional, caloric and electrolyte intake. Blood morphology, blood volume by the dye dilution technique, ECG's, blood pressure, EEG's, water balance, blood and urinary electrolyte levels, as well as various psychomotor proficiency were measured and analyzed. The results of the tests were striking. The subject reported progressively increasing weakness which ultimately necessitated termination of the experiment after seven days. Metabolic rate remained essentially unchanged. The subject's ECG and response to tilt table tests and pulmonary function tests were all consistent with the progressive and increasing physical fatigue. Blood morphology studies revealed only a moderate increase in the WBC count from 7,000 up to 15,000. Water balance studies showed an immediate outpouring of body water as evidenced by doubling of the normal urinary output for every 24 hours during the first three days of the tests. The increased urine output was associated with an increased urinary nitrogen excretion for the first three days; it then returned to normal. Biochemical analysis of the blood serum revealed essentially no change in the sodium, potassium, calcium, or chloride ion output from the control value to the immersed experimental condition. The only significant change in blood studies was marked by an increase in phosphate ion level on the fifth day. The subject's positive G tolerance was determined prior to being subjected to the water immersion and 12 hours after the termination of the experiment. These tests did not reveal a decrease in G tolerance but did reveal a great increase in heart rate in response to the G stress. This finding was considered to be abnormal. Blood studies also revealed a marked increase in albumin which began the first day after immersion. In addition, there was a marked increase in gamma globulin with a total decrease in albumin/globulin ratio. Psychomotor tests revealed a progressive decrement in performance proficiency. The subject also reported alteration in his diurnal sleep pattern so that he required less than two hours of sleep per day.[8]

Although the subject did not demonstrate a marked decrease in the "blackout" tolerance threshold for positive acceleration, he reported[8] that he believed that a critical state of deconditioning to acceleration stress might well result from exposure to true weightlessness.

Inasmuch as the Astronauts in the National Aeronautics and Space Administration (NASA) Project Mercury will be subjected to the weightless state from about 5 minutes to several hours, after which they will be subjected to transverse G loads of magnitudes on the order of 10 G during the period of deceleration as the capsule reenters the earth's atmosphere, it was believed to be important to reevaluate the possibility that a decrement in performance under transverse acceleration might occur following a protracted period of immersion in water. An experimental setup was designed to repeat the studies of Graveline but was oriented to a time period of immersion which would more accurately simulate the weightless period which the Mercury Astronauts would be expected to experience.

## METHOD

A galvanized iron tank, measuring 5 feet x 3 feet in area and five feet in height, was procured and connected to a metal oil drum by two 3-inch diameter hoses at the bottom of the tank. A pump on the bottom hose circulated the water continuously. The oil drum was fitted with four 2.5 Kw immersion heaters which were coupled to a thermostatic control so that water temperature could be maintained in the large tank at 34.4° C (94° F). A prototype Mercury contour couch was then attached to a framework which could be lowered into the tank so that the subjects would be in a reclining position with the water surface at neck level.

The subjects were equipped with standard rubber underwater swim suits and wore cotton and wool underwear beneath the suit. Rubber surgical gloves covered the hands. Three subjects wore a rubber hood over the head while four did not. Electrocardiographic tracings were obtained from electrodes worn beneath the rubber suit. A urinary collection system was incorporated into the suit and connected to a collection vessel outside the immersion tank. Pulmonary volumes were measured by using a 13.5 liter recording spirometer before, during, and after immersion.

The subjects were not restricted to diet prior to, or during, the experiment but fluid input and output were measured during the period of immersion in the tank. Blood was drawn before the experiment for determination of serum sodium, potassium, calcium, chlorides, bicarbonate, total protein and albumin/globulin ratio and specific gravity. Red blood cell count, white blood cell counts (total and differential), hemoglobin, and hematocrit were measured from the same specimen. Urinary electrolyte output was obtained from a specimen collected prior to tank immersion and a pooled specimen was collected during the period of water immersion. Urinary biochemical analyses included measurement of sodium, potassium, calcium, chloride and urinary nitrogen. The urine volume output, pH and specific gravity were measured. Body weights of the subjects were obtained before and after the experiment. Pulse rate, respiration, body temperature and ECG were all obtained at approximately one-hour intervals during the experimental procedure. EEG was obtained on some subjects.

A series of psychomotor tests was carried out prior to the run as a control and immediately after the acceleration run to follow the decrement in performance resulting from the immersion procedure. Some of these psychomotor tests were performed on different subjects during the period of immersion. Psychomotor performance was measured by use of a Complex Coordinator Device, Steadiness Meter, Discrimination Reaction Time Device, and a Complex Tracking Task. The detailed results of the psychomotor testing will be treated in a separate report.

The Complex Tracking Task consisted of a cathode ray oscilloscope on which a spot was presented to the subject. The spot was moved through a prescribed pattern by computer control and the subject was required to center the dot on the center of the cathode ray tube by proper manipulation of the controls. The control system consisted of a three-axis side-arm controller. The tracking task was used to measure performance while the subject was exposed to transverse acceleration with a G-time profile similar to that which the Mercury capsule could generate during reentry into the earth's atmosphere. The subject's error in tracking in the vertical and horizontal axes was measured during the centrifuge run before and after water immersion. Tolerance to supine acceleration (eyeballs in, $+G_X$) was obtained by exposing the subjects to a simulated Mercury type reentry acceleration profile of 4 minutes' duration and a peak acceleration of 8 G and measuring their tracking proficiency. Tolerance to positive G (eyeballs down, $+G_Z$) was determined by the use of the standard positive G peripheral light test, which presents a central and two red peripheral lights to the subject. These lights are turned on automatically and must be turned off by the subject as the test for visual function. Loss of peripheral vision and subsequent failure to turn off the red peripheral lights was taken as the subjects's tolerance to 4.5 positive G for 15 seconds' duration. Motion pictures were obtained of the subjects during the acceleration tests.

## RESULTS

The period of water immersion was varied from 5 hours to 24 hours with five of the subjects being immersed for approximately 12 hours. Seven male subjects, who ranged in age from 21 years to 43 years and in weight from 150 pounds to 180 pounds, participated in the experiment. The first subject tested was immersed for a period of 5 hours since this period approximated the time of exposure to weightlessness which is anticipated in Project Mercury. This period of immersion, however, revealed little change in most of the physiological and psychomotor parameters measured and it was believed that the duration of the test stimulus was insufficient.

The second subject was immersed in the water for a period of 23 hours. This subject had difficulty breathing during the first hour of immersion. The sensation of dyspnea was relieved when the subject voided after one hour of immersion in the water. This difficulty was again noticed by the subject when he was awakened from sleep by dyspnea and cardiac awareness. This was relieved by elevating his chest above the water. This subject demonstrated a continuous diuresis during the period of tank immersion and the specific gravity of the specimens was 1.005 or less. Electrocardiographic tracings obtained during the experiment showed no significant variation from those taken prior to immersion until the last hour of the experiment when atrial tachycardia was observed. This condition persisted until the subject was taken out of the tank and placed on the centrifuge for tests. This subject was severely weakened by the experiment. He became syncopal upon sitting upright and was unable to tolerate the post-immersion acceleration tolerance tests. Four hours after being removed from the tank, the subject again experience a paroxysmal tachycardia which persisted for about 45 minutes when it spontaneously reverted to a normal rate. This subject showed a weight loss of 6.5 pounds during the period of immersion; 5.5 pounds of which could be explained by the difference between fluid intake of 2100 ml., plus food, and a urinary output of 4600 ml.

TABLE I. SOME EFFECTS OF WATER IMMERSION

| Subject | Period of Immersion in Hours | Weight Loss in Lbs. | Urinary Output During Immersion in ccs. | Net Fluid Loss in ccs. | Min. Urinary Spec. Gravity During Immersion | Visual Response to Peripheral Light Stimuli During Positive 4.5 G | |
|---|---|---|---|---|---|---|---|
| | | | | | | Control | Post Immersion |
| B.A. | 11.6 | 6.0 | 3245 | 2570 | 1.003 | Clear | PLL |
| R.M. | 13.1 | 4.0 | 760 | 280 | 1.007 | Clear | BO |
| L.P. | 12.4 | 1.5 | 1035 | 395 | 1.007 | Clear | PLL |
| R.C. | 13.0 | 4.1 | 3260 | 1465 | 1.001 | Clear | PLL (Stopped answering lights during run) |
| H.M. | 13.2 | 1.5 | 3085 | 1565 | 1.002 | Clear | Clear |
| E.B. | 23.0 | 6.5 | 4600 | 2500 | 1.005 | Clear | PLL at 1 G |

PLL=Lost Peripheral Vision
BO=Lost All Vision

Because of these rather extreme physiological changes, the experimental procedure was re-evaluated. The syncope, dyspnea, and tachycardia were attributed to the prolonged period of negative pressure breathing which resulted from breathing atmospheric air while immersed in water. The duration of the experiment was therefore limited to 12 hours. This time was used for the immersion period for the remaining five subjects.

The 12-hour immersion period caused a weight loss in all subjects which, for the most part, was explainable on the basis of a fluid output in excess of fluid intake (Table I). The greatest weight loss in this group was that of 6 pounds, 5.6 pounds of which were explainable on the basis of excessive fluid output. The body temperatures of all subjects remained approximately the same during the period of immersion and any change in water temperature greater than ½° F. was immediately noticed by the subject. The subjects shivered if the water temperature dropped ½° F. below control value and perspired if the water temperature rose ½° F. above. Pulse rates on the subjects remained regular throughout the period of the water immersion and varied from a low of 60 beats/minute, recorded on three subjects during the diurnal low period of midnight to one o'clock, to a maximum of 92/minute. The respiratory rate of the subjects varied from a low of 10/minute to a high rate of 23/minute. The mean respiratory rate was 18 beats/minute which was higher than the pre-immersion mean resting rate. The urinary output of the five subjects varied from a maximum of 3245 on down to a minimum of 760 ml. This last subject (R.M.) had voluntarily dehydrated himself for a day and a half prior to the test. All subjects showed evidence of a diuresis with a decrease in the urinary specific gravity from control levels of approximately 1.020 down to maximum dilution values of 1.001 to 1.005 during the period of diuresis. Urinary biochemical studies showed considerable variation in the electrolyte excretion levels based upon the variation in the dietary intake during and before the experimental period. There was no evidence of abnormal excretion of urinary electrolytes during the period of immersion. Despite the availability of replacement fluids, subjects did not report thirst nor did they maintain their fluid intake.

Comparison of the blood morphology studies, done on the test subjects before and after experimentation, revealed insignificant changes in the white blood cell count and the red blood

TABLE II. SERUM PROTEIN VALUES OBTAINED PRE-IMMERSION AND POST-IMMERSION

| Subject | Condition | Titration Technique | | | Electrophoresis Technique | | | | | | Serum Phosphate MGM % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Percent of Total Protein | | | | | |
| | | | | | | | Globulin | | | | |
| | | Total Protein GM/100cc | Albumin GM/ 100cc | A/G Ratio | A/G Ratio | Albumin | Alpha 1 | Alpha 2 | Beta | Gamma | |
| B.A. | Pre | 6.9 | 4.1 | 1.46 | | | | | | | 3.18 |
| | Post | 8.5 | 5.6 | 1.93 | | | | | | | 4.18 |
| R.M. | Pre | 7.7 | 5.0 | 1.85 | 1.77 | 63.99 | 4.58 | 8.88 | 12.07 | 10.64 | 3.66 |
| | Post | 7.4 | 5.4 | 2.70 | 1.61 | 61.72 | 5.30 | 10.01 | 13.51 | 9.50 | 4.14 |
| L.P. | Pre | 7.0 | 5.0 | 2.5 | 1.61 | 61.73 | 4.99 | 8.71 | 11.25 | 13.37 | 4.1 |
| | Post | 6.5 | 4.9 | 2.93 | 1.48 | 59.78 | 4.85 | 9.04 | 11.68 | 14.69 | 3.88 |
| R.C. | Pre | QNS | — | — | — | 45.92 | 7.37 | 11.11 | 14.93 | 20.72 | 4.08 |
| | Post | 7.6 | 5.4 | 2.46 | | 48.35 | 4.41 | 10.67 | 16.76 | 19.86 | 5.06 |
| H.M. | Pre | 8.0 | 5.4 | 2.09 | 1.33 | 57.04 | 3.51 | 8.45 | 14.87 | 16.18 | 4.16 |
| | Post | 7.8 | 5.7 | 2.71 | 1.18 | 54.11 | 1.16 | 7.57 | 17.70 | 19.49 | 5.0 |
| E.B. | Pre | 6.4 | 4.1 | 1.79 | 0.85 | 41.58 | 8.24 | 10.76 | 15.75 | 23.78 | 3.82 |
| | Post | 7.2 | 5.1 | 2.43 | 0.93 | 46.91 | 8.24 | 10.71 | 13.51 | 20.88 | 4.92 |

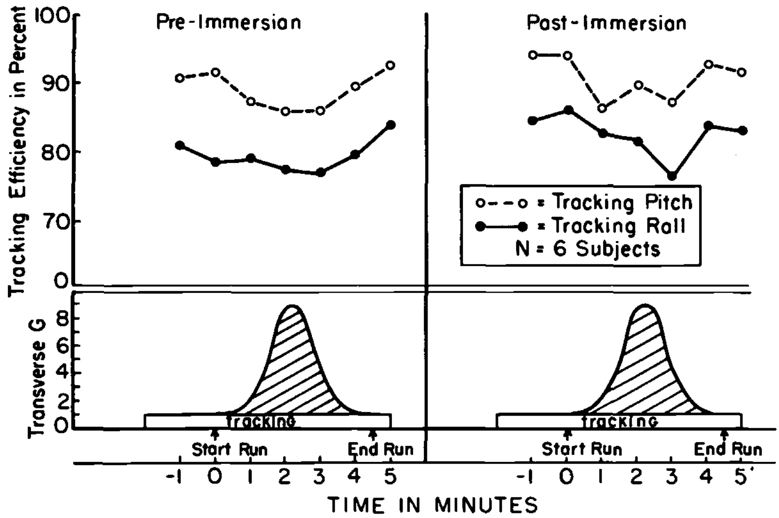


Fig. 1. Mean integrated tracking task scores for all subjects during pre- and post-immersion acceleration stress periods.

cell count with a significant increase in the post-run hematocrit on one subject.

Blood chemistry studies revealed no significant change in the blood urea nitrogen, sodium, potassium, chloride, bicarbonate, or calcium ion values following immersion. A significant increase in the serum phosphorus, measured as phosphate ion, was observed in five of the six subjects to give a mean increase from 3.83 to 4.63 mg per cent. There was an increase in the albumin/globulin ratio as measured by standard salt precipitation and nitrogen measurement techniques. However, the albumin/globulin ratios measured by electrophoresis revealed a decrease in the albumin/globulin ratio which was significant. Electrophoretic pattern of alpha 1, alpha 2, beta and gama globulin revealed no significant change as shown in Table II.

Acceleration tolerance tests revealed that one subject (R.M.) lost vision entirely at 4.5 positive G. He had been without symptoms at the same G level prior to immersion. Two others of the five subjects showed a decrease in positive G tolerance of approximately ½ G (Table I). There was no significant change between pre- and post-immersion tests of tracking task ability although all subjects showed a decrement in performance during both the pre- and post-immersion acceleration tests (Fig. 1).

Electrocardiographic studies revealed that there were no significant changes which resulted from this procedure except for one subject who experienced atrial tachycardia which occurred at the end of the 23-hour immersion period and again 4 hours after the end of the experiment and another subject (L.P.) who experienced a similar episode 24 hours past immersion.

Lung volume measurements (Table III) on all subjects revealed that there was a decrease of 3 per cent in the mean vital capacity of all subjects with an increase of 32 per cent of the mean inspiratory volume, associated with a decrease of 64 per cent of the expiratory reserve volume. The tidal volume of the subjects showed a mean decrease of 20 per cent. Positive pressure was delivered to all subjects in an effort to re-establish the normal compartmentation of the lungs and it was found that a pressure of between 6 and 11 mm. Hg was required to compensate for the hydrostatic pressure outside the chest.

TABLE III. PULMONARY VOLUMES MEASURED BEFORE AND DURING IMMERSION

| Mean Values of Respiration Measurements of Five Subjects | Control Values Subject Seated in Contour Couch Outside Tank | Experimental Value Subject Seated in Couch and Immersed in Water to Neck Level | Percent Change from Control Value |
|---|---|---|---|
| Tidal volume in liters BPTS | 0.64 | 0.51 | 80% |
| Expiratory reserve volume in liters BPTS | 1.56 | 0.56 | 36% |
| Inspiratory reserve volume in liters BPTS | 2.12 | 2.79 | 132% |
| Vital capacity in liters BPTS | 3.99 | 3.86 | 97% |
| Maximum breathing capacity in liters/min. | 110. | 90. | 82% |

The results of the target-aiming task conducted under water with the subject blindfolded showed that all subjects had an upward aiming error which persisted throughout the period of immersion, and that there was no significant learning trend demonstrated. The results of this psychomotor test are shown in Table IV.

TABLE IV. RESULTS OF TARGET AIMING TASK CONDUCTED WITH SUBJECTS IMMERSED IN WATER AND BLINDFOLDED

| Subject | Mean Errors Made by Subjects Recorded as Mean Displacement of Dot from Center of Target in Vertical (Y Axis) and Horizontal (X Axis) Errors Measured in CMS | | | | | |
|---|---|---|---|---|---|---|
| | Test No. 1 After 3 Hours Immersion | | Test No. 2 After 6 Hours Immersion | | Test No. 3 After 10 Hours Immersion | |
| | X Axis | Y Axis | X Axis | Y Axis | X Axis | Y Axis |
| R.M. | +3.3 | +6.5 | +2.1 | +7.2 | | |
| L.P. | −1.9. | +4.3 | −1.6 | +2.0 | | |
| R.C. | +2.7 | +7.5 | +3.3 | +4.7 | +3.6 | +9.6 |
| H.M. | +3.3 | +6.5 | +2.1 | +7.2 | | |
| E.B. | −5.4 | +8.8 | −3.4 | +8.8 | −4.3 | +4.8 |

The changes in sleep requirement which had been observed by Graveline et al[9] were not observed in these experiments. The experimental procedures were started at around midnight so that the subject started the test with little or no sleep for the day. Most subjects became drowsy shortly after being immersed in the tank. EEG traces were taken on two subjects to determine the level of sleep. One subject showed deep sleep patterns. However, the "snoring index" was considered to be sufficiently accurate for this experiment. It was found to be positive in five of the seven subjects. Subjects tended to sleep as much as the experimental protocol permitted between midnight and 8 o'clock, which amounted to about 4 to 6 hours for some subjects.

## DISCUSSION

The results of this study demonstrated significant alterations in the normal physiology which were not contemplated in the original experimental design. Although urinary diuresis had been reported by Graveline et al[9] the specific gravity determinations were not reported so that the severity of the diuresis was not anticipated. In these studies the onset of water diuresis began, in some subjects, within half an hour after being immersed in the tank. The diuresis continued throughout the duration of water immersion, not only in subjects immersed for 12 hours, but also in the subject immersed for 23 hours. It was significant that the water diuresis continued with continuous output of low specific gravity urine even though the subjects became progressively more dehydrated up to the point of a maximum water loss amounting to 6 pounds over 12 hours in one subject. Urinary water output can be likened to the renal washout which occurs in diabetes insipidus or the water excretion produced by negative pressure breathing.[1,3] The copious low specific gravity urine output and low electrolyte content of the urine suggests that the negative pressure breathing of partial water immersion up to neck level has activated the volume receptors of Gauer and Henry.[6]

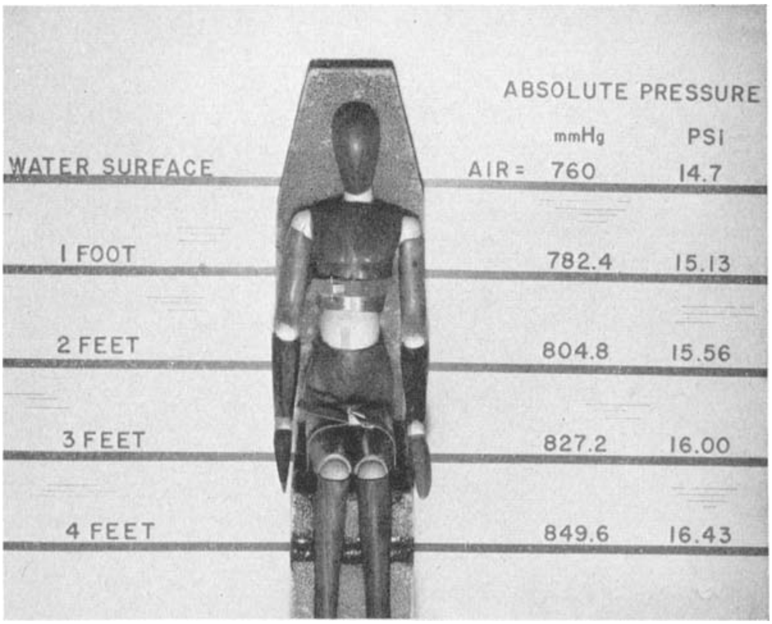


Fig. 2. Model showing the hydrostatic pressure exerted on the external chest.

Analysis of the physical system in which the subject is placed discloses that a subject who is immersed in water up to neck level has his lower body in a hydrostatic pressure system which is depth dependent so that at the lower chest level, he must breathe against a hydrostatic pressure of about 1 foot of water or approximately 22.4 mm. Hg (Fig. 2). However, since the subject is immersed only to neck level, the air pressure surrounding his neck and head is only one atmosphere or 14.7 psi and this pressure is exerted through the airway into the alveolar spaces of the lung. This difference between the pressure of the air in the lungs and the hydrostatic pressure external to the chest is basically a negative pressure breathing situation. This is demonstrated in these tests by the fact that an increase of between 6 and 11 mm. Hg positive pressure was required to re-establish the normal volumetric compartmentation of the lung. The magnitude of over-pressure on the chest wall and abdomen is comparable to the under-pressure used in the negative pressure breathing studies reported by Boyland.[3] These investigators studied the effect of negative pressure breathing at —15 cm. of water pressure in moderately hydrated men and found an increase in the excretion of free water with no characteristic changes which would account for the diuresis. They observed that 75 per cent of their test subjects showed a diuretic response to negative pressure breathing with an increase of 114 per cent in urinary output. They reported that the greatest percentage of the urinary increase was due to an increase in the output of free water.

The physiological alterations which accompany negative pressure breathing have been analyzed by Bader and Bader.[11] These investigators demonstrated that, due to negative pressure breathing at —10 to —16 cm. water pressure, there were changes in the pulmonary compartmentation comparable to those demonstrated by water immersion as follows: a slight decrease in the tidal volume, decrease in the expiratory reserve volume, increase in inspiratory volume, and no significant change in the vital capacity. These investigators have also reported an increase in the pulmonary blood volume and an increase in the work of breathing. The changes in respiratory physiology were likewise associated with changes in cardiac function with an increase of stroke volume of 40 per cent and an equal increase in the cardiac index as well as an increase in cardiac output. They reported an increase in forearm (peripheral) blood flow but no change in systemic blood pressure or the plasma volume. These investigators also reported a diuresis of 200 per cent with no change in electrolyte output and no change in renal hemodynamics.

Inasmuch as water immersion, under the conditions of this experiment, subjected the individuals, in effect, to negative pressure breathing with resultant renal function changes and pulmonary function changes comparable to those recorded by Bader, it may likewise be assumed that the changes in cardiac function reported by Bader could have also occurred in these experiments. The increase in the work of breathing was estimated, during water immersion, on the basis of the increase in pressure necessary to re-establish normal lung compartmentations to be approximately five times greater than the normal work of breathing. If such an increase in work of breathing was coupled with an increase in cardiac work, as predicted by increased cardiac output, the dyspnea reported by one subject, together with the evidence of increased cardiac work, would be reasonably expected.

It is significant that the diuretic effect persisted for the duration of the negative pressure breathing period. Previously reported studies on diuresis utilized negative pressure breathing periods which varied from 30 minutes[3] to 2 hours.[1] Negative pressure breathing periods of the duration used in this experiment have not been previously reported and it is signficant that the diuretic effect produced by the volume receptors in the left atrium of the central venous system should remain effective in producing diuresis for periods of time varying from 12 to 23 hours. It is likewise of interest in the investigation reported by Graveline et al[9] that the diuretic effect persisted for three days, at which time the urinary output returned toward the pre-run level. This, perhaps, establishes an upper limit for the duration of volume receptor diuresis.

The relationship between the physical and physiological conditions of partial water immersion and the zero G state are difficult to define. When the body is immersed in water while the pulmonary circuit is not pressurized, the hydrostatic pressure acts upon the venous blood distribution and shifts the blood into the unpressurized pulmonary circuit. This shift of blood volume was presumably sufficient in these experiments to trigger the volume receptors of the left atrium and induce diuresis. In the null-gravity state, the blood volume distribution would not be controlled by the dependent pressure effects so that blood volume distribution would be established by venomotor reflexes, tissue pressures of the extremities and the respiratory pressure pump. It may well be that a redistribution of blood into the central pool would occur under zero G conditions. The diuresis from an increased central blood volume might be induced under these conditions in the same way that it is by partial water immersion.

In the experiment reported by Graveline et al,[9] the change in the diurnal sleep pattern was believed to be quite significant in that the subject required less than 2 hours of sleep each day. EEG tracings were obtained on only two subjects in this experiment, one of whom showed deep sleep. The subjects, in general, were immersed in the tank between midnight and one o'clock in the morning and were not permitted to sleep before that time. Some subjects promptly fell asleep after being placed in the tank and the "snoring index" confirmed the indications of the EEG tracings. Some subjects slept four or five hours after being placed in the tank. This is indeed in variance with the findings of Graveline et al[9] and, perhaps, reflects the different motivations of the subjects.

The results of the G tolerance tests were quite variable. In general, it was apparent that although the subjects were obviously fatigued by the water immersion, tracking responses of most subjects to proficiency tests were satisfactory in the supine position after the period of water immersion. There was a decrement in performance of the tracking task in both the vertical and horizontal axes in the pre- and post-immersion tests. This finding indicates that there was a significant decrement in tracking ability caused by the acceleration. This finding further suggests that performance testing during exposure to the simulated acceleration profiles of launch and reentry will be required for all contemplated space vehicles utilizing human operators. Subjects also showed a decrease in positive G tolerance following immersion. This decrease in tolerance to the 4.5 positive G load could not be readily associated with any measured change and, no doubt, represents the same alteration in vasopressor response as the decreased cardiovascular response to tilt table tests reported by Graveline et al.[9]

The target aiming tasks also demonstrated a consistent error in target pointing during immersion in water which persisted over the 8-10-hour test period. These findings suggest that the learning period required to overcome the proprioceptive miscues under zero G will be prolonged during space flights.

The effect of immersion in water up to neck level suggests an interesting commentary upon the extreme fatigue which was reported in the last war by survivors from shipwrecks who were forced to remain in water for long periods of time before being rescued. The implications of the investigations of Gauer and Henry[6] suggest that diuresis would be produced by water immersion up to neck level. Personnel who are immersed in water and have their head supported only by a life jacket will be in a physical situation analogous to this experiment so that such personnel must perform negative pressure breathing. Diuresis must therefore be anticipated in any survivor who must depend on floatation from his life jacket alone. It would seem that the concept of survival by the use of life jackets may not be adequate and that a change in the concepts of survival from ship disaster should be considered so as to provide passengers and crews of seagoing vessels with a small personal life raft such as the one-man dinghy supplied to Naval aviators for survival at sea.

## CONCLUSIONS

1. Immersion of subjects in water up to neck level produced a continuous diuresis presumably on the basis of the Gauer-Henry left atrial volume receptor reflex.

2. Immersion in water up to neck level causes changes in pulmonary compartmentation represented by a slight decrease in vital capacity, decrease in the expiratory reserve volumes with an increase in the inspiratory volume and a de-

crease in tidal volume which is compensated for by an increase in respiratory rate.

3. Immersion of subjects in water up to neck level for periods of 12 to 23 hours resulted in a decrease in tolerance to positive acceleration.

4. Immersion of subjects in water up to neck level for 12 hours produced a moderate change in ability to perform a tracking task during exposure to 8 G, transverse acceleration, but without any significant change in physical ability to tolerate this acceleration.

## SUMMARY

Knowledge relative to the effects of prolonged weightlessness is needed in preparing man for space flight. The buoyant force exerted upon immersed bodies effectively simulates the weightless state with respect to proprioceptive sensory responses and perhaps in other ways. An investigation into the physiological effects of immersing subjects in water up to neck level was undertaken. It was found that water immersion produces an unnatural physiological situation in that, during respiration, the inspired air inflates the lungs to atmospheric pressure while the external pressure against the chest, abdomen, and legs, due to the water, is greater than atmospheric. This situation is equivalent to "negative pressure breathing."

A series of experiments involving seven subjects immersed in water up to neck level for periods of 5 to 23 hours (five subjects for 12 hours) showed a significant weight loss during the period of immersion, which was explained by the diuresis which occurred. Pulmonary volume measurements showed a decrease in the expiratory reserve volume and in the respiratory minute volume during immersion. There was no significant decrement in the performance of a tracking task, attributable to the water immersion, during exposure to a simulated space vehicle reentry deceleration profile. Exposure to 4.5 positive G for 15 seconds following water immersion revealed a decrement in tolerance in most subjects.

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