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# PHYSIOLOGIC RESPONSES TO WATER IMMERSION IN MAN: A COMPENDIUM OF RESEARCH

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16. Abstract

Since the advent of space flight programs, scientists have been searching for ways to reproduce the zero-gravity effects of weightlessness. Brief periods of weightlessness up to 1 minute were feasible using Keplerian trajectory, but comprehensive study of the prolonged effects of the weightless state necessitated the development of other methods. Thus far the two approaches most widely used have been complete bedrest and fluid immersion. Surprisingly, these simulated environments have produced essentially all of the symptoms found in astronauts.

This compendium contains reports appearing in the literature through December 1973. When the author's abstract or summary was adequate, it was used. If these were not available a detailed annotation was provided under the subheadings: (a) purpose, (b) procedures and methods, (c) results, and (d) conclusions. The annotations are in alphabetical order by first author; author and subject indexes are included. Additional references are provided in the selected bibliography.

Two other related compendia have been published: Greenleaf, J. E., C. J. Greenleaf, D. Van Derveer, and K. J. Dorchak, ADAPTATION TO PROLONGED BEDREST IN MAN: A COMPENDIUM OF RESEARCH, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, Calif. 94035, NASA TM X-3307, 1975. Dorchak, K. J. and J. E. Greenleaf, THE PHYSIOLOGY AND BIOCHEMISTRY OF TOTAL BODY IMMOBILIZATION IN ANIMALS: A COMPENDIUM OF RESEARCH, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, Calif. 94035, NASA TM X-3306, 1975.

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## INTRODUCTION

Since the advent of space flight programs, scientists have been searching for ways to reproduce the zero-gravity effects of weightlessness. Brief periods of weightlessness up to 1 minute were feasible using Keplerian trajectory, but comprehensive study of the prolonged effects of the weightless state necessitated the development of other methods. Thus far the two approaches most widely used have been complete bedrest and fluid immersion. Surprisingly, these simulated environments have produced essentially all of the symptoms found in astronauts.

A comparison of the physiologic effects of weightlessness with bedrest and water immersion procedures is beyond the purpose of this review. However, both simulated states lead to a deterioration of the circulatory system similar to that observed with prolonged weightlessness in space flight. Two discrete differences between true and simulated weightlessness of water immersion are immediately apparent: (a) hydrostatic forces exerted on the body surface produce a state of negative pressure breathing which shifts blood into the intrathoracic circulation and (b) gravitational influences during water immersion are still present but bodily movements require reduced muscular effort. Conversely, similarities between weightlessness and water immersion also exist: (a) prompt involuntary diuresis together with body weight and plasma fluid losses occurring within a few hours after immersion closely resemble changes observed in astronauts during space flight and (b) body deconditioning and orthostatic intolerance following prolonged immersion or weightlessness are very similar. A true weightless condition cannot be achieved through water immersion alone, however, a fundamental advantage of immersion is the rapidity with which physiologic mechanisms respond and adjust to immersion and closely duplicate the weightless state.

This compendium contains reports appearing in the literature through December 1973. When the author's abstract or summary was adequate, it was used. If these were not available a detailed annotation was provided under the subheadings: (a) purpose, (b) procedures and methods, (c) results, and (d) conclusions. The annotations are in alphabetical order by first author; author and subject indexes are included. Additional references are provided in the selected bibliography.

Two other related compendia have been published: Greenleaf, J. E., C. J. Greenleaf, D. Van Derveer, and K. J. Dorchak, ADAPTATION TO PROLONGED BEDREST IN MAN: A COMPENDIUM OF RESEARCH, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, Calif. 94035, NASA TM X-3307, 1975. Dorchak, K. J. and J. E. Greenleaf, THE PHYSIOLOGY AND BIOCHEMISTRY OF TOTAL BODY IMMOBILIZATION IN ANIMALS: A COMPENDIUM OF RESEARCH, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, Calif. 94035, NASA TM X-3306, 1975.

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## ANNOTATED REFERENCES

1. Adams, C. R. and G. K. Bulk. Zero-buoyancy: simulation of weightlessness to evaluate the psycho-physiological and anthropometric parameters that affect space station design. Aerospace Medical Association Preprints, 1965, p. 1-3.

*Purpose:* To evaluate psycho-physiological and anthropometric effects of weightlessness on orbital crewmen.

*Procedures and methods:* Space station mockups were immersed in water to enable a neutrally buoyant, completely immersed crewman to perform in simulated weightlessness.

*Conclusions:*

The proper use of existing hardware and arrangements of controls and displays obviates exact operator-to-panel-type orientation; thus the design of controls and displays that can be operated and interpreted from all orientations is not needed.

To keep the crewmen from floating or drifting about while asleep, a comfortable body restraint is required, but his position can be independent of the space-station interior orientation.

The type and amount of restraint depends on the specific task. Various experimental data from tasks performed during a Keplerian trajectory and an air bearing indicate that, in general, a man can perform tasks as accurately and as quickly during zero-G during normal 1.0 G condition if restrained.

Velcro tape is satisfactory in some situations where less restraint is needed.

Appropriately placed hand-holds and rails can provide casual restraint. A firmer restraint can be achieved by inducing a compression load between the rail or hand-hold and the deck.

Most operational maintenance, assembly, experimental, and crew support tasks require a restraint that leaves both hands free. Some methods investigated showed that reactive motions were eliminated by a waist belt-ring device, a special tie-down quick connect-disconnect device mating with the shoes, and various handrails for arm and/or leg support.

The crewman must be constantly attached to the space station for extravehicular operations.

Large or small structural components can be aligned or adjusted by by loosely attaching each part to its approximate position until the structure is grossly assembled; then each test item can be made firm, adjusted to fit, and calibrated.

Exercises can be performed in any orientation using available surfaces for compression and tension restraints.

Most intravehicular and extravehicular tasks can best be achieved by planning the steps with a function and task analyses, then executing the plan on a time-line basis. This procedure would establish the initial basic parameters for an economical and effective methodology compatible with the design of the space station and paraphernalia.

Stress, aversion, or discomfort were not apparent during the tests, a very pleasant and enjoyable experience.

Evidence indicates that if vision is the only component providing accurate orientation information, it predominates over other perceptions, and the crewman can be well oriented by vision alone.

2. Agostoni, E., G. Gurtner, G. Torri, and H. Rahn. Respiratory mechanics during submersion and negative-pressure breathing. *Journal of Applied Physiology* 21:251-258, 1966.

*Authors' abstract:* During submersion up to the neck the expiratory reserve volume of the sitting subject is reduced to 11 percent of the vital capacity in air, the same decrease is obtained breathing from a tank at -20.5 cm $H_2O$. The decrease in lung volume is mainly due to the cranial displacement of the abdomen, although at the end of spontaneous expirations during submersion the diaphragm is stretched almost as far as at full expiration, it is relaxed, whereas during a full expiration it contracts. The end-expiratory pressures across the rib cage, the diaphragm, and the abdominal wall are: –19, –14, that –13 cm $H_2O$ during submersion and -23.5, -11.5, and -12 during NPB. Notwithstanding the lack of the gravitational effect of the abdomen during submersion, the shape of the chest wall is almost the same as during negative-pressure breathing because of the low compliance of the rib cage. During submersion, the airways resistance increases by 58 percent because of the lung volume decrease; during negative-pressure breathing it increases by 157 percent, the extra increase being due to the compression of the extrathoracic airways.

3. Ananyev, G. V., V. P. Baranova, N. N. Gurovsky, M. M. Korotaev, T. N. Krupina, B. T. Romanov, and I. Ya. Yakovleva. On increasing human non-specific tolerance to environmental extremes. Proceedings of the XVII International Congress on Aviation and Space Medicine, Oslo, 1968. Edited by B. Hannisdahl & C. Wilhelm Sem-Jacobsen. Oslo: Universitetsforlaget, 1969.

*Authors' abstract:* Preparation for flights to other planets will require an increase in the compensatory-adaptive abilities of the human organism to withstand the effects of stressor factors. In this connection a problem urgently arises as regards strengthening the nonspecific stability of the organism. The studies carried out by us showed that the combined effect of a variety of factors – repeated radial acceleration of various intensities, hypokinetic condition, human sojourn in closed environments – result in a decrease of compensatory-adaptive abilities of the organism and its immunobiological responses. Tolerance to orthostatic and vestibular stimulations decreased. These alterations persisted for 2 weeks following the orthostatic effects and for 2-3 months following the vestibular effects.

Thus, the results of our experimental studies and clinical observations made it possible for us to suggest the following ways of increasing human nonspecific stability: physical training, vestibular training, acclimatization to hypoxia, and use of the adaptogens.

4. Arborelius, M., Jr., U. I. Balldin, B. Lilja, and C. E. G. Lundgren. Hemodynamic changes in man during immersion with the head above water. *Aerospace Medicine* 43:592-598, 1972.

*Authors' abstract:* Cardiac output (dye dilution method), right atrial, and brachial arterial pressures were recorded in 10 subjects sitting in neutral temperatures in air (28° C) or immersed with the head above water (35° C). Measurements were made both during air and oxygen breathing. In 3 air-breathing subjects the central blood volume and the pulmonary arterial pressure were also measured. During immersion and air breathing, cardiac output increased by 1.8 liters/min or 32 percent and stroke volume by 26 ml or 35 percent, while heart rate was almost unchanged. Right atrial and pulmonary arterial transmural pressure gradients increased in the immersed subjects by about 13 mm Hg. Systemic vascular resistance decreased by 30 percent. The central blood volume increased during immersion by about 0.7 liters. Extra systoles were sometimes seen during the first minutes of immersion. The relative changes in circulatory parameters measured during air and oxygen breathing were essentially the same.

5. Arborelius, M., Jr., U. I. Balldin, B. Lila, and C. E. G. Lundgren. Regional lung function in man during immersion with the head above water. *Aerospace Medicine* 43:701-707, 1972.

*Authors' abstract:* The distribution of pulmonary blood flow and ventilation before and after immersion to the neck during air and oxygen breathing was studied in seven healthy volunteers. Ventilation and perfusion

per unit lung were studied by $^{133}$Xenon-radiospirometry. The collimators recorded radioactivity in two large apical and two large basal lung regions. A slight redistribution of ventilation toward the apical regions occurred during immersion and apical blood flow increased and basal blood flow decreased so that the distribution of blood perfursion became even. The ventilation-perfusion ratio became more even with immersion which was mainly due to the marked change toward an even perfusion. The same relative findings were found both during air and oxygen breathing. There were no statistically significant changes in arterial blood gas tensions during immersion, but the technique involved measurements at TLC so that atelectasis formation, which otherwise might develop during immersion, was presumably prevented.

6. Balldin, U. I. Effects of ambient temperature and body position on tissue nitrogen elimination in man. *Aerospace Medicine* 44:365-370, 1973.

   *Author's abstract:* The influence of ambient temperature (25° 28° and 37° C) and different body positions (sitting and supine) on tissue nitrogen elimination during (2 hr) oxygen breathing was studied in six subjects. A persistently larger volume of eliminated nitrogen was recorded under warm (37° C) conditions compared to thermally neutral (28° C) conditions. The difference was particularly marked toward the end of the experiments, the mean nitrogen yield then being about 17 percent larger in 37° C. In cool temperature (25° C), there was a tendency for a slight increase in nitrogen elimination compared to neutral temperature conditions. During supine body position, there was a prompt increase in nitrogen elimination when compared to the sitting position, the nitrogen yield being 24 percent larger after 30 min and 15 percent larger after 2 hr (in neutral temperature). The most pronounced and sustained gain in nitrogen elimination was observed during the supine body position in warm environments, the nitrogen yield being about 30 percent larger than in sitting position and at a neutral temperature both after 30 min and 2 hr. It is suggested that the increased nitrogen elimination induced both by supine body position and warm environment was due to enhanced blood circulation. The present observation may bear on decompression routines.

7. Balldin, U. I., G. O. Dahlback, and C. E. G. Lundgren. Changes in vital capacity produced by oxygen breathing during immersion with the head above water. *Aerospace Medicine* 42:384-387, 1971.

   *Authors' abstract:* Oxygen breathing and immersion for 2 hr, with the head above water, reduced the vital capacity (VC) in 13 healthy subjects by an average of 22.4 percent compared with controls during immersion before oxygen breathing. Oxygen breathing without immersion did not reduce VC but it was reduced by 7.8 percent by immersion per se. Immersion apparently strongly potentiated the adverse effect that oxygen may have on the lungs, in particular, by promoting atelectasis formation. The theory of atelectasis formation was supported by the subjects having cough and chest pain which initially was increased but finally was relieved by forced inspirations. Forced inspirations also partly restored the VC.

8. Balldin, U. and C. Lundgren. The effect of immersion on inert gas elimination. *Acta Physiologica Scandinavica,* Supp. 330:83, 1969.

   *Authors' abstract:* The greater risk of decompression sickness in wet than in dry dives induced this work. The effects of submersion itself on nitrogen elimination were studied. Nitrogen elimination from the tissues was measured continuously with an electronic nitrogen-meter during oxygen breathing. In the wet experiments the subjects sat immersed to the chin in water with temperatures between 32° and 37° C. During submersion there was a significantly higher rate of nitrogen elimination than under dry conditions (temperature about 29° C). For instance, the amount of nitrogen eliminated was 15 to 70 percent larger in a 60-min period of oxygen breathing sitting in water of 35° C as compared to dry conditions. Apart from the effects of temperature, an important factor increasing the nitrogen elimination appears to be the submersion itself.

   Submersion might influence the ventilation-perfursion ratio in the lungs, cardiac output and its distribution, and the rate of transfer of gas between tissue and blood.

Preliminary experiments performed in collaboration with S. Mellander and J. Lundvall showed that intramuscular deposits of $^{133}$Xe were cleared at a faster rate from dependent regions during submersion than in dry conditions. This might at least partly be related to the opening up of capillaries, increasing the capillary exchange surface. The submersion leads to decreased vascular transmural pressure which, in turn, may reduce the myogenic precapillary sphincter tone normally prevailing in dependent regions.

9. Balldin, U. I. and C. E. G. Lundgren. Effects of immersion with the head above water on tissue nitrogen elimination in man. *Aerospace Medicine* 43:1101-1108, 1972.

*Authors' abstract:* Nitrogen elimination during oxygen breathing was studied in five subjects in dry conditions and during immersion with the head above water. Sitting in water of neutral temperature (35° C) yielded 40 percent more nitrogen after the first 30 min and 29 percent more after 2 hr compared to sitting dry at neutral temperature (28° C). In warmer water (37° C) the increase was 49 percent after 30 min and 36 percent after 2 hr. In cool water (32° C) the increase was 26 percent after 30 min but there was no significant difference after 2 hr. Body temperature, pulse rate, and oxygen consumption increased toward the end of the 2-hr period in warm water compared to sitting dry. In cool water there was also a slight increase in oxygen consumption but a decrease in body temperature compared to dry conditions. The augmentation of nitrogen exchange during immersion, which might bear on diving safety, appears to be caused by an increase in the circulation of blood.

10. Balldin, U. I., C. E. G. Lundgren, J. Lundvall, and S. Mellander. Changes in the elimination of $^{133}$Xenon from the anterior tibial muscle in man induced by immersion in water and by shifts in body position. *Aerospace Medicine* 42:489-493, 1971.

*Authors' abstract:* The elimination of $^{133}$Xe from a deposit in the anterior tibial muscle was studied in sitting human subjects under dry conditions and during water immersion to heart level. Studies were made both during air and oxygen breathing. In a supplementary study, the rate of Xe-elimination from the same muscle was recorded in erect and supine body position. Immersion led to an increase of Xe-clearance above that during dry conditions, averaging 130 percent during air breathing and 103 percent during oxygen breathing. Xe-clearance in supine position exceeded that in the erect position by 102 percent. These effects may reflect corresponding increases of muscle blood flow. Increased functional capillary surface area possibly also contributed to the enhanced Xe-elimination. The vascular adjustments in muscle, mainly related to altered gravitational influence on the circulatory system, might explain the increased overall elimination rate of nitrogen from the body during oxygen breathing observed during immersion.

11. Bazett, H.C. Studies on the effects of baths on man. I. Relationship between the effects produced and the temperature of the bath. *American Journal of Physiology* 70:412-429, 1924.

*Purpose:* To attempt to distinguish between the mechanical effects of immersion from temperature effects.

*Procedure and methods:*

Fourteen subjects (including 4 women).

Five were exposed to hot moist air environments (36.5° – 37.5° C). Thirty-six experiments were carried out in water temperature initially held at 35.5° – 36.5° C for 4 hr and then rapidly raised 4° C in either direction. The subjects assumed a semireclining position with the knees bent and stood at hourly intervals to urinate. In a few cases the rectal temperature was recorded; but usually the urine temperature was taken as an estimate of body temperature.

*Results:*

Pulse rate increased in hot water, the rise was proportional to the rise in body temperature. Alveolar

$CO_2$ tension fell markedly in the neutral as well as the hot baths. Urinary loss and sweating may proceed at a rate of 1.6% of body wt/hr. Increased urinary output was most marked within 1 hr of immersion – a six-fold increase that was independent of water temperatures. Blood pressure was lowered in neutral water and the significant fall in blood pressure in hot water brought the subjects to the verge of fainting.

*Conclusions:*

The general changes observed in man as the result of immersion in a hot or warm bath are reviewed and an attempt is made to distinguish the mechanical effects of the bath from those due to temperature. Further details of particular responses are included in later papers.

The circulatory and respiratory changes observed are dependent mainly on changes both in body and skin temperatures.

A diuresis of considerable degree is observed and is relatively independent of the temperature of the bath, but the amount of titratable acid excreted per hr is influenced greatly by changes in body temperature.

A summary is given of the symptoms so far observed during the experiments. These included dyspnea, palpitation, and pulsation of the extremity blood vessels in 38 – 40° C water. Later, hyperexcitability and fainting may ensue. Muscle tetany including tonic spasms of the hands, legs, thighs, and abdomen were also observed. Mental confusion was only moderate when the bath temperature was rapidly increased, but tetany was more readily induced.

12. Bazett, H. C., J. C. Scott, M. E. Maxfield, and M. D. Blithe. Effect of baths at different temperatures on oxygen exchange and on the circulation. *American Journal of Physiology* 119:93-110, 1937.

*Purpose:* To test the applicability of empirical calculation of cardiac output from blood pressure and pulse wave velocity.

*Procedure and methods:* Cardiac output was estimated by the acetylene method and from blood pressure and pulse wave velocity. Four subjects were immersed to the neck in neutral (35° C) and warm (38° C) water baths. Eighteen experiments were recorded. In another series of tests, 6 experiments were conducted on 4 subjects as the water was rapidly cooled from 35° C to 31–32° C. Rectal temperature, oxygen consumption, blood pressure, pulse rate, and cardiac output were obtained in warm and cool baths. Experiments conducted during the summer months were compared with those obtained in the winter.

*Conclusions:*

Comparisons have been made between estimates of cardiac output by the acetylene procedure and by calculation from blood pressures and pulse wave velocities, when the subjects were immersed in cool, neutral or warm baths. In spite of marked changes in the vascular conditions the two methods gave results which indicated the same picture and did not differ from one another on the average by more than ±14.7 percent, provided that experiments made in the summer months on two subjects be excluded. Normal agreement was obtained in these subjects in the winter.

Such systematic discrepancies were only seen when the cardiac outputs estimated from the blood pressures exceeded 3.4 liters per square meter per minute; it is argued that the cardiac outputs were probably high, and beyond the capacity of the acetylene method with the sampling times used.

On such interpretations the cardiac output might be slightly increased or decreased with a slowing pulse in cool baths. It was considerably increased with a larger stroke volume and increased pulse rate in the early stages of warm baths and was reduced to a basal level in spite of a high oxygen consumption in the later stages of warm baths as the result of dehydration. In this latter stage the stroke volume was very small. The subjects were much more susceptible to such dehydration in the winter, so that the initial increase in cardiac output was less marked, and any increase in stroke volume rarely demonstrable.

In the terminal stages of winter experiments with warm baths quite high A–V differences (up to 82.5) might be found. In view of the high skin circulation, these must have implied very low saturations in active tissues.

In warm baths both systolic and diastolic pressures may be lowered initially, but the fall in diastolic pressure is far less than those commonly described. During incipient circulatory failure following dehydration both pressures tend to be raised.

The large arterial trunks show properties which imply their utilization as a blood reservoir; the pulse wave velocity in the ascending aorta is slowed in cool baths when the peripheral arterioles are constricted, quickened in warm baths when these are dilated, and becomes still more rapid as the individual attempts to compensate for dehydration.

The pulse pressure may be considerably increased, even when the stroke volume is decreased; such changes depend on decreased distensibility of the large arterial trunks.

Pulse rate changes to temperature are not explicable as the simple effect of either surface or rectal temperature changes; the factors involved are complex.

The increased oxygen consumption with rise in body temperature cannot be readily be related to changes in rectal temperature; if, however, it be compared to changes in average body temperature the data give a value for $Q_{10}$ of about 2.9.

13. Bazett, H. C., S. Thurlow, C. Crowell, and W. Stewart. Studies on the effects of baths on man. II. The diuresis caused by warm baths, together with some observations on urinary tides. *American Journal of Physiology* 70:430-452, 1924.

*Purpose:* To characterize the diuresis produced by warm water baths.

*Procedure and methods:* Urinary secretion rates were studied during rest in bed followed by early morning observations and during and after immersion in warm baths. Three subjects underwent repeated bedrest (10 hr) and water immersion (2-3 hr) tests for the determination of urine secretion patterns. Water immersion (36° C) was routinely performed 2-3 hr following breakfast (7 A.M.) or lunch. Urine was analyzed for urea, chloride, pH, ammonia, and phosphates. In some instances subjects were partially immersed at different body positions to allow immersion of the abdomen and thorax while the lower limbs were resting out of the water. Partial immersion, in which the subject sat in the bath at different heights, was also attempted.

*Conclusions:* In many subjects, a urinary alkaline tide is seen on waking even when no food is taken and the subject remains in bed.

On waking there is also nearly always a chloride tide, often accompanied by an actual increase in the chloride concentration of the urine.

Some partial interdependence of alkaline, chloride, and phosphate tides is suggested by the results obtained. These do not appear to be caused by changes in body temperature although they are possibly affected by them.

Lying down causes an increase in the urine secreted per hour, with a considerable rise in the urea excreted and often a rise in the ureas concentration. Increased intestinal absorption is suggested as a possible cause.

Immersion in baths of neutral temperature causes the excretion of a large volume of urine consisting mainly of water in which the chlorides drop to about 0.04 N, although the total excretion of chloride per hour is increased. The urea concentration however, often drops very little so that the urea output per hour is much increased. Even if the subject has been lying down for some time previously so that the effect of this is passing off, the urea excretion may be much increased by the bath. The phosphate excretion is practically unchanged.

The bath diuresis is almost invariably seen, but varies in degree in different subjects and in the same subject on different occasions. The degree of diuresis reached in any subject has proved to be less the greater the chloride concentration of the urine in the preliminary control period. No constant relationship has been seen between the rates of urine formation before and in the bath.

The diuresis usually subsides in a few hours after the excretion of some 300 to 800 cc of excess fluid.

The diuresis is induced by immersing the trunk in water without the limbs being immersed,but is not caused by immersing the lower half of the body up to the level of the unbilicus.

The baths when entered cause a sensation of warmth. The hemoglobin percentage has fallen slightly on entering the bath in some subjects, but later in all subjects it has shown a concentration.

It is tentatively suggested that the pressure of the water on the abdomen raises venous pressure and that, in adjusting to this condition, new salt and water balances are set up, causing secretion of urine and absorption of fluid. The main source of this fluid may be the intestine.

14. Beavers, W. R. and B. G. Covino. Immersion hypothermia: Effect of glycine. *Proceedings of the Society for Experimental Biology and Medicine* 92:319-322, 1956.

*Purpose:* To find a metabolic stimulant to aid in the rewarming process of hypothermia. Proteins were chosen because of their high specific dynamic action.

*Procedure and methods:* Ten dogs were anesthetized and immersed in 8° C water and cooled to a rectal temperature of 28° C and allowed to rewarm. Five dogs received 5 percent glycine solution IV (500 cc), five controls received 5 percent glucose (500 cc).

*Conclusions:*

Glycine-treated animals took a longer time to cool to end point and rewarmed at a faster rate due to a higher metabolic rate than controls for any given rectal temperature.

Thermogenic aids may augment the rate of rewarming. The mechanism responsible is difficult to evaluate; it may be a hyperglycemia effect via glycogenolysis or the specific dynamic action of amino acids on another mechanism.

15. Beckman, E. L. A review of current concepts and practices used to control body heat loss during water immersion. Research Task MR005.13 – 4001.06, 1966. Bureau of Medicine and Surgery, Navy Dept.

*Author's abstract:* The problem of providing adequate clothing for personnel who either during normal operations or accidently are immersed in cold water has continued to challenge clothing manufacturers. In the past decade the development of foamed plastics and other clothing materials has offered new possibilities.

Likewise advances in energy conversion and storage systems offer new solutions to this critical operational problem.

The basic physical and physiological concepts which relate to the problem of limiting thermal loss from the immersed human will be reviewed. Newer technical developments with relation to these basic concepts.

16. Beckman, E. L., K. R. Coburn, R. M. Chambers, R. E. Deforest, W. S. Augerson, and V. C. Benson. Physiologic changes observed in human subjects during zero G simulation by immersion in water up to neck level. *Aerospace Medicine* 32:1031-1041, 1961. (also NADC-M-6107, U. S. Naval Air Development Center, Johnsville, Pennsylvania, April 1961).

*Purpose:* To determine the effect of 12-24-hr immersion in 34.4° C water on diuresis and lung function.

*Conclusions:*

The slight decrease in the vital capacity of five subjects was due to a decrease in expiratory reserve volume.

Immersion for 12-23 hr decreased tolerance to positive acceleration.

Body weight losses ranged from 1.5 to 6.5 lb. The thirst mechanism was not stimulated despite dehydration and fluid availability.

17. Beckman, E. L. and E. Reeves. Physiological implications as to survival during immersion in water at 75° F. *Aerospace Medicine* 37:1136-1142, 1966.

*Authors' abstract:* It has been determined in previously reported experiments that immersion at water temperatures of 75° F (23.8° C) may be limited by failure of the body's physiological compensatory mechanisms. This investigation was designed to study the physiological responses of subjects immersed to neck level in 75° F water for periods up to 12 hr. Measurements relating to the body loss of heat, energy, fluids, and electrolytes were obtained. It was found that a 12-hr period of immersion could not be tolerated by all the subjects for various reasons: (1) loss of body heat with a reduction in deep body temperature to below the predetermined limiting temperature of 95° F, (2) extreme discomfort with muscle cramps following prolonged shivering, and (3) decrease in blood glucose to levels below the predetermined limiting value of 60 mg percent. The changes in blood morphology, blood electrolytes, oxygen utilization, and urinary excretion during the period of immersion, in addition to the physiological changes which caused the termination of some experiments, are directly related to tolerance of immersion. It was also found that some subjects experienced a significant adrenocortical stress response with subsequent adrenocortical insufficiency. These factors are of importance in survival from the involuntary immersion associated with disasters at sea.

18. Beckman, E. L., E. Reeves, and R. F. Goldman. Current concepts and practices applicable to the control of body heat loss in aircrew subjected to water immersion. *Aerospace Medicine* 7:348-357, 1966.

*Authors' abstract:* The problem of providing adequate clothing for personnel who either accidentally or otherwise are immersed in cold water has continued to challenge clothing manufacturers for the past decade. The development of foamed plastics and other clothing materials offers new possibilities. Likewise new advances in energy conversion systems offer new solutions to this critical operational problem.

The basic physical and physiological concepts which pertain to the problem of limiting thermal loss from the immersed human are reviewed. The newer technical developments in insulative clothing and supplemental heating systems are reviewed and discussed with relation to these basic concepts.

19. Behn, C., O. H. Gauer, K. Kirsch, and P. Eckert. Effects of sustained intrathoracic vascular distension on body fluid distribution and renal excretion in man. *Pflügers Archiv* 313:123-135, 1969.

*Authors' abstract:* Intrathoracic blood volume was increased by prolonged immersion in thermo-indifferent (34° C) water. Urinary excretion patterns of free water and electrolytes during immersion were compared with those for an identical period of the previous day when the subjects were performing routine activity. Plasma volume changes during immersion were compared with the concomitant urine volume which under these conditions can be equated with total fluid loss. The nature of the immersion diuresis depended on the state of hydration. Normally hydrated subjects showed a rise in free water clearance whereas a hydropenic group increased urine volume by an augmentation of osmolar clearance. Sodium excretion during immersion rose from 118 ±48 (SD) to 180 ±51.7 (SD) $\mu$eq./h X kg in normally hydrated subjects ($p > 0.05$) and from 66.8 ±22.5 (SD) to 152 ±43.3 (SD) $\mu$eq./h X kg ($p < 0.01$) in the hydropenic group.

Immersion led to plasma volume reduction in all cases. Plasma volume reduction constituted a much greater percentage of the urine volume in hydropenic subjects (98.8 ±35.4 (SD) percent) than in the normally hydrated ones (19.3 ±8.56 (SD) percent). It is concluded that engorgement of the intrathoracic volume-sensitive vascular areas may not only lead to increased fluid elimination by the kidney but at the same time to a shift of fluid from plasma into the interstitial space. Both effects serve the homeostatic control of blood volume.

20. Behnke, A. R. and C. P. Yaglou. Physiological responses of men to chilling in ice water and to slow and fast rewarming. *Journal of Applied Physiology* 3:591-602, 1951.

*Authors' summary and conclusions:* Two nude subjects were immersed shoulder-deep in ice water for about 1 hr until the toes became numb, then the exposure was terminated. The average water temperature varied from about 42° F in the winter to as high as 50° F in the summer. Following this drastic chilling, the subjects were rewarmed by exposure to air at 73° to 100° F or to water at 100° to 102° F. A third subject dressed in outdoor winter clothing was chilled in a cold chamber at -20° F for about 3 hr until his toes became numb. He was then rewarmed in air at 100° F without changing clothes.

Skin temperatures fell abruptly upon entering the cold bath, and the subjects experienced excruciating pain all over the body during the transistory period of vasoconstriction. Rectal, gastric, and oral temperatures, after an initial rise, fell continuously during the chilling period despite violent shivering and a sixfold increase of metabolic rate.

In rewarming of chilled subjects, skin temperatures rose abruptly, while deep temperatures continued falling for some time at a rate that was even greater than that during the preceding immersion period. A second cold shock was experienced during the first stage of rewarming which was even more distressing than the initial immersion shock. Its duration depended on the rapidity of rewarming. Rewarming in air at 70° to 100° F consumed several hours and unnecessarily prolonged the agony from shaking chills. Best results were obtained by rapid rewarming in water at 100° to 105° F. Under the conditions of our experiments, the need for rapid rewarming to prevent a precipitous after-drop of deep temperatures, and associated distress, is imperative.

21. Benson, V. G., E. L. Beckman, K. R. Coburn, and R. M. Chambers. Effects of weightlessness as simulated by total body immersion upon human response to positive acceleration. *Aerospace Medicine* 33:198-203, 1962. (also Bureau Medicine and Surgery, NADC-MA-6132, Rept. 12, June 26, 1961).

*Authors' abstract:* Twelve members of Underwater Demolition Team 21 used underwater breathing equipment while completely immersed in water for 18 hr. Their response to positive acceleration was determined by observing the G level at which the limitation of ocular motility under acceleration (LOMA) occurred. This G level is approximately the same as when loss of peripheral vision or greyout occurs when subjects are exposed to positive acceleration. The period of immersion was well tolerated. A small but statistically significant decrease in the G level at which LOMA occurred was found following the period of immersion.

22. Benson, V. G., E. L. Beckman, K. R. Coburn and R. E. Deforest. Weightlessness simulation by total body immersion: Physiological effects. NADC-MA-6134, U. S. Naval Air Development Center, Johnsville, Pa., 1961. 20 pp.

*Authors' summary:* In this series of experiments an attempt was made to eliminate the negative pressure breathing and the diuresis by equipping the subject with a full-face diving mask with a compensating regulator and completely immersing him in water for a period of 12 hr. The ability to withstand acceleration forces was measured prior to and following the water immersion period. Physiological and psychological changes that occurred as a result of the water immersion were also measured. Of the seven subjects tested, only three were able to tolerate the 12-hr period of water immersion. The remaining four terminated early in the study due to the stress of the underwater environment and were not exposed to acceleration forces following their immersion periods. Of the three who completed the study, two did not show any reduction in their ability to withstand the same acceleration forces following the period of water immersion; however, one was rendered unconscious by the same acceleration force he was able to withstand prior to the immersion period. Due to the small size of the water tank the subjects were in the sitting position during periods of psychological testing and also while watching television. This position resulted in a negative pressure breathing situation with the resultant profuse diuresis.

23. Black-Schaffer, B. and G. T. Hensley. Protection against acceleration by immersion during hypothermic suspended animation. *American Medical Association Archives Pathology* 69:499-505, 1960.

*Purpose:* To determine the effect of immersion against lethal acceleration forces.

*Procedure and methods:* Eight 12-day-old mice were made hyperthermic and centrifuged.

*Conclusions:*

When the mice were immersed, they were protected against lethal centrifugation forces and had a longer survival time post-acceleration.

24. Boening, D., H.-V. Ulmer, U. Meier, W. Skipka, and J. Stegemann. Effects of a multi-hour immersion on trained and untrained subjects: I. Renal function and plasma volume. *Aerospace Medicine* 43:300-305, 1972.

*Authors' abstract:* In 30 experiments, the effects of 8-hr recumbency and 4- to 8-hr immersion in thermo-indifferent water on renal function and plasma volume of trained and untrained persons were consecutively followed. Recumbency led to an increased diuresis and sodium excretion. With immersion the diuresis rose even more. For the trained subjects the urine excretion increased more slowly than in the case of the untrained. No reproducible difference of electrolyte excretion between both groups could be substantiated. The plasma volume was diminished after recumbency and immersion. No difference between trained and untrained persons could be substantiated. The decrease of plasma volume depended mainly on the amount of urine excreted. The later rise of diuresis for trained persons may exhibit an adaptation of the volume regulating reflexes to blood volume fluctuations during frequent work.

25. Boening, D., H.-V. Ulmer, U. Meier, and J. Stegemann. Effects of a multi-hour immersion on trained and untrained subjects: II. Blood protein and electrolyte concentrations. *Aerospace Medicine* 43:415-418, 1972.

*Authors' abstract:* Serial measurements on blood protein and electrolyte content were carried out during 4- to 8-hr immersion of trained and untrained human subjects. After an initial drop the hematocrit value and the hemoglobin concentration showed a general increase which could be accounted for by water displacement.

There was no significant change in total protein and albumin content in plasma. The sodium concentration fluctuated and the potassium concentration increased temporarily. Inorganic phosphate concentration, probably because of a change in metabolism, increased steadily. In the erythrocytes, the potassium concentration fluctuated and the chloride concentration decreased. No important differences could be ascertained between trained and untrained subjects.

26. Bondurant, S., W. G. Blanchard, N. P. Clarke, and F. Moore. Effect of water immersion on human tolerance to forward and backward acceleration. *Journal of Aviation Medicine* 29:872-878, 1958.

*Authors' summary:* A preliminary investigation of the effect of water immersion on tolerance to forward and backward acceleration is reported. Respiration was maintained during acceleration by use of a system modified from that used by skin divers. Acceleration time tolerances at 6 to 14 G were greater than twice any previously reported. As expected, immersed subjects are able to move with freedom during acceleration in water. Post-acceleration symptoms seem to be less severe than following equivalent acceleration of non-immersed subjects.

27. Booda, L. Man-in-the-sea projects will go deeper, stay longer. *Undersea Technology* 1965, pp. 16-19.

*Author's abstract:* The present organizations involved in human undersea capabilities and the testing of hardware systems are the U.S. Navy, Office Francais de Recherches Sous-Marines (French Undersea Research Office), and Ocean. Facilities support systems, hardware development, and health safety practices are discussed in relation to Sealab II. The influence of Jacques-Yves Cousteau's man-in-the-sea activities on the future development of commercial operations is also included.

28. Boutelier, C., J. Colin, and J. Timbal. Determination of the heat exchange coefficient in turbulent flowing water. *Journal of Physiology (Paris)* 631:207-209, 1971.

*Authors' abstract:* Subjects were immersed for 80 to 180 min in constant temperature moving water to determine the heat loss by convection from the body. This proved to be a mean of 53.3 ±0.8 Kcal/m$^2$ h °C, a value which is in good agreement with the results obtained by other authors.

29. Bowers, J. A., W. B. Hood, Jr., R. H. Murray, C. W. Urschel, and J. K. Goldman. Hemodynamic effects of water immersion. Aerospace Medical Association Preprints, 1965, pp. 32-33.

*Purpose;* To compare the hemodynamic effects of 8-hr periods of bedrest and water immersion.

*Procedure and methods:* Five Air Force volunteers, aged 19-29, were subjected to water immersion and bedrest. Using fluoroscopy, arterial and venous catheter tips were positioned in the superior vena cava and subclavian artery. During immersion (WI), a modified Air Force breathing helmet was adapted to a dry suit. Helmet flow was maintained at 120 liter/min at –6 mm Hg pressure. Hydration was maintained by oral fluid ingestion and intravenous fluids.

*Conclusions:*

Heart rate decreased about 6 beats/min during the first hour of WI but not during bedrest.

Central venous pressures during WI decreased about 6 mm Hg during WI.

During WI, mean arterial pressure fell approximately 6 mm Hg.

Cardiac index remained at control levels.

Central blood volumes after 3 hr of WI tended to be lower, while peripheral vascular resistance exhibited a slow rise.

In response to 60° head-up tilt, the post-WI subjects had a greater rise in heart rate upon tilting.

No significant differences were noted in the pre- and post-bedrest or WI tilts. However, all tilts demonstrated marked decreases in control blood volume and stroke volume. Cardiac output fell moderately.

30. Bowers, J. A., M. McCally, and R. H. Murray. Water balance and plasma volume during water immersion. *Aerospace Medicine* 37:266, 1966.

*Authors' abstract:* During both manned space flight and water immersion, decreases in circulating plasma volume and diuresis have been demonstrated. In order to determine the duration and extent of these changes during water immersion, 15 head-out water immersion experiments were performed on Air Force volunteers for periods varying from 4 to 16 hr of immersion. Fluid intake was maintained at 200 cc/hr (forced hydration) except for four experiments in which no fluid intake was allowed. Plasma volume using Evans Blue dye was determined pre- and post-immersion. Urinary output and fluid balance (intake minus output) were determined. A progressive fall in plasma volume was observed over the entire 16 hr of immersion. The greatest decrement occurred during the first 6 to 8 hr, averaging 830 ml ($p < 0.05$). After 8 hr of immersion only slight additional decreases in plasma volume were noted. Negative water balance was evident after 2 hr in all experiments. At the end of 8 hr, water balance averaged 1215 ±251 cc. After 12 hr of immersion, water balance was 1594 ±447 cc, and after 16 hr, 1582 ±444 cc. No significant differences were present between the responses of the forced hydrated subjects and the dehydrated subjects. It is concluded that during water immersion (a) circulating plasma volume decreases markedly during the first 8 hr, (b) a marked negative water balance is present for the first 12 hr after which a new equilibrium state is reached, and (c) the amount of fluid intake has only little effect on the above changes.

31. Boyer, J. T., J. R. E. Frazer, and A. E. Doyle. The haemodynamic effects of cold immersion. *Clinical Science* 19:539-550, 1960.

*Authors' summary:* The haemodynamic effects of immersion of part of a limb in icewater have been studied in 20 normal and 21 hypertensive subjects. Significant changes in cardiac output were frequently observed. The pressor response to cold immersion was not related to the magnitude or direction of change in either cardiac output or total peripheral resistance alone. The significance of these findings is discussed in relation to the prognostic value of the pressor response to cold and its use as an index of peripheral vascular reactivity.

32. Brown, J. L. Orientation to the vertical during water immersion. *Aerospace Medicine* 32:209-217, 1961.

*Author's summary:* Subjects were immersed in water at a depth of either 18 or 25 ft and then rotated in a tucked position on a rod through three, four, or five revolutions. Rotation was terminated with the head in sone of four positions: upright, inclined forward, down, or back. Upon termination of rotation, subjects were directed to point in the up direction, then to nod the head and correct the direction of pointing if necessary, and finally to swim toward the surface. There were errors in direction of initial pointing of as much as 180°. Errors were greatest with the head down or back and least with the head up or forward. Nodding of the head was followed by consistent improvement in the direction of pointing. There was little indication of any difficulty in swimming in the upward direction. Greater density of the legs as compared to the trunk resulted in fairly rapid vertical orientation of the body upon release of the rod. The results are interpreted to reflect the relative inefficiency of the utricles as gravity sensors when the head is in certain positions. The simulation of zero gravity may be enhanced by utilizing these positions with water immersion.

33. Brozek, J., A. Henschel, and A. Keys. Effect of submersion in water on the volume of residual air in man. *Journal of Applied Physiology* 2:240-246, 1949.

*Authors' summary:* Determinations of the volume of residual air were made under ordinary conditions with the subjects exhaling in air, and during complete submersion. Nine normal young men served as subjects.
The average values, obtained in two sets of measurements made about a week apart, indicated that the underwater values were smaller by 118 and 140 cc, respectively. There were large individual differences in the response to submersion and the overall average decrement of 129 cc did not quite reach the 5 percent level of statistical significance. Using the average values of residual volume determined in air rather than those obtained for submersed subjects would lower the estimated fat content of the body by less than 1 percent.

34. Bullard, R. W. and G. M. Rapp. Problems of body heat loss in water immersion. *Aerospace Medicine* 41:1269-1277, 1970.

*Authors' abstract:* A simple model is utilized for development of the concepts involved in body heat loss in water immersion. In the model, metabolically produced heat and heat stores from the core are transferred down the thermal gradient ($T_c$-$T_s$) to the skin surface. The fixed resistance to heat flow of subcutaneous fat and body structural components is discussed as well as the more complex resistance varied by alteration in skin and extremity blood flow. Extremely high resistance to heat flow or minimal conductance is developed by a marked reduction in extremity blood flow and establishment of countercurrent heat exchange. The highest attainable resistance to heat flow is quite dependent on subcutaneous fat deposits. Transfer of heat from body surface to water encounters a very low resistance. The problem is treated herein by utilizing classical heat transfer physics and nondimensional quantities derived from the thermal physical properties of water.

35. Buskirk, E. R. and J. Kollias. Total body metabolism in the cold. *New Jersey Academy of Science,* The Bulletin Special Symposium Issue, March 1969.

*Authors' abstract:* Continuous measurements of oxygen consumption were obtained during exposure of young men to cool air, 10° C (50° F) and cool water, 20° C (68° F) and 15° C (59° F). Exposure in air and water was 120 and 60 min, respectively. The subjects varied widely in body size (50 to 150 kg) and body composition (4 to 40 percent body fat). Smaller lean subjects responded with the largest increase in heat production ($\bar{M}$) during exposure in 10° C (50° F) air. Obese subjects failed to demonstrate an appreciable rise in $\bar{M}$ while large lean subjects of comparable body size and surface area showed an intermediate response. Body heat loss was greatly increased in all subjects during immersion in water. Regardless of body size, and heat production of lean subjects in cool water increased 4 to 6 Met whereas the obese subjects rarely exceeded 2 Met. $\bar{M}$ was dependent on the insulation provided by body fatness in all three environments, being greater for the lean than obese subjects and relatively greater for small as compared to large subjects. Although subcutaneous body fat provides effective thermal insulation, large body size also favors maintenance of central thermal equilibrium. The large subject has a smaller surface to mass ratio than the small subject, a factor which favors preservation of core temperature.

36. Buyanov, P. V., A. V. Beregovkin, N. V. Pisarenko, and V. I. Slesarev. Prolonged hypokinesia as a factor changing the functional condition of the cardiovascular system of a well man. *Problemy Kosmicheskoy Meditsiny,* Moscow, 1966, pp. 80-81.

*Purpose:* To examine the circulatory effects of prolonged hypokinesia of bedrest (11 subjects) and water immersion (2 subjects) lasting 10-15 days and to evaluate the role of periodic physical exercise and massage of the lower extremities.

*Conclusions:* Arterial pressure, cardiac ejection, and vascular tonus were reduced while peripheral resistance rose noticeably. All changes were maximum between 4-8 days with subsequent stabilization at the new level. Also evident were tachycardia, increased cardiac output, and lowering of the tonus of the main vessels; bioelectric cardiac activity changes and disturbances in functional capability of the myocardium were observed. All these changes were prominent during physical exercise and orthostatic tests.

Somewhat greater detraining changes were noted during the "water" series compared with bedrest. The detraining was less in exercising subjects and those receiving lower extremity massage.

37. Campbell, L. B., B. A. Gooden, and J. D. Horowitz. Cardiovascular responses to partial and total immersion in man. *Journal of Physiology* 202:239-250, 1969.

*Authors' summary:* Short-term cardivoscular effects of partial and total immersion of 18 human subjects in the horizontal plane have been examined. Brachial arterial pressure, heart rate, forearm blood flow, and respiratory movements were monitored simultaneously throughout the experiments. Forearm vascular resistance was calculated from the mean blood pressure and mean flow.

Total immersion, including the face, with breath-holding resulted in a 61 ±43 percent increase in forearm vascular resistance with an associated 29 ±15 percent reduction in forearm blood flow. The concurrent bradycardia was significantly different from the heart-rate changes during breath-holding with the torso only immersed, or during total immersion with snorkel-breathing. Neither breath-holding in air or with only the torso immersed nor total immersion with snorkel-breathing produced such a diving response.

Breath-holding, after several minutes of total immersion and snorkel-breathing, produced an attenuated diving response. It, therefore, appears that a full diving response can be obtained only when the apnoea commences at the moment of face immersion.

The present investigation supports the concept that, in man, face immersion is an essential predisposing factor for the diving response, and cortical inhibition of the respiratory center is important for its initiation and maintenance.

38. Campbell, L. B., B. A. Gooden, R. G. Lehman, and J. Pym. Simultaneous calf and forearm blood flow during immersion in man. *Australian Journal of Experimental Biology and Medical Science* 47:747-754, 1969.

*Authors' summary:* Forearm and calf blood flows were recorded simultaneously in 11 subjects in the horizontal plane during 1-min breath-holds in air, in water with the torso immersed but the face out, and with total body immersion. Brachial arterial pressure, electrocardiogram, and respiratory excursions were also recorded continuously throughout the experiments.

Breath-holding with total immersion caused a fall in forearm blood flow of 28 ±17 percent and in calf flow of 47 ±30 percent. Forearm vascular resistance increased by an average of 70 percent and calf resistance by 147 percent.

Breath-holding in air resulted in an increase in forearm blood flow and a decrease in calf flow in subjects. The average response of all subjects showed a significant vasoconstriction in the calf (average 72 percent) but no significant change in the forearm resistance.

Breath-holding with the torso immersed but the face out of water caused a response which was intermediate between that shown in air and that during total immersion. Thirty to 60 sec after this maneuver, there was a significant overshoot in both forearm and calf blood flow, unlike the former procedures.

39. Carlson, L. D. Cardiovascular studies during and following simulation and weightlessness. *Life Sciences and Space Research V, 7th International Space Science Symposium,* Vienna, Austria, May 10-18, 1966, pp. 51-54.

*Author's abstract:* Two major characteristics of space flight may be simulated to some degree by bedrest and by water immersion. These are inactivity and the lack of the hydrostatic stress on the systematic circulation. Studies prior to the advent of space flight led to the prediction of orthostatic intolerance, muscular weakness, and calcium loss. Prolonged space flight has heightened the interest in these simulations to provide information concerning the temporal cause of the "deconditioning" or disuse syndrome and the value of simulation for testing the effectiveness of remedial measures. This report will evaluate the extent to which the simulation appears valid.

In its gross effects, orthostatic intolerance can be studied with respect to its temporal course, etiology, and effectiveness of remedial measures. The intolerance develops more rapidly during water immersion with respect to cause as well as effect. The short term of immersion studies does not allow study of the secondary change in blood volume due to red cell mass changes. Remedial measures seem clearly defined in water immersion simulation and less clear in bedrest. Measures of venous pooling following water immersion appear different than those obtained following weightlessness.

There also appear to be differences in the results of evaluation of protective devices and measures and in the time course of development and recovery of orthostatic intolerance.

Correlates of the cardiovascular responses such as muscle tone, skeletal strength, and endocrine change (catecholamines, vasopressin, and aldosterone) suggest a marked alteration in physiology during hypodynamic status.

To date, work on exposure to increased G force has provided only extrapolated data concerning metabolic requirements.

40. Carlson, L. D., A. C. L. Hsieh, F. Fullington, and R. W. Elsner. Immersion in cold water and body tissue insulation. *Journal of Aviation Medicine* 29:145-152, 1958.

*Authors' summary:* Subjects in whom fat constituted 8 to 32 percent of the body weight were immersed at 33°, 25°, 20° C, and in some cases, at 9° C. One subject was a professional distance swimmer. All experiments began with a control period at 33° C. The water temperature was then lowered to the desired temperature. Body insulation, calculated by the Burton equation, varied directly with specific gravity, ranging from 0.10° C/cal/m$^2$/hr to 0.40° C/cal/m$^2$/hr. However, the fraction of the body calculated to be involved as insulation was always greater than the estimated fat content. The professional swimmer increased his metabolism without visible shivering or loss of tissue insulation. Visible shivering always was accompanied by a reduction in body insulation. These results seem to explain the wide variation in survival times during cold-water immersion.

41. Chambers, R. M., D. A. Morway, E. L. Beckman, and V. G. Bensen. Changes in performance proficiency under conditions simulated by water immersion and centrifugation. *Aerospace Medicine* 32:225, 1961.

*Authors' abstract:* An attempt was made to investigate changes in piloting proficiency and related human performance under gravitational conditions simulated by water immersion and centrifugation. Seven dimensions of human ability felt to best reflect the influence of these gravitational environments were studied: (1) tracking, (2) G-tolerance, (3) target aiming, (4) positioning, (5) complex discrimination-reaction time, (6) complex coordination, and (7) time estimation. Two separate experiments, a neck level immersion and complete immersion experiment, were performed each using six male subjects immersed for periods up to 12 hr. Before and after reduced gravity simulation in a water tank, the subjects were exposed to an 8 G reentry profile produced by a human centrifuge. Changes in piloting skill level and in related performance capabilities were found.

42. Chambers, R. M., D. A. Morway, E. L. Beckman, R. DeForest, and K. R. Coburn. The effects of water immersion on performance proficiency. NADC-MA-6133, Aviation Medical Acceleration Lab. U. S. Naval Air Development Center, Johnsville, Penn., Aug. 1961.

*Authors' summary:* In an attempt to study a wide range of human performance abilities associated with weightlessness and the transition from weightlessness to a high G reentry environment, the technique of water immersion and centrifugation was used to simulate these conditions. Six male subjects were immersed in water to the neck level for a 12-hr period and one subject for a 23-hr period. Eight selected performance tasks were administered: (1) before immersion, (2) during immersion, (3) after immersion and centrifugation, so that gross motor and perceptual behavior could be sampled. It was found that behavior was not apparently affected by prolonged water immersion followed by reentry-type accelerations.

43. Clarke, D. H. Effect of immersion in hot and cold water upon recovery of muscular strength following fatiguing isometric exercise. *Archives of Physical Medicine and Rehabilitation* 44:565-568, 1963.

*Author's abstract:* Two fatiguing exercise bouts were given to 30 male subjects. They were separated by 1 week and each consisted of a single contraction of the hand-gripping muscles held maximally for 2 min. Maximum strength samples were taken at intervals of 60 sec, thereafter for a period of 10 min, during which time the arm was immersed in a water bath on one occasion at a temperature of 10° C, and on the other of 46° C. The recovery curves were described mathematically by a two-component exponential equation. The two occasions did not differ significantly in the total amount of recovery obtained; however, there was a significant difference between the means at 120 sec. It was concluded that the local application of hot and cold water after the cessation of exercise did not appreciably alter the return of strength.

44. Code, C. F., E. H. Wood, and E. J. Baldes. Hydrostatic anti-blackout protection; the protection afforded man against the effects of positive acceleration by immersion in water. *Federation Proceedings* 4:15, 1945.

*Authors' abstract:* The motion picture shows the methods used in this study and illustrates the average protection afforded man against the effects of positive acceleration by immersion in water.

The study was carried out on the human centrifuge. A specially constructed bathtub was placed in the gondola or cockpit of the centrifuge. The subjects sat in this tub in the same position as that assumed by a pilot in a fighter airplane. Each test included the determination of the subject's g tolerance while sitting in the tub – first, without water, then with water added to various body levels, and finally again without water as a recheck of the control determinations. On the average, immersion in water to the xyphoid gave 0.9 g protection and immersion in water to the level of the third rib gave 1.7 g protection.

45. Cohen, R., W. H. Bell, H. A. Saltzman, and J. A. Kylstra. Alveolar-arterial oxygen pressure difference in man immersed up to the neck in water. *Journal of Applied Physiology* 30:720-723, 1971.

*Authors' abstract:* Immersion of nine subjects up to the neck in water resulted in a mean decrease of $PaO_2$ of 10 mm Hg and a mean increase in $(A\text{-}a)DO_2$ of 9 mm Hg. Four of the subjects, while submerged 10 cm below the water surface, had a mean increment in the $(A\text{-}a)DO_2$ of 16 mm Hg. Breathing oxygen at a reduced ambient pressure diminished the $(A\text{-}a)DO_2$ in two of the subjects immersed to the neck but did not obliterate the increase in $(A\text{-}a)DO_2$ in three other subjects immersed to the neck or in two subjects studied while totally submerged. It is concluded that a change in ventilation-perfusion distribution was responsible for the decreased $PaO_2$ during immersion in some subjects whereas in others an increase in true venous admixture seemed responsible.

46. Costill, D. L., P. J. Cahill, and D. Eddy. Metabolic responses to submaximal exercise in three water temperatures. *Journal of Applied Physiology* 22:628-632, 1967.

*Authors' abstract:* Eight subjects were studied during 20 min of submaximal swimming in three different water temperatures (17.4°, 26.8°, and 33.1° C). During exercise and recovery, various body temperatures, heart rates, and respiratory values were recorded. The energy requirements for the performance of exercise were not significantly affected by the water temperatures. Heart rates during recovery were found to be lowest following the exercise in 17.4° C water and highest after the swim in water at 33.1° C. The core temperature increase during exercise was positively related to water temperature.

47. Craig, A. B. and M. Dvorak. Thermal regulation during water immersion. *Journal of Applied Physiology* 21:1577-1585, 1966.

*Authors' abstract:* Ten subjects were studied during head-out immersion in nine different water temperatures ranging from 24° to 37° C. The period of immersion at each temperature was 1 hr, during which time various body temperatures, pulse rate, blood pressure, and $\dot{V}_{O2}$ were observed. In water temperatures less than 35.6° C, there was a reduction in central body temperature despite the fact that vasomotor controls of heat loss were evident. Increased heat production was noted if the water temperature was 30° C or less. Water temperatures of 36° C or more imposed a heat stress on the subject, causing an increase in the pulse rate and pulse pressure. It is suggested that there is a very narrow range of water temperature (35.0°–35.5° C) which can be considered as "neutral."

48. Craig, A. B. and M. Dvorak. Thermal regulation of man exercising during water immersion. *Journal of Applied Physiology* 25:28-35, 1968.

*Authors' abstract:* Ten subjects were studied during head-out immersion in different water temperatures ranging from 24° to 35° C while exercising. With a light work load, the $\dot{V}_{O2}$ averaged 0.70 liter/min for the hour of immersion, and with the heavier load it was 0.92 liter/min. Changes in ear temperature indicated that the increased heat production associated with the exercise effectively buffered the cooling of immersion. With the light load the changes in rectal temperature were the same as noted previously in resting subjects, but with the heavier load the rectal temperatures did not decrease as much. In this range of temperatures there was an indirect linear relationship between the changes in ear temperature and the water temperature. Pulse rate for a given workload was less for subjects in cool than in warm water. These observations are interpreted as indicating that in this range of water temperature increasing heat production by exercise is a more effective way of preventing a decrease in heat stores than the vasomotor responses which provide protection for the resting subject.

49. Craig, A. B., Jr. and M. Dvorak. Comparison of exercise in air and in water of different temperatures. *Medicine and Science in Sports* 1:124-130, 1969.

*Authors' abstract:* Exercise in air and in water was studied using an ergometer which required the same type of muscle action in both environments. The $\dot{V}_{O2}$ for a given load was the same in air and in water of 30°C and 35° C and was linearly related to the rate of work. In 25° C water, $\dot{V}_{O2}$ was 0.14 liter/min greater than under the other conditions. In water, respiratory frequency was slightly greater than in air but relationships between $\dot{V}_E$ and $\dot{V}_{O2}$ were not different. Temperature measurements during 30 min of work at 80 W in one lean individual revealed that the increase of temperature in the external auditory canal ($T_{ear}$) was directly related to the water temperature, but in an obese subject there was no such relationship. However, weight loss during the exercise was related to water temperature in both subjects. Heart rate of the lean subject was slower in cool water than in air or warm water, but for the obese subject pulse rate did not correlate with the water temperature. Except for differences related to thermal regulation and the mechanics of respiration, responses to exercise are the same in water as those in air.

50. Craig, A. B. and D. E. Ware. Effect of immersion in water on vital capacity and residual volume of the lungs. *Journal of Applied Physiology* 23:423-425, 1967.

*Authors' abstract:* The vital capacity and residual volume of 21 healthy adult males were measured with the subjects seated in air and then immersed upright to the level of the neck in water. The vital capacity was decreased from a mean value of 5.33 liters in air to 5.10 liters during immersion. The residual volume in air was 1.44 liters and in water was 1.38 liters. The change in the vital capacity was statistically significant while

the change in residual volume was not. There was no difference in the results between one-half of the group studied in water 27° C and the other half in water in 35.5° C.

51. Dahlback, G. O. and C. E. G. Lundgren. Pulmonary air-trapping induced by water immersion. *Aerospace Medicine* 43:768-774, 1972.

*Authors' abstract:* Pulmonary air-trapping in 20 subjects immersed up to the mouth was measured with a nitrogen washout and rebreathing technique. The influence of voluntarily controlled changes in end expiratory lung volume were studied. The volume of trapped air when breathing at FRC amounted to 90 ml or 2.0 percent of VC, when breathing at RV + 5 percent of VC it amounted to 3.3 percent of VC, at RV + 12 percent of VC to 1.8 percent of VC and at RV + 20 percent of VC to 1.1 percent of VC. No statistically significant difference was found between smokers and nonsmokers. It is noted that during immersion air-trapping is, on the average, not eliminated until lung volume is increased to between 38 and 43 percent of the VC. The possibility that airway closure and air-trapping induced by immersion may add to the danger of lung rupture during so-called free ascent is considered.

52. Dawson, W. J., F. J. Kottke, W. G. Kubicek, M. E. Olson, K. Harstad, J. E. Bearman, P. L. Canner, and J. B. Canterbury. Evaluation of cardiac output, cardiac work and metabolic rate during hydrotherapy and exercise in normal subjects. *Archives of Physical Medicine and Rehabilitation* 46:605-614, 1965.

*Authors' abstract:* Cardiac performance has been studied in six normal young men following resting states, hydrotherapy, and step-test exercise. Cardiac output was greater at supine rest than at sitting rest. Exercise produced marked increases in both cardiac output and work, while hydrotherapy showed little such effects. While no appreciable differences were shown between the first and second weeks of experimentation, cardiac output was definitely less on the Tuesday test days than on the Thursday test days. Exercise increased oxygen consumption to 5.7 times rest values, doubled the pulse rate, and increased blood pressure slightly. Hydrotherapy increased oxygen consumption only to 1.2 times and pulse rate only to 1.4 times rest rates. Experimental design attempted to duplicate actual therapeutic conditions.

53. Delhez, L. and J. Lecomte. Influence de l'immersion verticale sur l'activité électrique des muscles abdominaux et du diaphragme. *Journal de Physiologie (Paris)* 65:386A-387A, 1973.

*Authors' conclusions:* Vertical immersion to the thorax, at the point of buoyancy, neutralized the activity of the antigravity and abdominal muscles; hydrostatic pressure caused a net increase in the motor activity of the diaphragm.

54. Denison, D. M., P. D. Wagner, G. L. Kingaby, and J. B. West. Cardiorespiratory responses to exercise in air and underwater. *Journal of Applied Physiology* 33:426-430, 1972.

*Authors' abstract:* Respiratory gas exchange, end-tidal gas tensions, alveolar ventilation, respiratory frequency, cardiac output, and pulse rate were measured in four healthy adult males at rest and during mild and moderate exercise ($\dot{V}_{O2}$ = 0.2 - 2.0 liter/min) in air at 18°–22° C and underwater at 35.0°–35.5° C. Subject respired at eupneic pressures from the same breathing circuit throughout and 64 determinations of each variable were made in each environment. Immersion was associated with a 10 percent increase in pulse rate and cardiac output at all levels of exercise. There were no changes in end-tidal $CO_2$ tension or alveolar ventilation. It is concluded that horizontal subjects breathing at eupneic pressures and working against mild and moderate loads in warm water show the same responses to exercise as in air.

55. Diefenbach, W. S. The ability of submerged subjects to sense the gravitational vertical. Internal Res. 993-044, Cornell Aeronautical Lab. Inc., Cornell Univ., Buffalo, N.Y., Jan. 1961. 39 pp.

*Author's abstract:* The ability of human subjects to perceive the vertical when submerged in a buoying fluid and subjected to varying amounts of body tilt was studied in a series of pilot experiments. Experimental equipment employed attempted to minimize positional cues other than those arising from the vestibular apparatus and visceral sources. Gross errors in perception of the vertical were made by all subjects. These errors were repeatable within subjects, and had a high linear correlation with the amount of body tilt. In addition, evidence was found that precision in positioning an unseen control may vary with body tilt. Possible simulation of weightlessness and implications for design of space controls are briefly discussed and further research studies are suggested.

56. von Diringshofen, H. Die Wirkungen des hydrostatischen Druckes des Wasserbades auf den Blutdruck in den Kapillaren und die Bindegewebsentwässerung. *Zeitschrift für Kreislaufforschung* 37:382-390, 1948.

*Author's summary:* The effect of the hydrostatic pressure of the water bath on blood pressure in the capillaries and on connective tissue dehydration was investigated on the basis of Schade's observations on water exchange between blood and connective tissue. It was shown, by means of model presentations, that an increase of the water level in the bath, because of hydrostatic pressure transfer to the connective tissue, shifts the fluid exchange between blood and connective tissue in the direction of connective tissue dehydration. Therapeutic possibilities for utilization of this effect, especially using baths with rhythmically alternating bath water level, are indicated.

57. von Diringshofen, H. The water bath as a partial simulator for weightlessness in space medicine. *Archives für physikalische Therapie* 4:307-311, 1962.

*Author's abstract:* One of the oldest healing arts, balneology, is discussed in light of current space medicine experimental investigations. Despite hydrostatic effects, water immersion can be successfully employed in the elimination of body weight. American and Russian investigations are discussed in regard to blood and urine changes, sleep, psychic changes, vertical orientation, systemic blood pressure changes, and vertigo.

58. Dlusskaya, I. G., L. A. Vinogradov, V. B. Noskov, and I. S. Balakhovskiy. Effect of hypodynamia and other spaceflight factors on the excretion of 17-hydroxycorticosteroids and aldosterone. *Kosmicheskaya Biologiya i Meditsina* 7:43-48, 1973.

*Authors' abstract:* The excretion of 17-hydroxycorticosteroids and aldosterone in the urine was investigated under hypodynamic conditions. In different experimental runs, diminished motor activity was combined with other exposures, such as water immersion, altered work-rest cycle, physical exercises of known intensity, and electric stimulation of limb muscles. The excretion of 17-hydroxy corticosteroids decreased mostly during exposure to hypodynamia and water immersion or hypodynamia and a fixed, invariable work-rest cycle. The aldosterone excretion increased during an exposure to prolonged hypodynamia brought about by the body being in a recumbent position.

59. Eckert, P., K. Kirsch, C. Behn, and O. H. Gauer. Water and saline balances during prolonged immersion in a water bath. *Pflugers Archiv* 297:R70-71, 1967.

*Authors' abstract:* In an extension of earlier studies, the behavior of water and electrolyte elimination when immersion time is lengthened to 48 hrs was studied in five test subjects. As in short-term trials, simulated weightlessness caused an initial water diuresis with an an increase in the hematocrit value and plasma protein concentration.

In three of the test subjects, the changes dropped off considerably in 12 to 20 hrs.

In contrast, water and electrolyte elimination increased considerably during the entire immersion time for two subjects, with a simultaneously intensifying sensation of thirst. Both $K^+$ and protein concentrations in the plasma and the hematocrit values had increased by the end of the trial. Body weight had decreased considerably. Orthostatic load capacity in the tilting table test was reduced. This was described for the first time by Graveline. A considerable reduction in sleep time was observed for these subjects during immersion.

Immersion produced a tendency toward water and electrolyte losses via the diuretic reflex. Whether the hypothalamic system adapts and reverses initial changes appears to be a function of central nervous systems which, among other things, determine the sleep/wake rhythm.

60. Ekert, F. X-ray kymographic investigations of the central circulatory organs in therapeutic baths and in hydrostatic pressure elevation. Their technology, results and potential developments. A review. *Archives für physikalische Therapie* 8:66-82, 1956.

*Author's summary:* The author reviews the technology, the equipment required, the past results, and the possibilities for future development of X-ray kymographic investigations of the central circulatory organs during the action of simple and therapeutic full baths, partial baths, and flat tub baths as well as experimental man-deep standing baths. The method determines changes in sizes of the heart and vascular band shadows, in the shape of these organs, and in their marginal movements. In part, rather considerable differences appear between the different applications, even in respect to the size and form of the heart-vascular band shadows during the application. This is referred primarily to the different hydrostatic pressure and temperature effects and in part, perhaps, as a result of a tighter state of filling. In the author's opinion, it would probably be informative to continue these investigations using the recently reported X-ray technological equipment, perhaps even with occasional X-ray cinematographic checks. The latter, of course will be possible in large extent only after further development of electron-optical image converters. Brief reference is made to the relations of such studies, which served balneotherapeutic purposes primarily, to circulatory physiology, X-ray diagnostics, and other specialties.

61. Epstein, M., D. C. Duncan, and L. M. Fishman. Characterization of the natriuresis caused in normal man by immersion in water. *Clinical Science* 43:275-287, 1972.

*Authors' summary:*

The effects of 4–6 hr of water immersion on the renal excretion of water and electrolytes were studied in 13 normal male subjects in balance on a constant diet containing 150 mEq of Na and 100 mEq of K per day. Each subject was studied during a control period consisting of quiet sitting, during water immersion to the neck.

Immersion resulted in a natriuresis beginning within the first hour, with the rate of sodium excretion eventually exceeding that of the control period by 3–4-fold; potassium excretion also increased. Despite a progressively negative water balance during the immersion studies, urine flow was greater during the first 4 hr and free water clearance was greater during the first 2 hr of immersion than during the control study.

The demonstration of a highly significant increase in fractional excretion of sodium during immersion suggests that the natriuresis of water immersion is not attributable to changes in filtered sodium load.

The prompt onset of the natriuresis, the concomitant kaliuresis, and the fact that aldosterone secretion under the conditions of study was probably already suppressed make it unlikely that the natriuresis of water immersion is mediated solely by decreases in aldosterone activity.

The data suggest that the natriuresis caused by water immersion is the result of decreased fractional reabsorption of sodium proximal to the renal diluting site. The mechanism whereby increased proximal tubular sodium rejection occurs in relation to immersion remains unclear.

62. Epstein, M., D. C. Duncan, and B. E. Meek. The role of posture in the natriuresis of water immersion in normal man. *Proceeding of the Society for Experimental Biology and Medicine* 142:124-127, 1973.

*Authors' summary:* Water immersion to the neck has been demonstrated to produce a profound natriuresis in seated and standing subjects. Since an immersion-induced hydrostatic pressure gradient with a resultant redistribution of blood volume has been postulated to produce this natriuresis, it was of interest to examine this postulate by assessing renal sodium handling during immersion in supine subjects. Renal sodium, potassium, and water handling was assessed in seven normal subjects during a control period and during water immersion under identical conditions of diet, supine posture, and time of day. Although assumption of the recumbent position during immersion was associated with a gradual increase in $U_{Na}V$ the resultant increase did not differ from the increase in $U_{NA}V$ following the assumption of recumbency during control. These data support the hypothesis that the natriuresis of water immersion is mediated by an immersion-induced hydrostatic pressure gradient acting on the vascular beds of the lower extremities and body trunk.

63. Epstein, M., L. M. Fishman, and H. B. Hale. Dissociation of aldosterone and 17-hydroxycorticosteroid (17-OHCS) release during water immersion in normal man. *Proceedings of the Society for Experimental Biology and Medicine* 138:939-942,1971.

*Purpose:* To assess the effects of water immersion on both aldosterone and 17-hydroxycorticosteroid (17-OHCS) release in normal man under conditions of carefully controlled sodium and potassium balance, posture, and time of day.

*Procedure and methods:* Six healthy male airmen between the ages of 19 and 25 were studied. The composition of each subject's diet remained constant throughout the study, 10 mEq sodium, 88-120 mEq potassium, and 2500 ml of water. Daily 24-hr urine collections were made for determination of sodium, potassium, and creatinine. When each subject had achieved sodium balance, a control study was carried out on day 5 and an immersion on day 7 of dietary sodium deprivation. On study days, identical protocols were carried out as follows:

The subject was awakened at 0600 and instructed to sit quietly for 1.5 hr. At 0645, he was given a 400-ml oral water load.and, at 0730 blood was drawn for determination of plasma renin activity, plasma cortisol, serum electrolytes, and serum creatinine. After voiding and completely emptying his bladder, the subject then assumed a seated position for 8 hr. During control studies, the subject sat quietly outside the immersion tank for the 8-hr period. During immersion, the subject sat in the study tank immersed in water to the neck for 4 hr (immersion), followed by 4 hr of quiet sitting outside the tank (recovery). At hourly intervals, and subject stood briefly on a platform in the immersion tank to void spontaneously. To maintain an adequate urine flow, 200 ml water was administered orally every hour during each study. Sodium, potassium and creatinine were measured on aliquots of the hourly urine collections. Aldosterone and 17-OHCS excretions were determined on aliquots of pooled 2-hr urine collections. Blood was collected at 2-hr intervals throughout the study.

The water temperature was maintained constant at 34 ±0.5°. Plasma renin activity (PRA) (ng/ml/hr), plasma 17-hydroxycorticosteroids (17-OHCS), urinary aldosterone and urinary 17-OHCS were measured.

*Results:*

Aldosterone excretion was significantly lower throughout the immersion and recovery periods as compared to the control values.

Plasma renin activity (PRA) during immersion decreased 30 percent as compared to preimmersion values. By the second and fourth hours of recovery, the mean value increased to and slightly above control levels.

Water immersion did not significantly alter urinary 17-OHCS excretion.

At hours 2 and 4 of immersion, when PRA was clearly suppressed plasma 17-OHCS was not significantly different from control.

*Conclusions:* There was a marked decrease in aldosterone excretion during immersion and during the initial 2 hr of recovery ($p < 0.005$). In contrast, neither urinary nor plasma 17-OHCS was significantly altered by immersion. The dissociation observed between the effects of immersion on aldosterone and 17-OHCS activity suggests that the suppression of the renin aldosterone system is selective and further supports the concept of independent control of adrenal mineralocorticoid and glucocorticoid secretion.

64. Epstein, M., M. Miller, and N. Schneider. Depth of immersion as a determinant of the natriuresis of water immersion. *Proceedings of the Society for Experimental Biology and Medicine* 146:562-566, 1974.

*Authors' abstract:* Water immersion to the neck has been demonstrated to produce a profound natriuresis in normal seated subjects. Since an immersion-induced hydrostatic pressure gradient with a resultant redistribution of circulating blood volume has been postulated to produce this natriuresis, it was of interest to examine this postulate by sequentially assessing renal sodium handling at varying depths of immersion. Renal sodium handling was assessed in nine normal subjects on four occasions while in balance on a 150 mEq Na diet, control, waist immersion, chest immersion, and neck immersion, under identical conditions of diet, posture, and time of day. Immersion to the mid-chest was associated with a significant increase in $U_{Na}V$ compared to waist immersion ($P < 0.05$). Immersion to the neck resulted in a further increment in $U_{Na}V$ compared to chest immersion ($P < 0.05$).

These data are consistent with the hypothesis that the immersion-induced hydrostatic pressure gradient acting on the vascular beds of the lower extremities and body trunk participates in mediating the natriuresis of water immersion.

65. Epstein, M. and T. Saruta. Effect of water immersion on renin-aldosterone and renal sodium handling in normal man. *Journal of Applied Physiology* 31:368-374, 1971.

*Authors' abstract:* The effect of 6 hr of water immersion on plasma renin activity, urinary aldosterone excretion, and renal sodium and potassium handling was assessed in eight normal male subjects. All subjects were studied on three occasions while in balance on a 10 mEq Na, 88-120 mEq K diet: control, waist immersion, and neck immersion. Waist immersion produced a decrease of 1/3 in plasma renin activity beginning at 2 hr without changing urinary aldosterone excretion or $U_{Na}V$. Neck immersion produced a decrease in plasma renin activity exceeding that induced by waist immersion with a 2/3 decrease in urinary aldosterone excretion. The rate of sodium excretion ($U_{NA}V$) was 20-fold greater than either control or waist immersion at the end of 6 hr. Since water immersion to the neck initially results in a redistribution of blood volume with a relative increase in intrathoracic block volume, the current study lends further support to the concept of intrathoracic and/or cardiac receptors which are important in volume regulation in man.

66. Ferguson, J. C., R. M. Chambers, C. F. Schmidt, and W. S. Wray. Psychological aspects of water immersion studies. NADC-MA-6328, U. S. Naval Air Development Center, Johnsville, Pa. Dec. 1963. 28 pp.

*Authors' summary and conclusions:* The purpose of this paper is to review the recent water immersion literature, placing special emphasis on the psychological aspects of these studies. The adequacy of water immersion as a technique for simulating weightlessness is discussed and its disadvantages are reviewed. The most serious limitation of water in simulation studies was found to be the fact that the body is surrounded by water rather than air. Immersion results in a significant change in the normal physiology and it cannot be ascertained whether the performance and physiological results in water immersion studies would be similar to those in a zero gravity environment. Water immersion facilities and procedures are described and it was found that the wide variation in procedures brings about difficulties in comparing results.

The areas of perceptual and motor performance, boredom and fatigue, sleep, orientation, and personality and emotional aspects of water immersion were selected as being of special psychological interest.

In the area of perceptual and motor performance, a seven-day immersion study demonstrated a gross disruption of psychomotor performance after the subject came out of the water. Studies of less duration showed no significant decrement in psychomotor performance, except for certain perceptual-motor tasks involving arm movements, where the disruption of the normal kinesthetic feedback was thought to be an important contributing factor. After immersion, several of these studies investigated perceptual-motor performance under centrifugation, but no clear cut conclusions could be drawn concerning the effect of water immersion on GG tolerance. It was concluded that much more research needs to be conducted in the area of perceptual-motor performance. Problem areas which were suggested were those of kinesthetic feedback, knowledge of results, interaction effects, reduced mobility, exercise, and the determination of underwater sensory thresholds for pain, pressure, touch, kinesthesis, and proprioception.

In the area of boredom and fatigue, the studies reviewed demonstrated that boredom is a factor which must be considered in immersion studies, but that subjects were able to tolerate boredom by sleeping or keeping active. Fatigue was found to be detrimental to performance in a seven-day immersion study, but in studies of shorter duration, the feeling of fatigue was not a reliable indicator of muscle fitness and did not affect performance. It was felt that the studies in this area have contributed significantly in answering the relevant questions and no new problem areas were discussed.

The results of the sleep studies were found to be ambiguous and contradictory. In a seven-day immersion study, the subject required a maximum of 4 hr sleep per day, but in a study of shorter duration, the subjects required more sleep than they did normally outside the water, sleeping almost half the time they were in the water and a full 8 hr in bed at night. Some critical problems are the amount of sleep that is adequate for an immersed subject and the measurement of the depths of sleep. Improved underwater instrumentation was called for to provide an answer for these problems.

The immersion studies demonstrated a considerable disorientation in the water, especially in the head down and back position. However, in this area the most critical problem is still that of controlling or eliminating the cues that the subject uses to indicate his body position. For that reason, caution must be exercised in interpreting the results of these studies or using the results to provide support for a vestibular theory. These extraneous cues are enumerated and the need for more precise design and instrumentation is emphasized to eliminate or control these extraneous variables.

One of the areas of greatest research potential is that of personality and emotional aspects of water immersion. The two studies reviewed demonstrated few individual variations in the form and sequence of mental functioning during immersion. Fantasies, complete boredom, loneliness, and hallucinations of varying intensity and content were experienced by all subjects. Further research is called for to verify the possible enhancement of sensory acuity and of the ability to fix attention brought about by the water. There is a need for a more theoretical orientation by researchers in the area to provide an understanding of the personality dynamics underlying hallucinations and other emotional changes.

67. Ferris, S. H. Magnitude estimation of absolute distance underwater. *Perceptual and Motor Skills* 35:963-971, 1972.

*Author's abstract:* Direct estimates of absolute distance were obtained in air and in water of varying turbidity. Distance in water was under- or overestimated, depending on the interaction of three factors: (1) a general tendency to underestimate, (2) optical distortion, which causes underestimation, and (3) water turbidity, which increases the magnitude of judgments and whose effect increases with distance. Also, whereas the power-function exponent for distance estimation in air was slightly less than 1.0, exponents in water were greater than 1.0 and increased with increased turbidity.

68. Ferris, S. H. Improving distance estimation underwater: Long-term effectiveness of training. *Perceptual and Motor Skills* 36:1089-1090, 1973.

*Author's abstract:* Due to both optical distortion and water turbidity, divers are usually inaccurate when they estimate distances underwater. Previous studies have demonstrated that training with feedback improves accuracy of judgment. The present study showed that the effect of training diminishes considerably during 9 weeks following training. A more extensive training program is recommended for diving tasks in which distance estimation is important.

69. Flynn, E. T., H. A. Saltzman, and J. K. Summitt. Effects of head-out immersion at 19.18 Ata on pulmonary gas exchange in man. *Journal of Applied Physiology* 33:113-119, 1972.

*Authors' abstract:* Pulmonary gas exchange was studied during the performance of graded exercise in two normal male subjects breathing a mixture of helium and oxygen ($PIO_2$ = 167–172 mm Hg) while immersed to the chin in water at a simulated depth of 600 ft (19.18 Ata). When compared to control observations at a simulated depth of 5 ft (1.15 Ata), exercise at 19.18 Ata was accompanied by decreases in respiratory rate, $\dot{V}E$, and $(A\text{-}a)DO_2$ and by increases in VT, VD, and $PaCO_2$. These changes were believed to be due to the interaction of several factors including the increased density of the inspired gas medium, the added external resistance to respiration, the hydrostatic pressure of the environment, and the influence of immersion on pulmonary *gaseous* and blood volumes. In neither subject, however, were the alterations in ventilatory or gas exchange parameters sufficient to impair the performance of heavy exercise or to produce arterial hypercapnia or hypoxemia.

70. von Framing, H.-D. Veränderungen der maximalen Sauerstoffaufnahme, des Leistungspulsindex und der Maximalkraft von Trainierten und Untrainierten nach langfristiger Immersion in Wasser. *Pflügers Archiv* 307:91, 1969.

*Author's abstract:* Maximal oxygen intake and performance heart rate index according to E. A. Muller (PHI) on a bicycle ergometer as well as maximal muscular force of upper-arm benders were measured in four trained (sports majors) and untrained test subjects following 6 hr of immersion in water of different temperatures.

In both groups, maximal oxygen intake decreased: in the trained group, by about 18 percent and in the untrained group by about 12 percent. The PHI increased significantly among the trained and the untrained groups. Maximal muscular force showed a decreasing trend following immersion in both groups.

71. Francis, R. D. Intra-subject stability of isolation tolerance. *Perceptual and Motor Skills* 23:89-90, 1966.

*Author's abstract:* Twenty-two subjects were tested for toleration time of isolation by immersion. The intercorrelations on 12 tests were compared for the toleration time extremes. It appears that each of the two extreme groups of 6 subjects is internally homogeneous but unlike the other. Thus it appears that some stable individual difference factor distinguishes the high- and low-isolation tolerator.

72. Fry, R. H. GE underwater test facility studies in zero G simulation. In Space Simulation, a symposium sponsored by NASA, New York, N.Y., May 1-3, 1972, pp. 89-102.

*Author's abstract:* The Underwater Test Facility is an indoor controlled environment test facility designed specifically for zero G simulation, hydrospace manned and unmanned equipment development, and personnel training for both space and underwater exploration.

The General Electric Underwater Test Facility is unique in the nation in that its capabilities range from controlled buoyancy experimentation to the development of Closed Cycle Rebreathing units which are operable to 1500 ft underwater for a maximum duration of 8 hr, to zero G simulation blood transfusions underwater. All of these programs are conducted in an indoor controlled environment.

73. Gauer, O. H., C. Behn, P. Eckert, D. Kaiser, and K. Kirsch. The reflex control of blood volume and the deconditioning of space pilots during weightlessness. *Astronautica Acta* 17:113-117, 1972.

*Authors' abstract:* Astronauts in orbital flight experience a disturbance of body fluid balance which unfailingly results in a considerable weight loss. They also exhibit a strng tendency toward orthostatic collapse after landing. Using the technique of whole body immersion, this condition may be provoked and, in some individual cases, grossly exaggerated in the laboratory. The ensuing picture shows features of diabetes insipidus and resembles in many respects an overcompensation of dropsy of congestive heart failure. It is now widely accepted that intravascular stretch receptors in the circulation, especially in the atria of the heart, play an important role in the homeostatic control of the circulation and fluid balance. This volume control reflex will be reviewed with particular emphasis on its various effector mechanisms in an attempt to arrive at a better understanding of the state of deconditioning of the space pilots.

74. Gauer, O. H., P. Eckert, D. Kaiser, and H. J. Linkerbach. Fluid metabolism and circulation during and after simulated weightlessness. Second International Symposium on Basic Environmental Problems. International Astronautical Federation, International Academy of Astronautics, Paris, 1965, pp. 212-221.

*Authors' abstract:* Orthostatic hypotension can readily be produced by whole body immersion in water lasting not longer than 8 hr. Such experiments were conducted with the view to the diuretic reflex (Gauer and Henry) which is initiated by an increase of the intrathoracic blood volume. This in turn leads to an increase in depressor signals from the baroreceptors in the circulation, especially those in the heart chambers. The effect is mediated by hemodynamic changes and the excretory function of the neurohypophysis. In several sets of experiments, the following results were obtained.

Contrary to the "normal" picture of volume, conditioned diureses induced by other procedures osmotic clearance is frequently increased in addition to the usual increase in free water clearance.

By a single injection or a slow infusion of Vasopressin, the diuresis of water immersion can be interrupted or prevented in the same manner as a water diuresis of the same strength incuded by water drinking.

As shown by bioassay, it is very likely that the diuresis of immersion is not solely due to a reduction of vasopressin but also to the appearance of a diuretic factor in the plasma.

Measurements with Evans Blue revealed an average reduction in plasma volume of 14 percent after 8 hr.

Infusion of Vasopressin during water immersion in a dose too small to exert any effect on blood pressure prevented orthostatic collapse in five subjects. This beneficial effect may be due to a prevention of diuresis and loss of blood volume. An effect on the tone of the capacity vessels must also be considered.

A cautious application of this body of evidence to the circulatory conditions encountered during and after the state of weightlessness is attempted.

75. Gilmore, J. P. and M. L. Weisfeldt. Contribution of intravascular receptors to the renal responses following intravascular volume expansion. *Circulation Research* 17:144-154, 1965.

*Authors' abstract:* The renal responses to acute isotonic, iso-oncotic intravascular volume expansion have been studied in the normal dog, the vagotomized dog, and the dog with carotid sinus denervation. It was observed that either vagotomy or carotid sinus denervation attenuates significantly the diuretic response to intravascular volume expansion without influencing significantly the natriuretic response. The results indicated that carotid sinus receptors and receptors which have afferent fibers in the vagus nerves contribute substantially to the control of plasma volume by a mechanism which influences free water excretion. The receptors of the low-pressure system probably play a primary role under conditions of hypervolemia while receptors of the high-pressure system appear to play a primary role under conditions of hypovolemia.

76. Glaser, E. M. Immersion and survival in cold water. *Nature* 166:1068, 1950.

*Purpose:* To predict survival times of one man immersed in 3°–20° C water from metabolic and thermal measurements.

*Conclusions:*

In cold water, a man can produce by swiming hard as much heat as he is losing; plus he should not die from cold as long as he is able to swim. Stiffness of the muscles may eventually interfere with swimming efficiency.

Fit men exposed to cold-water immersion should continue to swim or struggle as long as they possibly can. Failure to do so will result in death from cold exposure.

77. Goetz, K. L., G. C. Bond, A. S. Hermreck, and J. W. Trank. Plasma ADH levels following a decrease in mean atrial transmural pressure in dogs. *American Journal of Physiology* 219:1424-1428, 1970.

*Authors' abstract:* Plasma levels of antidiuretic hormone (ADH) were measured in conscious dogs, before, during, and after mean atrial transmural pressure (MATP) was reduced by atrial tamponade. There was no significant change from control values in the level of plasma ADH after 5 and 30 min of atrial tamponade, but renal sodium excretion and urine flow were significantly reduced after 30 min of tamponade. These results indicate that decreases in urine flow elicited by reductions of MATP of 6-8 mm Hg in these experiments are not mediated by changes in plasma ADH. It is likely that the decrease in urine flow is secondary to a reduction in sodium excretion induced by atrial tamponade.

78. Goff, L. G., H. F. Bruback, H. Specht, and N. Smith. Effect of toal immersion at various temperatures on oxygen uptake at rest and during exercise. *Journal of Applied Physiology* 9:59-61, 1956.

*Authors' abstract:* Oxygen uptake was measured on four subjects at rest and during mild exercise in air and in water in the temperature range of 29.5°–36.5° C over 20-min periods. At comparable temperatures, oxygen consumption and heart rate appeared to be affected to a greater extent by average skin temperature than by immersion per se. Failure to give a normal reduction in heart rate on immersion in water below body temperature may indicate unfitness for tasks involving underwater work.

79. Goldman, J. K. Free fatty acid responses to tilting after water immersion. *Journal of Applied Physiology* 20:395-397, 1965.

*Author's abstract:* Water immersion is accompanied by decreased urinary excretion of noradrenaline and is followed by orthostatic intolerance. The latter has been postulated to result from impaired noradrenaline metabolism. Such an impairment would produce, in addition, a diminished rise in plasma free fatty acids in response to tilting. This response was measured in normals after office control, water immersion, and exposure to a thermal environment identical to that found in the immersion facility. The plasma free fatty acid response to a tilt is impaired after water immersion as would be expected if sympathetic nervous system dysfunction is involved in postimmersion orthostatic intolerance.

80. Gollwitzer–Meier, K. The relationship between gas exchange and volume per minute in the heart for baths at various temperatures. *Balneology* 4:58-63, 1937.

*Author's abstract:* If we simultaneously observe the variations in the circulatory system size, total gas exchange and respiration in cold (26°-30°), thermoindifferent (34°-35°) and in warm (39°-40°) baths with the same test person, one observes the same direction and magnitude of these variations.

The heart output volume per minute increases from cold baths to thermoreceptor-indifferent and to warm baths. The gas exchange which has increased in the cold bath decreases to a minimum over a wide "metabolic indifferent" heat zone (between 32°-38°, instead of 34°-35° in the thermoreceptor indifferent zone). This minimum is 8 percent below the norminal gas exchange (basic metabolism) in air surroundings, on the average. It then again increases in warm baths (39°-40°). The respiratory intensity is subjected to about the same changes as the total gas exchange for the three types of baths.

81. Goodall, McC., M. McCally, and D. E. Graveline. Urinary adrenaline and noradrenaline response to simulated weightless state. *American Journal of Physiology* 206:431-436, 1964.

*Authors' abstract:* Sixteen normal subjects were placed in a simulated weightless state, that is, water immersion. After 6 hr of water immersion, urine samples were collected and bioassayed for adrenaline and noradrenaline. The excretion of adrenaline was moderately increased ($P < 0.15 > 0.10$), possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was signifcantly ($P < 0.01$) reduced during immersion. Six subjects were also studied during passive verical tilt following the immersion. The increase in pulse rate and decrease in pulse pressure were signficantly greater than those observed during a control tilt. The results of these experiments indicate that the decrease in orthostatic tolerance following a simulated weightless state is probably related to a decrease in sympathetic nerve activity, which, in turn, is reflected by a decline in the urinary output of the sympathetic neurohormone noradrenaline.

82. Grausz, H., W.J.C. Amend, Jr., and L.E. Earley. Acute renal failure complicating submersion in sea water. *Journal of the American Medical Association* 217:207-209, 1971.

*Authors' abstract:* Acute renal failure is a recognized complication of near-drowning in fresh water and is generally attributed to the combination of hemolysis and hypotension. Hemolysis does not result from aspiration of sea water, and renal failure has not been regarded as a complication of near-drowning in salt water. In the present report, two cases of acute and reversible oliguric renal failure followed episodes of submersion in sea water. Hemolysis was not present. We concluded that acute renal failure in both patients represented acute tubular necrosis resulting from a combination of hypoxia and hypotension.

83. Graveline, D. E. Effects of posture on cardiovascular changes induced by prolonged water immersion. ASD-TR-61-563, Oct. 1961.

*Authors' abstract:* Previous hypodynamic research using water-immersion techniques has been done with the subjects in a semireclining position. To evaluate the possible influences of posture and relative immobilization on the cardiovascular deterioration associated with prolonged water immersion, we employed a technique which allowed complete freedom of activity, position, and attitude. Five subjects were evaluated for functional change after 6 hr in this environment. The results indicate that postural factors play an insignificant role in the mechanism of cardiovascular alteration induced by water immersion.

84. Graveline, D. E. Maintenance of cardiovascular adaptability during prolonged weightlessness. *Aerospace Medicine* 33:297-302, 1962. (also ASD-TR-61-707, Dec. 1961.)

*Purpose:* To determine the effectiveness of limb tourniquet application on orthostatic tolerance following immersion.

*Conclusions:* Tourniquets placed on a subject's limbs, which were inflated and deflated to produce hydrostatic pressure changes to promote cardiovascular reflexes during immersion, were found to maintain normal blood pressure responses to tilt table tests.

85. Graveline, D. E. and B. Balke. The physiologic effects of hypodynamics induced by water immersion. Rept. 60-88, School of Aviation Medicine, Brooks Air Force Base, Texas. Sept. 1960, 11 pp.

*Authors' abstract:* Body immersion in water was used to produce an experimental situation in which the normal weight sensation was altered and in which slow movements were effortless. The hypodynamic effects of such immersion on orthostatic tolerance, on cardiorespiratory adaptability to physical stress, and on other biologic and psychophysiologic parameters were studied on one human subject in experiments of 2 and 7 days' duration, respectively. Pronounced functional deterioration resulted from the hypodynamic situation in both experiments; cardiovascular reflexes were severly disturbed and muscualr tone was diminished. The extensive biochemical studies on blood and urine showed marked deviations from the normal. Psychomotor effectiveness, tested on a complex systems task, was impaired noticeably. The need for sleep appeared to be markedly reduced during the periods of water immersion.

This area of research is vital to the man-in-space program. Weightless or near-weightless conditions in space flight are expected to produce a similar hypodynamic effect on the organism as was caused by water immersion. Such loss of functonal reserves may severely interfere with the astronaut's capability to adjust adequately to returning gravitational forces.

86. Graveline, D. E., B. Balke, R. E. McKenzie, and G. Hartman. Psychobiologic effect of water immersion-induced hypodynamics. *Aerospace Medicine* 32:387-400, 1961.

*Authors' abstract:* One subject underwent 7 days immersion. Sleeping hours were markedly reduced to about 4 per day. Diminished muscle tone, and a deterioration of the cardiovascular system were noted after immersion. These results suggests that in prolonged space flight under true weightlessness conditions a critical state of deconditioning will seriously attenuate the astronauts' tolerance for re-entry stresses and the normal gravitational environment.

87. Graveline, D. E. and G. W. Barnard. Physiologic effects of a hypodynamic environment: short-term studies. *Aerospace Medicine* 32:726-736, 1961.

*Purpose:* To determine tolerance times to prolonged water immersion and its accompanying debilitating effects.

*Procedure and methods:* Four subjects underwent water immersion for 6, 12, and 24 hr.

*Conclusions:*

Tilt table, centrifuge, and heat chamber studies demonstrated significant cardiovascular deterioration even after 6-hr runs and became progressively more severe with 12- and 24-hr experiments.

Hemodilution was prevalent at 6 hr, followed by hemoconcentration at 24 hr.

Urinary output during the first 6-hr period was not excessive but tended to increase with immersion time.

88. Graveline, D. E. and M. M. Jackson. Diuresis associated with prolonged water immersion. *Journal of Applied Physiology* 17:519-524, 1962.

*Purpose:* To investigate the diuretic response during complete immersion with compensated respiratory pressure and unrestricted activity.

*Procedure and methods:* Five young men (21-31 yr.) were immersed in a 7 x 7 x 9 ft tank filled with 33°C water. The subjects wore modified dry rubber skin-diving suits without skin contact with the water. The only instructions were to "do anything you want, but remain primarily upright." The test runs began at 8:00 a.m. and continued for 6 hr. Blood samples were drawn at 8:00 a.m. and 2:00 p.m. and analyzed for plasma osmolality, serum sodium, potassium, and urea nitrogen. Urine samples taken at 8:00 a.m. and 2:00 p.m. were analyzed for osmolality, sodium, potassium creatinine, and urea determinations.

*Results:* During the 6-hr test periods, the following was observed as compared to control values:

Urinary volumes increased.

The diuresis increased from 3 to 10 times control value.

Urinary osmolality decreased in all subjects from a control average of 898 mOsm/liter to an average of 289 mOsm/liter.

Urinary specific gravity ranged from 1.002 to 1.004 during the test periods.

Osmolar clearance increased during immersion.

Urine/plasma osmolar ratio decreased for all subjects.

The hematocrits increased from an average value of 45 to an average value of 47.2.

The 2:00 p.m. plasma osmolality values were slightly lower than the 8:00 a.m. values.

There was decreased concentration in the urine of Na, K, and creatinine, but increased urinary outputs.

There was a 74 percent increase in glomerular filtration rate during the immersion test.

The urea output was considerably elevated in all subjects despite a decreased urine concentration.

The urea nitrogen in blood specimens drawn immediately after the immersion test (2:00 p.m.) was slightly decreased for all subjects, from an average pretest value of 11.2 mg/100 ml to a post-test value of 9.3 mg/100 ml.

Control urea clearance ranged from 27 to 72 ml/min compared with the test results of 105-279 ml/min.

*Conclusion:* The results suggest that the low specific gravity diuresis observed in water immersion may be an extension of the diuresis of recumbency, utilizing the same mechanisms.

89. Graveline, D. E. and M McCally. Sleep and altered propriocetive input as related to weightlessness: water immersion studies. AMRL-TDR-62-23, Wright-Patterson Air Force Base, Ohio. Aug. 1962.

*Purpose:* To evaluate the depth of sleep by monitoring electrooculographic (EOG) and electroencephalographic (EEG) recordings of completely immersed, neutrally buoyant subjects.

*Procedure and methods:* Wearing a dry-type rubber suit, 5 subjects (age 20-31 yr.) were immersed in a 9 x 7 x 7 ft tank. Water temperature was maintained at 33° C. Balanced respiratory pressures were maintained by a regulator installed in the outflow air line. The EEG and EOG were recorded by means of floating mine leads. A 10 percent sample of eye movement and brain wave activity was obtained at 100 sec intervals. After having been awake for 20 hr, the subjects reported at 0200 hr and monitoring began at 0300 hr. Subjects were monitored using both the tether and clamshell techniques, both of which were compared to normal bedrest records.

*Results:* In all subjects, the EEG characteristics during both the tether and clamshell experiments showed no apparent deviation from normal bedrest. The EOG recordings indicated that body movement and rapid eye movements characteristically occurred only during periods where "lightening" to stage 1 had occurred and appeared to yield objective evidence for the presence of dreaming. Subjective impressions were that the tether test felt somewhat unstable but more comfortable than a regular bed. The clamshell felt good but feelings of insecurity were prevalent.

*Conclusion:*

Substantial decreases in mechanoreceptive feedback to the central nervous system were noted.

While immersed, orientational information of vestibular origin is present, but surprisingly few clues are afforded.

Considerable individual variation existed in the ability to sleep under conditions of reduced mechanoreceptive input.

A wide range of individual variation in free-floating sleep patterns was observed, perhaps a reflection of personality development.

90. Graveline, D. E. and M. McCally. Body fluid distribution: implications for zero gravity. *Aerospace Medicine* 33:1281-1290, 1962.

*Authors' abstract:* In a weightless enviroment, hydrostatic pressure effects are eliminated. In the situation of recumbency in which hydrostatic pressure influences are minimized by the horizontal position, significant redistribution of body fluids occurs. In recumbency, blood volume initially increases and is redistributed cephalad with increased intrathoracic filling. Atrial volume receptors are presumably stimulated reflexly inhibiting the release of ADH, causing a water diuresis. Renal blood flow is augmented nad glomerular filtration is increased. The urine excreted in this circumstance is characterized by decreased osmolarity and by decreased concentration but increased output of sodium, potassium, and urea. This response appears to be directly related to hydrostatic pressure influences and suggests the possibility that in a weightless state significant redistribution of body fluids can be expected with a compensatory diuretic response having the above characteristics.

91. Graveline, E., M. McCally, and M. M. Jackson. Mechanisms of the water-immersion diuresis. *Aerospace Medicine* 34:256, 1963.

*Authors' abstract:* A significant free water diuresis occurs during recumbency and water immersion. This diuresis was studied in six subjects during 6 to 8 hr of complete water immersion and during similar periods of routine office activity (control). Urinary flow, serum and urinary solute, urea, creatinine osmolar and free water clearances, and hemoglobin and hematocrit were determined. There is an increase in osmolar clearance during immersion, reflecting increased solute excretion particularly of urea and sodium ($P < 0.01$). Free water clearance becomes positive during immersion, presumably reflecting the inhibition of the antidiuretic hormone (ADH), and urinary flow is significantly increased (P 0.01). The administration of Pitrissen during immersion returns urinary flow and solute excretion to control levels. Plasma volume change was determined serially during immersion by hemoglobin and hematocrit dilution and confirmed by whole blood and plasma volume determinations using the dilution of radio-iodinated serum albumin (RISA). Plasma volume increased approximately 15 percent during the first 30 min of immersion and then decreased over the remaining 5 or 6 hr to approximately 20 percent less than control. The mechanisms of the water immersion diuresis are discussed and inferences made to human exposure to zero gravity with its absence of hydrostatic pressure effects.

92. Gray, R. F. and M. G. Webb. High G protection. *Aerospace Medicine* 32:425-430, 1961.

*Authors' abstract:* Model studies are discussed concerning mechanical principles thought to be important in solving some problems of protection against high accelerations. Also discussed are (1) a study of the effects of accleration on humans in the positive G (+Gz) position when submerged to eye level in a tank of water. Breath-holding permitted water pressure to increase the air pressure in the respiratory system of these subjects, and (2) subjects were studied in the prone position (-Gx) while completely submerged with respiratory pressurization. One subject's tolerance was increased by 13 G in the positive G position and by 15 G in the prone position. Other subjects showed unusually high G-tolerance in these positions. Undesirable effects had to do with translocation *of air headward* with the subjects in the positive G position and with bleeding and pain in the frontal sinuses and abdominal pain when the subjects were in the prone position.

93. Graybiel, A. and B. Clark. Symptoms resulting from prolonged immersion in water: The problem of zero G asthenia. *Aerospace Medicine* 32:181-196, 1961. (also Bureau of Medicine and Surgery Research Project MR005.15-2001, Subtask 1, Rept. 4, July 15, 1960.)

*Authors' abstract:*

*Problem:* Only a limited number of experimental studies have been concerned with the effects of reduced G on human behavior because of the difficulties involved in reducing the effects of G on the body for longer than 20 to 40 sec. The purpose of this study was to develop a technique to simulate the effects of reduced G on the muscular system of human subjects and then make preliminary observations of any changes in cardiovascular function and muscular strength and coordination.

*Conclusions:* In order to reduce the effects of G on the body, three subjects were floated in tanks of physiological saline solution for 10 hr/day for 2 weeks. The subjects were slightly supported in the water by a net and a sponge-rubber pillow which served to keep the head and ears clear of the water. The remaining 14 hr of the day, the subjects were confined in bed. Systematic attempts were made to eliminate any effects of sensory deprivation; someone was with the subjects constantly, 24 hr a day. Tests of cardiovascular function (tilt-table) and muscular strength and coordination were given before, during, and after the experiment. The results indicated little or no systematic change in the tests of muscular strength and coordination. On the other hand, all three subjects showed marked postural hypotension on the tilt-table during and following the period of immersion. For example, in contrast with control tests, it sometimes became necessary to return the subjects to horizontal before the 15-min test period was completed. These results are discussed in terms of possible implications for space flight.

94. Guyatt, A. R., F. Newman, F. F. Cinkotal, J. I. Palmer, and M. L. Thomson. Pulmonary diffusing capacity in man during immersion in water. *Journal of Applied Physiology* 20:878-881, 1965.

*Authors' abstract:* During immersion in water to the neck, 7 seated resting normal subjects showed, without exception in 14 trials, an increase in diffusing capacity of the lung ($DL_{CO}$) which averaged 16.2 ±0.79 SD percent of the control (unimmersed) values ($P < 0.001$). At an intermediate depth of immersion at which the calculated hydrostatic pressure (gauge) was approximately halved, the rise in $DL_{CO}$ was also halved. The hemodynamic readjustment to external pressure was completed within a few minutes since no further change in $DL_{CO}$ occurred during continuous immersion to the neck for as long as 90 min. Immersion produced a rise in "permeability" of the lung (Kco) which was on the average 5.8 percent greater than that in $DL_{CO}$. In three subjects, the pulmonary capillary blood volume (Vc) rose on the average 47 percent at the deeper level of immersion, suggesting that, as in the pressure suit, the rise in $DL_{CO}$ was due to pulmonary vascular engorgement.

95. Hamilton, W. F. and J. P. Mayo. Changes in the vital capacity when the body is immersed in water. *American Journal of Physiology* 141:51-53, 1944.

    *Purpose:* To determine the effect of water immersion on vital capacity.

    *Conclusions:* In 10 men, the vital capacity is reduced about 300 when the body is immersed to the nipple line than it is standing in air. When diastolic pressure cuffs are placed around the bases of arms and legs in water, the vital capacity is about 175 cc higher than without the cuffs. Increased venous return during immersion may be sufficient to increase volume of blood in lungs and decrease the space available for air.

96. Hanna, T. D. Psychomotor performance during total body water immersion for massed and spaced learning on a complex task. *Aerospace Medicine* 34:256, 1963.

    *Author's abstract:* An analysis is presented of the learning curves for a complex psychomotor task acquired by two equally matched groups of water immersed subjects under conditions of either massed or spaced practice. The task consisted of a constant-demand, multiple-stimuli learing situation requiring immediate decision-making and different motor responses. Whereas the shape of the two learing curves was similar, significant differences were observed between the elevation of the two groups and the difference between early and late trials. The within-session decrement to performance between initial and final values for the 30-min massed trials was not found during the 10-min spaced trials. It is concluded that under the experimental conditions, massed sessions incur attentional drift (boredom) rather than fatigue.

97. Hardy, J. D., J. A. J. Stolwijk, H. T. Hammel, and D. Murgatroyd. Skin temperature and cutaneous pain during warm water immersion. *Journal of Applied Physiology* 20:1014-1021, 1965.

    *Authors' abstract:* Measurements of skin temperature were made during the sudden immersion of the skin of human subjects in water baths at 36°–41° C and related to the reports of pain elicited during the first few seconds of immersion. Within 0.5 sec the skin temperature rose to bath temperature and remained at this level during the 10-15 sec of immersion, pain was reported at 37-41° C occurring 1-5 sec after the start of the immersion and adapting in 2-6 sec. Calculation of the subcutaneous temperature and thermal gradients indicate maximal thermal gradients in superficial skin layers during the first 0.1-0.2 sec of immersion (60° C/mm), that decreased rapidly during the first 5 sec to 6° C/mm. Analysis of the transient pain indicated that it could be considered as the more sensitive "phasic" response of the pain ending of which the "static" unadapting response occurs at skin temperatures of 43°–46° C. Several alternative explanations including subcutaneous thermal gradients, vasomotor reactions, and thermochemical changes in the nerve membrane were considered as possible explanations. The last most likely possibility requires a second-order kinetic system of three capacities with highly temperature-sensitive reaction velocities to account for both the phasic and static components of the pain.

98. Harned, H. S., Jr., R. T. Herrington, and J. I. Ferreiro. The effects of immersion and temperature on respiration in newborn lambs. *Pediatrics* 45:598-605, 1970.

*Authors' abstract:* The effects of immersion on respiration of term lambs during the perinatal period were studied under various conditions. After consistent breathing had developed in the newborn animal, immersion of the entire animal, immersion of its head, or introduction of fluid retrogradely into the trachea produced very marked respiratory depression as determined by a pneumotachometer attached to a trachial airway. Less marked, but still significant, respiratory depression was noted in animals subjected to snout immersion and to immersion with the head kept above the water bath. In this latter group, warm water depressed breathing more than cool water. The inhibitory effect of immersion on the initiation of breathing was shown by lack of survival of intubated lambs delivered into a water bath.

99. Hartman, B., R. E. McKenzie, and D. E. Graveline. An exploratory study of changes in proficiency in a hypodynamic environment. School of Aviation Medicine, Brooks Air Force Base, Texas. Rept. No. 60-72, 1960, 13 p.

*Authors' abstract:* As a part of an exploratory study of the effects of prolonged exposure to a hypodynamic environment, which simulates many aspects of weightlessness, changes in psychomotor efficiency were assessed. Proficiency was measured in two different phases: (a) during immersion on a relatively simple task and (b) upon return to the normal 1-G state. Systematic increases in response time during the 7-day period in the hypodynamic enviroment were obtained. Gross disruptions in psychomotor behavior upon return to the normal 1-G state were observed. When compared to a control run, these were increased response times in three different kinds of tasks. These results suggest that the functional capabilities of a man exposed to a prolonged period of weightlessness will be seriously impaired during the reentry phase of space flight.

100. Hayward, J. S., M. Collis, and J. D. Eckerson. Thermographic evaluation of relative heat loss areas of man during cold water immersion. *Aerospace Medicine* 44:708-711, 1973.

*Authors' abstract:* Infrared thermography was used to provide illustrations of the regional differences of temperature of the surface of the human body before and after immersion in water of 7.5° C for 15 min. Thermal gradients over the surface are increased by cold-water immersion, with areas such as the lateral thorax, upper chest, and groin having the highest temperatures. It is predicted that heat loss in the water would be greatest from such areas and that these findings would be useful in the design of thermally protective lifejackets and for advice on body posture in the water to minimize heat loss. Swimming activity increased the amount of the body surface having higher relative temperatures, thereby increasing overall heat loss.

101. Hervey, G. R. The physiology of cold/wet survival. *Journal of the Royal Naval Medical Service* 58:161-170, 1972.

*Author's abstract:* The physiology and effectiveness of the body's thermoregulatory mechanisms are studied. The working of the control system is discussed and its effects demonstrated. The general effect of this thermoregulation on the likelihood of survival is considered, together with the principles of treatment for those suffering from immersion or exposure.

102. Hong, S. K., P. Cerretelli, J. C. Cruz, and H. Rahn. Mechanics of respiration during submersion in water. *Journal of Applied Physiology* 27:535-538, 1969.

*Authors' abstract:* The changes in the lung volumes, the total intrapulmonary pressure (Pr), the intragastric pressure (Pg), and the total work of breathing during submersion in water to the neck level were studied in four human subjects. Control measurements were made with the subject submerged up to the level of the xiphoid process. The Pt curve shifted to the right by 16 cm $H_2O$ during submersion, while Pg increased gradually from 0 to 35-45 cm $H_2O$. Both the vital capacity (VC) and the expiratory reserve volume decreased while the tidal volume remained unchanged during submersion. Increases in ΔVC obtained immediately following a Valsalva maneuver after submersion suggest that approximately 60 percent of the reduction in VC obseved is due to an increased intrathoracic blood volume and the rest to hydrostatic forces. The total work of breathing for a tidal volume of 1 liter increased during submersion by approximately 60 percent most of it due to an increase in the elastic work.

103. Hong, S. K., E. Y. Ting, and H. Rahn. Lung volumes at different depths of submersion. *Journal of Applied Physiology* 15:550-553, 1960.

*Authors' abstract:* Vital capacity and expiratory reserve volumes of the lung were measured in seven subjects in the supine position. These were reduced when subjects were submersed at depths of 10, 20, and 30 and 40 cm below the surface while breathing through rigid tubes. The reduction in these lung volumes is similar to that observed when subjects are subjected to continuous negative pulmonary pressure. The equivalence of pressurization of the thorax by air and water is discussed. When man in the supine position is just submersed, the resting lung volume changes are equal to that when a negative pulmonary pressure of 6 cm $H_2O$ is applied.

104. Hood, W. B., Jr., R. H. Murray, C. W. Urschel, J. A. Bowers, and J. K. Goldman. Circulatory effects of water immersion upon human subjects. *Aerospace Medicine* 39:579-584, 1968.

*Authors' abstract:* Changes in hemodynamics were studied in five human volunteer subjects during two separate 8-hr periods of bedrest and total water immersion. During immersion, subjects showed a decline in pulse rate, arterial blood pressure, and peripheral vascular resistance, and elevation of stroke volume compared to the control state. Central venous mean blood pressure fell within immersion, presumably in response to the relative negativity of the airway pressure supplied to the subjects. These findings suggest that water immersion results in these circulatory changes: (1) relative bradycardia, with a secondary increase in stroke volume and (2) peripheral vasodilation with secondary decline in arterial pressure. These findings are not explained either by loss of plasma volume or by relative negative pressure breathing, and presumably are a consequence of exposure to the "buoyant state."

105. Howard, P., J. Ernsting, D. Denison, D. I. Fryer, D. H. Glaister, and G. H. Byford. The effects of simulated weightlessness on the cardiovascular system. *Aerospace Medicine* 38:551-563, 1967.

*Purpose:* To determine whether the cardiovascular deconditioning effects accompanying immersion are secondary to the dehydrating effect of diuresis.

*Procedure and methods:* Five subjects (aged 31-46 yrs.) were studied before and after total body immersion for 6 hrs. in a bath maintained at 34° C. Care was taken to exclude negative pressure breathing. Orthostatic tolerances was tested before and after immersion by passive tilting to 70° from the horizontal for 12 minutes unless syncope supervened. Plasma volume, blood pressure, heart rate, oxygen consumption, and carbon dioxide production were also measured.

*Conclusions:*

Response to passive tilting was unchanged after immersion.

Plasma volume changes during immersion were minimal. The latter was due to the absence of duiresis by maintenance of abnormal intrathoracic pressure throughout immersion and was responsible for failure to demonstrate anthostatic intolerance after immersion.

106. Hunt, N. C. A factorial study of immersion diuresis and its inhibition by positive pressure. Aerospace Medical Association Preprints, 1965, pp. 131-132.

*Purpose:* To determine the role of negative pressure breathing in immersion diuresis, the possibility of restoring near normal pulmonary dynamics by positive pressure breathing (PPB), and to observe diuretic influence.

*Procedure and methods:* Twelve dehydrated subjects underwent 3-6 hr immersion: (a) reclining in deck chairs, (b) ambulatory, (c) immersion above shoulders in deck chairs, and (d) PPB at 20-cm water pressure during immersion.

*Results:* Immersion diuresis and natriuresis are reversed by PPB.

*Conclusion:* The findings confirm the role of negative pressure breathing during immersion as the stimulus for diuresis.

107. Hunt, N. C. A comparison of the effects of vasopressin and positive pressure breathing on the cardiovascular deconditioning of water immersion. Aerospace Medical Association Preprints, 1967, pp. 52-53.

*Purpose:* To compare the effects of dehydration and water immersion on fluid balance and tilt-table performance, and also to assess the effects of Vasopressin and positive pressure breathing (PPB) on the change in fluid volume and tilt-table performance resulting from water immersion.

*Procedure and methods:* Six USAF men were exposed for 6 hr to the following conditions: (1) routine daily activity (RDA), (2) confinement to a deck chair in a semirecumbent position (C), (3) semirecumbent confinement position immersed to the neck in 33°–34° C water, and (4) water immersion with 20 mm Hg positive pressure breathing (WIPP). The first three phases were also utilized to compare the effects of Vasopressin vs. saline placebo. Total 6-hr urine volumes were measured. A tilt-table test following each experimental condition consisted of a 10-min baseline followed by 15 min of 70° tilt. Pulse rate and blood pressure were recorded every other minute.

*Conclusions:* Short periods of inactivity and recumbency tend to produce a slight diuresis, but did not change tilt-table results. Water immersion increased diuresis and decreased tilt-table tolerance; the diuresis could be inhibited about 70 percent by PPB and also improved tilt-table performance. Vasopressin reduced saline diuresis by 50 percent without affecting tilt-table tolerances. Neither Vasopressin nor PPB totally reversed immersion diuresis. Tilt-table tolerance with PPB exceeded that of RDA. Examination of factors other than fluid balance appear necessary to explain the wide differences in cardiovascular response.

108. Hunt, N. C. III. Immersion diuresis. *Aerospace Medicine* 38:176-180, 1967.

*Author's abstract:* The effect of water immersion on urine composition was studied in 12 dehydrated subjects. Acting as their own controls, the subjects were submitted to three separate 6-hr periods of (a) routine daily activity, (b) water immersion to neck level, reclining in a deck chair, and (c) reclining in a deck chair, non-immersed. Reclining in a deck chair, relative to routine daily activity, was associated with a natruresis accompanied by a small volume of osmotically obligated water. Water immersion, relative to reclining in a deck chair, was associated with a marked diuresis, consisting primarily of nonsolute obligated water and, secondarily, of water obligated to a significantly increased sodium excretion. In 6 subjects, Pitressin treatment tended to suppress immersion diuresis. Whereas the release of nonsolute obligated water is best explained by ADH inhibition accompanying the negative pressure breathing inherent to immersion, another reason must be sought for the enhanced sodium excretion. The mechanism for natruresis was not defined by indirect measurements of glomerular and tubular activity; possible mechanisms are discussed.

109. Hunt, H. C. Positive pressure breathing during water immersion. *Aerospace Medicine* 38:731-735, 1967.

*Author's abstract:* Continuous positive pressure breathing was applied to 12 healthy USAF volunteers during water immersion in an attempt to overcome the diuresis and tilt-table intolerance associated with immersion. During the 6-hr treatment period, the subjects reclined in a deck chair, immersed to neck level in water, and breathed a continuous 20 cm $H_2O$ positive pressure. The resultant urine composition and tilt-table tolerance were compared to that associated with 6 hr (a) immersed and (b) non-immersed in the same position and without positive pressure. The use of positive pressure respiration inhibited the diuresis associated with water immersion; this inhibition applied to both nonsolute obligated water and excretion of sodium salts. Tilt-table tolerance following positive pressure surpassed that seen in the non-immersed control. It was concluded that the diuresis was inhibited by the action of positive pressure respiration on volume receptor sites. Possible mechanisms for tilt-table protection are discussed.

110. Ioffe, L. A., A. V. Korobkov, L. A. Lantsberg, and Ye. I. Fel'shina. Changes in human water-mineral metabolism during water immersion. *Kosmicheskaya Biologiya i Meditsina* 5:15-19, 1971.

*Authors' abstract:* The effect of a 5-day water immersion test (involving five young healthy male test subjects) on the state of mineral metabolism was investigated. An increase in diuresis (mostly water) and a change in urinary electrolyte excretion were observed. Variations in the renal function of water and ion excretion during the immersion experiment were accompanied by an increase in sodium and potassium content in the plasma and erythrocytes. During the first to third days after the experiment, water and mineral excretion was delayed. During the experiment, the hematocritic index increased substantially, possibly an indirect indication of a reduction in the volume of circulating plasma and, accordingly, the blood concentration. Following the immersion test, significant changes were noted in the hematocritic index in response to a standard load. Mechanisms of the observed changes are discussed.

111. Jarrett, A. S. The effect of immersion on lung volumes. FPRC/1221, Flying Personnel Research Committee, Great Britain, 1963. 11 pp.

*Purpose:* To differentiate the effects of body position and surrounding medium on the overall effect of immersion on lung volumes and to aid in the design of lifesaving jackets.

*Procedure and methods:* Five subjects (24-33 yr) were used to measure residual volumes in four situations, sitting and lying in air and water, by the closed-circuit helium method. The vital capacity and its subdivisions were measured by a recording closed-circuit spirometer with circulating pump and soda-lime carbon-dioxide absorbent cannister. Residual volumes, vital capacities, expiratory and inspiratory reserve volumes, tidal volumes, and lung volumes were determined.

*Results:*

LUNG VOLUMES
(percent)

| Volume | Air | | Water | | |
|---|---|---|---|---|---|
| | Sitting | Lying | Sitting | Lying | Lifejacket |
| Total lung capacity | 100 | 96 | 94 | 95 | |
| Vital capacity | 76 | 74 | 73 | 73 | 71 |
| Residual volume | 24 | 22 | 21 | 22 | |
| Inspiratory reserve | 47 | 55 | 60 | 58 | 59 |
| Expiratory reserve | 22 | 12 | 6 | 7 | 5 |
| Tidal volume | 7 | 7 | 8 | 8 | 8 |

The effects of position and immersion on the lung volumes and the mean for the five subjects in any situation were calculated; these mean volumes are expressed as percentages of the total lung capacity while sitting upright in air.

*Conclusions:* The general effects of both recumbency and immersion are similar, namely, to bring about an absolute decrease in both residual volume and total lung capacity and to increase the inspiratory reserve volume at the expense of the expiratory reserve volume. It is suggested that muscular tone is the most important factor determining the reduction in expiratory reserve volume. This has important implications for the design of lifejackets, for an unconscious man will be fully relaxed and can be expected to have an expiratory reserve volume of zero. The loss of this buoyancy must be foreseen by manufacturers of lifejackets.

112. Jarrett, A. S. Effect of immersion on intrapulmonary pressure. *Journal of Applied Physiology* 20:1261-1266, 1965. (also Flying Personnel Research Committee, Great Britain, N65-12843 FPRC/1220, 1963.)

*Author's abstract:* Pressure-volume relaxation curves have been determined for relaxed, breath-holding subjects lying and sitting in air and water. Immersion in water resulted in a marked increase in intrapulmonary pressure, the whole pressure-volume curve appearing to be shifted along the pressure axis. From the regression equations of the four curves, the pressures at normal relaxed chest volume were calculated, and the center of pressure of the immersed chest shown to lie 19 cm below and 7 cm behind the sternal angle. The significance of this to the positioning of a diver's demand valve is discussed.

113. Kaiser, D., P. Eckert, O. H. Gauer, and H.-J. Linkenbach. Circulation and water balance during immersion in a water bath. *Pflügers Archiv* 278:52-53, 1963.

*Procedure and methods:* Fifteen subjects remained in a resting supine position for an average of 8 hr in a temperature-controlled water bath. Blood pressure, pulse, urine volume, electrolyte excretion, and urinary osmolarity were monitored at half-hour intervals. Orthostatic tolerance, plasma volume, hematocrit, serum electrolyte, and body weight were measured at the beginning and end of the experiment. In addition, serum samples were checked for diuretic activity in rat tests before and after the experiment.

*Results:* There was a constant drop in the systolic and diastolic blood pressures with a constant pulse. Half of the diuresis, which was 3.5 times that in the controls, was drawn from the plasma water. The plasma volume dropped by 16 percent on the average. At the end of the experiment, the capacity for orthostatic circulatory regulation was markedly reduced. 0.25 ml of serum from blood samples taken in sitting and lying positions and in the bath was tested on rats at the peak of diuresis. Serum from reclining subjects produced a mild diuresis. Serum which was collected at the peak of bath diuresis induced a strong diuretic effect in rats.

*Conclusions:* Overfilling of the thoracic vascular bed takes place in the bath. As in the experiments of Roddie et al. and Doutheil and Kramer, intrathoracic baroreceptors evoke depressor reflexes in the circulation. In addition to this vasomotor component, a pronounced effect on the water balance can be seen. The elimination of plasma water as a result of bath diuresis is sufficient to be solely responsible for the tendency toward collapse with subsequent orthostatic stress.

At the peak of diuresis the increased appearance of a substance which has a diuretic effect in rat tests could be detected.

114. Kaiser, D., P. Eckert, O. H. Gauer, and H. J. Linkenbach. Die diurese bei Immersion in ein Thermoindifferentes Vollbad. *Pflügers Archiv* 306:247-261, 1969.

*Authors' abstract:* The increase in urine flow during immersion in a bath of indifferent temperature is interpreted as water diuresis reflexly caused by an expansion of the intrathoracic blood volume and mediated through a reduction of blood ADH. If the control urine flow is increased to a water diuresis of 4 ml/min, water immersion remains without effect.

A concomitant increase in osmolar clearance is interpreted as a washout effect.

An increase in sodium excretion (+27 percent) can only partly be explained by an increase in filtration rate (+11 percent). It is probably due to a reduction in tubular sodium reabsorption.

115. Kaiser, D. and O. H. Gauer. Study of venous tonus in the forearm during simulated weightlessness. *Pflügers Archiv* 289:R76-77, 1966.

*Authors' abstract:* After several hours of simulated weightlessness (immersion in a thermally neutral bath), a tendency toward collapse occurs under orthostatic loads (tilting table). In earlier experiments, it had been possible to show that under these conditions – after 8 hr of immersion – plasma volume is reduced by 14 percent. A study was now made as to whether a reflex slackening of the veins also favors the tendency toward collapse. Prior to immersion – and at regular intervals after immersion – circumferential pressure diagrams were taken with the aid of a venous inflatable cuff, a Whitney gauge, and Stratham strain gauge manometer about the upper arm. A reduction in venous tonus, probably a function, in part, of temperature, occurred immediately after immersion. Several hours of immersion also usually causes further relaxation of the veins.

116. Kaiser, D., H. J. Linkenbach, and O. H. Gauer. Anderungen des Plasmavolumens des Menschen bei Immersion in ein Thermoindifferentes Wasserbad. *Pflügers Archiv* 308:166-173, 1969.

*Purpose:* To provide confirming evidence that intrathoracic volume expansion is responsible for immersion diuresis and subsequent and orthostatic intolerance.

*Procedure and methods:* Twenty-four experiments were performed on 28 men (average age 23) before and after 8 hr immersion. Immersion proceeded when a constant urinary flow was established. The following measurements were obtained: plasma volume (Evan's Blue method), hematocrit, urinary volume, body weight, and orthostatic tolerance (standing upright for 10 min).

*Results:* In 18 subjects average plasma volume decreased 494 ml while body weight loss averaged 6.4 kg. Hematocrit increased 3.1 percent and calculated blood volume decreased 9.7 percent. Orthostasis was experienced by 5 subjects.

*Conclusion:* Decreased orthostatic tolerance following immersion is related to the decrease in plasma volume.

117. Keatinge, W. R. Cold immersion and swimming. *Journal of the Royal Naval Medical Service* 58:171-176, 1972.

*Author's abstract:* Experiments to indicate the effects on survival after immersion in water of such factors as subcutaneous fat, exercise, and clothing are described. The causes of sudden death in water are discussed and advice is given on action to be taken to preserve life after immersion. Several factors influence body cooling rates and survival times. Subcutaneous fat behaves as an insulating agent, since the rate of heat loss is roughly proportional to the reciprocal of fat thickness, thin people cool much more rapidly than fat people. Exercise promoted a greater loss of body heat than remaining still, indicating that attempts to increase metabolism also increases body heat loss and greater body cooling. Sudden death during exposure to cold water can occur following rescue which may be due to impaction of water into the back of the nose causing ragol arrest of the heart.

118. Keatinge, W. R. and M. Evans. The respiratory and cardiovascular response to immersion in cold and warm water. *Journal of Experimental Physiology* 46:83-94, 1961.

*Authors' abstract:* During their first few minutes of immersion in stirred water at 5° and 15° C, the pulmonary ventilation of 12 unclothed men was high, and their end-tidal $pCO_2$ fell. The $pCO_2$ then returned to or a little above its original level but did not greatly exceed it even in working experiments lasting 20 min in water at 5° C or 40 min in water at 15° C. Although work reduced or reversed the initial fall in $pCO_2$, these results therefore do not bear out predictions that the $pCO_2$ would rise to dangerous levels during hard work in cold water, at least in immersions of moderate duration.

In water at 37.8° C, the men's heart rates rose steadily; in water at 25° C they fell and remained low; and in water at 5° and 15° C, they rose and then fell. Repeated immersion at 15° C reduced or abolished the early respiratory and heart-rate responses to immersion and the metabolic response, but did not significantly increase the falls in rectal temperature. Clothing also reduced the reflex responses to immersion. A number of ventricular extrasystoles were observed during the first 2 min of immersion in water at 15° C, and it is suggested that ventricular fibrillation due to increased venous and arterial pressures, adrenaline, and hyperventilation may be responsible for some cases of sudden death in cold water.

119. Keatinge, W. R. and P. Howard. Effect of local cooling of the legs on tolerance to positive acceleration. *Journal of Applied Physiology* 31:819-822, 1971.

*Authors' abstract:* Local cooling of the legs without change in trunk skin temperature or oral temperature improved the ability to withstand positive (headward) acceleration in the sitting position. Arterial systolic, diastolic, and pulse pressures were maintained at higher levels, ankle circumference increased less, and the acceleration at which peripheral vision was lost increased on average by 0.27 G, when the legs were cold. The effects of leg cooling were attributable to reduced pooling of blood and increased vascular resistance in the legs, due in turn to direct effects of low temperature on their blood vessels.

120. Kerr, R. Movement time in an underwater environment. *Journal of Motor Behavior* 5:175-178, 1973.

*Author's abstract:* The effect of an underwater environment on the human motor capacity, as measured by Fitts' Law, was determined. Five subjects performed a reciprocal tapping task both on land and underwater. The results showed that movement time (MT) was significantly slower ($p < 0.01$) underwater than on land. Underwater the amplitude of the movement was found to have a greater influence on MT than the required precision of the movement. On land the reverse was found to be true with movement precision having a greater influence on MT.

121. Kinney, J. S., S. M. Luria, and D. O. Weitzman. Effect of turbidity on judgments of distance underwater. *Perceptual and Motor Skills* 28:331-333, 1969.

*Authors' abstract:* Judgments of the distance of an underwater target at various locations were obtained as a function of water clarity. When the target was close to the subject, its distance was underestimated. Judgments changed to overestimation as the actual physical distance was increased. Estimates were invariably greater in turbid water than in clear water. These data resolve the apparent conflict between expectations from optical considerations and actual distance estimates made in natural waters.

122. Knight, L. A. An approach to the physiologic simulation of the null-gravity state. *Journal of Aviation Medicine* 29:283-286, 1958.

*Author's abstract:* Special orientation during water immersion was undertaken to examine the blind spot of Quix. Subjects were placed on a tilt table in a 7-ft-deep swimming pool. Vision was occluded and high-pressure breathing device supported breathing. In three subjects, a mean change of 17° was required before the positional change was identified. The blind spot of Quix was not positively identified. Bilateral acute otitis externa precluded further experiments. Underwater immersion closely simulates the weightless state and is valued as an experimental approach.

123. Kobayasi, S., T. Ogawa, C. Adachi, F. Ishikawa, and K. Takahashi. Cutaneous factor in immersion bradycardia in man; preliminary report. *Acta Medica et Biologica* 19:101-108, 1971.

*Authors' abstract:* Heart-rate responses to face immersion and to graded body immersion without breath-holding were examined in 10 healthy male subject at varied water temperatures. Bradycardia could be initiated by water immersion of any part of the body, not restricted to the facial region. In body immersion at any given level as well as in facil immersion, heart rate decreased to the minimal value in around 30 sec and returned almost to the resting value in 90-120 sec while the subject remained immersed. The magnitude of the response was dependent on water temperature. Stimulation of cold receptors may play a significant role in response to immersion without breath-holding. The return of the heart rate during immersion may be attributed to the adaptation of the receptors.

124. Kollias, J., L. Barlett, V. Bergsteinova, J. S. Skinner, E. R. Buskirk, and W. C. Nicholas. Metabolic and thermal responses of women during cooling in water. *Journal of Applied Physiology* 36:577-580, 1974.

*Authors' abstract:* The metabolic and thermal responses of 10 young women, 3 lean (21 to 24 percent fat) and 7 obese (29 to 41 percent fat), were measured during head-out immersion in a stirred water bath maintained at 20° C. Continuous measurements of heat production (M), rectal ($T_{re}$), esophageal ($T_{es}$), and skin temperatures were obtained. The rate and magnitude of the increase in M and decrease in core temperatures were significantly greater in the lean than the obese group. Tissue insulation values for lean women were similar to those reported for diving and nondiving Korean women in 30° C water. Lean women with 22 percent body fat have a larger SA/mass ratio than men of comparable body fat content and cool at a greater rate. It is concluded that SA/mass as well as body fatness and size must be considered in the overall metabolic and thermal responses to cold exposure.

125. Korobova, A. A., A. V. Ovsyannikov, G. G. Ratishvili, and A. V. Korobkov. Effect of immersion on certain motor function indices. II. Physiological functions of an organism during extreme actions. *Problems of Space Biology* 16:34-48, 1971.

*Authors' abstract:* The article presents results of a study of certain indices of a simple movement with visual adjustment and without it, and also a determination of the peculiarities of the functional state of the segmentary apparatus of the spinal column during the period of organization of voluntary movements of man during prolonged stay in a physiological solution.

Reduction of the threshold value of the H-reflex during a 3- to 4-day stay in conditions of immersion is seen as a consequence of the increase of reflector excitability of alpha-motor neurons of the spinal column.

Increase of the average time of the latent period in each of the test subjects on the second day of their stay in conditions of an immersion medium gives the basis for supposing that in these conditions the functional state of the supraspinal centers is lowered.

Comparative evaluation of execution of a motor problem with visual adjustment and without it shows the well-defined nature of shifts during shut-off of the visual adjustment both in background examinations and after immersion on all days of recovery. The immersion medium has a different effect on the postural tonic and phase musculature, and correspondingly also on the nature of execution of motor acts.

126. Korz, R., F. Fischer, and C. Behn. Renin-angiotensin system in simulated hypervolemia induced by immersion. *Klinische Wochenschrift* 47:1263-1268, 1969.

*Authors' abstract:* The relationship between plasma renin activity, sodium and potassium excretion, and plasma volume was studied during a control period and after immersion in neutral-temperature water (34°-34.5° C) for 6 hr. Plasma renin activity decreased by 28 percent, and the Na/K ratio increased, possibly reflecting decreased aldosterone secretion. Plasma volume decreased by 14.1 percent; no inverse relationship to plasma renin activity is found. The early natriuretic effect of immersion is concluded to be independent of aldosterone secretion. The early increase in tubular sodium load is considered to cause the decreased renin activity, inducing a reduction in aldosterone secretion, in turn responsible for altered electrolyte excretion after prolonged immersion.

127. Korz, R., W. Pontzen, and C. Behn. Renaler Phenolsulfonphthaleintransport bei Vergrosserung des zentralen Blutvolumens durch Immersion. *Klinische Wochenschrift* 47:1220-1225, 1969.

*Authors' abstract:* The renal mechanism of phenolsulfonphthalein excretion during simulated hypervolemia by complete body immersion in neutral-temperature water (34°–34.5° C) was investigated. An increase of 6 percent in phenol red clearance as compared to a control period was observed in six healthy young men upon immersion. The ratio of phenol red clearance to effective renal plasma flow increased. Renal hypercirculation was ruled out as the cause of increased phenol red clearance. A 6.8-percent decrease in the plasma albumin fraction was also observed during immersion. Hypoalbuminemia increases the protein-unbound PSP fraction and therefore glomerular filtration and tubular secretion of the dye. This decrease in plasma albumin is discussed as a possible reason for the increase in the clearance of phenol red.

128. Kotovskaya, A. R., R. A. Vartbaronov, and S. F. Simpura. Change in the capacity of man to withstand transverse stresses after hypodynamia of varying duration. *Problems of Space Biology* 16:56-65, 1971.

*Authors' abstract:* This study investigates the capacity of man to withstand transverse stresses (+Gx) after resting in a supine position for 3 to 6 hr. Gradual reduction in the resistance to the action of maximum stresses was detected at time periods of hypodynamia from 7 to 15-20 hr. Later resistance to stresses was preserved approximatley at the same level up to the 60th hour of hypodynamia. Similar shifts were obtained in a study of the reactivity of the cardiovascular and breathing systems to stresses determined according to the level of pulse strain and increase of pulmonary ventilation before and after hypodynamia of varying duration. The results obtained give a basis for supposing the existence in the process of hypodynamia of two phases in reactions of an organism to stress. The presence of the second phase (stabilization) may support the development of a unique adaptation to conditions of hypodynamia.

129. Kroetz, C. and R. Wachter. The minute volume of the heart in various types of bath. *Klinische Wochenschrift* 12:1517-1520, 1933.

*Authors' abstract:* Determinations of the minute volumes of the hearts of three healthy subjects who took five different kinds of baths gave the following results:

In the freshwater bath, the minute volume increased 20-24 percent. Here and in all the other types of bath, there were unmistakable and consistent differences between the individual reactions of the subjects.

In the carbon dioxide brine bath from Bad Nauheim spring No. XII, we obtained somewhat higher values, on the average 31 and 34 percent.

In the oxygen bath, the minute volumes of the subjects increased by an average of 12-18 percent. Thus, the oxygen bath is to be placed next to the freshwater bath and not to the carbon dioxide bath with respect to the minute volume.

In the carbon dioxide gas bath, we observed increases of only about 6-8 percent, for the reasons explained in greater detail above.

The air bath gave no reaction.

The time periods immediately following the baths, in which the minute volume returned to normal with variable speed, was investigated once again. Only with the $CO_2$ brine bath was the minute volume higher on some occasions as late as 40 min after the bath – another proof of the more prolonged effect of the natural $CO_2$ bath.

130. Landis, E. M., W. L. Long, J. W. Dunn, C. L. Jackson, and U. Meyer. Studies on the effects of baths on man. III. Effects of hot baths on respiration, blood and urine. *American Journal of Physiology* 76:35-48, 1926.

*Purpose:* To determine the effects of hot and neutral bath temperatures on man.

*Procedure and methods:*

Three subjects were immersed in a neutral bath temperature and then the water temperature was raised.

Rectal temperature, ventilation, respiratory rates, and urinary excretion were measured.

*Results:*

Rectal temperature increased quite rapidly and attained in some cases near 40° C. Ventilation and respiratory rates also increased. Alveolar $CO_2$, blood, and urine pH rose slightly. Several tests ended by the development of tetany.

*Conclusions:*

Hot baths cause a hyperpnea whose severity depends on the rate of rise of body temperature and also on the temperature level at which the rise takes place.

Hyperpnea involves a change in both rate and depth; there is never a shallow respiration except in the first few moments when there is strong skin stimulation and during the recovery period.

pH change of blood to the alkaline side is apparently determined by the hyperpnea but is not proportional to it.

There may take place an excretion of urine which is more alkaline than blood, probably with varying efficiency in different individuals.

Oxygen does not relieve tetany, but carbon dioxide gives definite improvement.

On two occasions, a change in the pH of the blood toward the acid side was demonstrable within a few minutes of the onset of definite tetany, and the pH change was accompanied by a fall in the total carbon dioxide content of the blood. This might readily be explained if lactic acid was produced during tetany. No evidence was obtained of any definite pH level at which tetany would occur, nor even of any critical degree of change in the pH level.

131. Lapp, M. C. and G. K. Gee. Human acclimatization to cold water immersion. *Archives of Environmental Health* 15:568-579, 1967.

*Purpose:* To determine the effect of repeated short-term cool water immersion on acclimatization processes.

*Procedures and methods:* Three men and 5 women were immersed 1 hr/day, twice weekly for 8 weeks in water at 31.7° C (89° F) to 21° C (70° F).

*Conclusions:*

Subjects apparently acclimatized to cool water immersion based on increased thyroid $^{131}I$ uptake, increased metabolic rates, and improved mental ability performance.

Mean thyroid $^{131}I$ uptake increased 14 percent after acclimatization indicating a hormonal adaptation.

Time of onset of shivering responses were increased and apparently related to the increased transfer of peripheral heat to the core.

Body surface area appears to be a significant factor in body heat loss during cold water immersion.

132. Lewis, B. M., R. E. Forster, and E. L. Beckman. Effect of inflation of a pressure suit on pulmonary diffusing capacity in man. *Journal of Applied Physiology* 12:57-64, 1958.

*Authors' abstract:* Previous work has shown that inflation around the lower half of the body of a tightly fitting pneumatic suit to a pressure of 75 mm Hg produces an acute increase in pulmonary arterial and wedge pressures of about 25 mm Hg in normal subjects. Effects of this procedure upon the pulmonary capillary bed were investigated by measuring the diffusing capacity of the lung for CO (DL) at different alveolar $O_2$ tensions from below 100 mm Hg to above 600 mm Hg in four healthy subjects using a 10-sec breath-holding technique. Measurements made when the suit was inflated were compared with control measurements made immediately before and/or after with the suit deflated. In none of 11 series of experiments was a significant change in mean DL produced by inflation of the pneumatic suit. The true diffusing capacity of the pulmonary membrane for CO (Dm) and the volume of the blood in the pulmonary capillaries (Vc) were also calculated from the value of DL at different alveolar $O_2$ tensions. Dm fell following suit inflation in two subjects and was unchanged in one subject. These changes were probably not significant. Inflation of the suit produced gas "trapping" in the lung. While it is possible that this gas "trapping" produced an underestimate of DL during suit inflation, one would have expected that, if the procedure had either markedly dilated patent pulmonary capillaries or opened capillaries previously closed, a significant increase in DL, DM, or VC would have been observed.

133. Linkenbach, P. Eckert, and O. H. Gauer. Nachweis eines diuretischen Factors in menschlichen Serum wähnen der durch Expansion des intrathorakalen Blutvolumens ausgelösten Diurese. *Pflügers Archiv* 293:107-114, 1967.

*Authors' abstract:*

Blood serum of subjects who showed a diuresis due to assumption of the prone position or immersion in a bath was tested for diuretic activity in hydrated rats anesthetized with alcohol.

Control serum taken from the sitting subject showed a slight anti-diuretic activity, whereas the serum of the prone or immersed subject produced diuresis. Although the values in the serum showed considerable scatter, the diuretic effect was statistically significant ($p < 0.02-0.03$).

After storage of the serum at 2°–4° C or room temperature for 20 hr, the diuretic activity was abolished.

It is concluded that in addition to a change of renal hemodynamics and the secretion of vasopressin, a humoral diuretic agent of an unknown nature is at play in the release of a diuresis induced by a change of the intrathroacic blood volume.

134. Litman, M., P. Cerretelli, A. Chinet, J. P. Farber, L. E. Farhi, and D. W. Rennie. Redistribution of pulmonary blood flow during submersion. *Physiologist* 12:285, 1969.

*Authors' abstract:* Cardiogenic oscillations of $O_2$ and $CO_2$ normally found on the alveolar air plateau have been observed by Cerreteeli and Rennie to disappear during headout immersion in water. Since these oscillations are commonly thought to reflect heterogeneous distribution of $\dot{V}_A/\dot{Q}$, their disappearance may indicate changes in distribution of $\dot{V}_A$, $\dot{Q}$, or both. However, a change in distribution of $\dot{V}_A$ has been ruled out since cardiogenic oscillations of an inert, poorly soluble tracer (argon, single breath) are not altered by submersion. A breath taken in air followed by expiration after immersion still shows $O_2$ and $CO_2$ oscillations. Negative pressure breathing in air slightly diminishes oscillations and positive pressure breathing in water may partially restore them. Gradual submersion leads to progressive disappearance of the oscillations, except in unusually tall subjects, but not when venous tourniquets have been placed around the upper portion of the extremities before submersion. We suggest that the disappearance of cardiogenic oscillations is due to a redistribution of pulmonary blood flow probably caused by increased venous return and/or increase in pulmonary blood volume during immersion.

135. Loats, H. L., Jr. and G. S. Mattingly. A study of the performance of an astronaut during ingress and egress maneuver through airlocks and passageways. Environmental Research Associates, Randallstown, Maryland. Rept. No. NASA-CR-66340; ERA-64-6, Aug. 1964.

*Authors' abstract:* A comparative time-displacement analysis (motion picture) was performed to quantitatively assess the feasibility and utility of experiments involving pressure-suited astronaut egress as a result of balanced gravity conditions such as would exist on orbiting nonrotating space stations and vehicles. The experiments were performed using a full-scale airlock provided by Langley Research Center, comprising three distinct hatch configurations enclosing a cylindrical passageway. The experiments were performed in the following three modes: ground/normal gravity, water immersion/neutral buoyancy, and aircraft/balanced gravity. Each of these modes has certain inherent restrictions, for example, the aircraft is severly space-time limited, water immersion allows external balanced gravity conditions only, and the ground experiment is subjected to normal gravity. Comparison analysis of the three modes was accomplished with suit pressure, subject, and suit type as parameters.

The results of this analysis indicate that the performance of manned egress maneuvers using the water immersion and aircraft modes could be successfully correlated as regards psychological as well as the operational considerations. Due to the mobility decrement afforded by the pressure suit and normal gravity effects, the character of egress performance differed between the ground and the two remaining modes. The major dissimilarity evidenced was in the total times of egress as well as discrete task performance times and modes.

Valid experimentation of manned egress under balanced gravity require the performance of water immersion tests backed up with a reduced number of aircraft tests. Ground/normal gravity experiments are additionally required to serve a control and procedure determination function. Due to the scope of phase I, insufficient testing was accomplished to qualify this conclusion further. Considerably greater effort will be carried out pertinent to this effect in phase II.

136. Luria, S. M., J. S. Kinney, and S. Weissman. Estimates of size and distance underwater. *American Journal of Psychology* 80:282-286, 1967.

*Authors' abstract:* Estimates of both the size and the distance of unknown objects in air and in water were compared. A 4-in. square was placed at distances of 5 and 12 ft from 0 for the size estimates and at 4-15 ft for the distance estimates. The observations in air were made out of doors, and the under-water observations were made from a porthole in a submerged tower. Estimates of size were reasonably accurate in both air and water, but they were somewhat larger in water, the increase corresponding to the increase in the size of the retinal

image resulting from the refraction of light waves passing from water to air. At the same time, distances were overestimated in water as compared to estimates in air, and overestimations increased with distance. It is concluded that these results are not explained by size-distance invariance and that, in the absence of distinct cues, distance will be overestimated.

137. Mackay, D. E. The problem of cold/wet survival. *Journal of the Royal Naval Medical Service* 58:158-160, 1972.

*Author's abstract:* A general introduction sets the scene for the Symposium. The practical problems of the preservation of life following exposure are stressed, with particular reference to the lone survival of a trawlerman following a disaster in Arctic waters. Development of protective clothing should be considered for individuals who are daily confronted with the dangers of being swept into the sea. Treatment of rescued personnel varies among individuals. Too few physicians have actually observed cases of hypothermia and cannot, in many circustances, determine the appropriate treatment. Body composition plays an important role in survival, fat individuals have better chances of survival.

138. Mahan, C. S., W. S. Lovrinic, W. E. Jones, D. P. Goldstein, E. L. Beckman, R. E. DeForest, C. F. Schmidt, and W. S. Wray. Effect of gradient pressure upon physiological systems. NADC-MA-6218, U. S. Naval Air Development Center, Johnsville, Pa. Dec., 1962.

*Authors' abstract:* Dehydration is one of the serious problems resulting from prolonged water immersion following disasters at sea. This dehydration is aggravated by a marked diuresis which is apparently activated through the Gauer-Henry reflex. The effect of varying the temperature of the water from 95° to 75° F was evaluated with relation to the magnitude of this reflex-induced diuresis, both with and without replacement of fluid. A series of experiments was carried out involving four subjects immersed in water up to neck level for periods of 4, 6, and 9 hr at a temperature of 75°, 85°, and 95° F, respectively. This study showed that during partial body immersion at water temperature of 85°, and 75° F with fluid replacement, the magnitude of the diuresis was the same for all temperatures. When the fluid loss was not replaced, the magnitudes of the diuresis, induced by immersion in 75° and 85° F water, were approximately equal and were about double the urinary output resulting from immersion in water at 95° F. This was attributed to the active peripheral vasoconstriction of the cold water. A gradual rise in urinary pH was observed during the period of the immersion. The urinary specific gravity decreased from over 1.020 to 1.001-1.005 at the onset of immersion. The urinary specific gravity remained low throughout the immersion period of the fluid replacement studies as well as the studies in 75° and 85° F water without replacement. The urinary specific gravity approached preimmersion values only in the 95° F immersion without replacement. There was a consistent decrease in heart rate under the conditions of negative pressure breathing. The periods of immersion in water at 85° and 75° F caused a severe heat loss from the body as evidenced by a drop in body core temperature. This loss in body heat caused a drop in core temperature to below 95° F in some subjects immersed in water at 85° and 75° F for 2 hr. The currently held concept, that survival from disaster at sea when immersed in water at temperatures above 70° F is not limited by heat loss, becomes suspect in the light of these results.

139. Margaria, R. and T. Gualtierotti. Avoidance of acceleration forces in the animal by immersion in water. *Journal of Aviation Medicine* 28:210, 1957.

*Authors' abstract:* A body immersed in a liquid of the same density is not subjected to acceleration forces. The *specific weight of the single components of the animal body is not the same; therefore, the consequences of* the immersion in a liquid of the same density of the animal as a whole, when subjected to acceleration forces, ought to be limited to the differences of density of the single organs. This is expected to be a minor effect. Fishes subjected to centrifugation at 1500 G for up to 10 min survived over 24 hr having only the otholitic system destroyed. Frogs, centrifuged when immersed in water, survived when exposed to several hundred G for some minutes. Mice contained in a missile in free fall for 9 min and decelerated to stop in 1 cm were killed instantly, but they survived a number of successive such falls when immersed in water.

140. Margaria, R., T. Gualtierotti, and D. Spinelli. Protection against acceleration forces in animals by immersion in water. *Journal of Aviation Medicine* 29:433-437, 1958.

*Authors' abstract:* Animals immersed in water can withstand acceleration forces more than 10 times greater than in air, the probability of survival being very high even at 1000 G. A limit to the resistance to acceleration forces is given by parts of the body having a specific weight different from that of the rest of the body, particularly the lungs for their air content, and the otoliths.

141. McCally, M. Plasma volume response to water immersion: Implications for space flight. *Aerospace Medicine* 35:130-132, 1964.

*Purpose:* Plasma volume change was measured in five subjects during 6 hr of complete water immersion and during 6 hr of office activity control by the determination of relative changes in hematocrit and hemoglobin concentration and by the dilution of radio-iodinated ($I^{131}$) serum albumin (RISA).

*Procedure and methods:* Five normal young men, ages 18-28, were studied in periods of immersion of from 1 to 6 hr. Subjects were completely immersed in modified SCUBA gear in water at 33° C with instruction to rest in any conformable position. The immersion tests began at 0800 after 12 hr of fasting. The 6-hr immersion and all control subjects were given one can of Nutrament food supplement at the end of the third hour.

Blood was drawn just prior to immersion and after 25, 40, 60, 120, and 240 min of immersion; the subjects partially emersed for each venepuncture. Control samples were drawn begining at 0800, after 0, 25, 40, 60, 120, 240, and 360 min of routine office activity. Hemoglobins and macro-hematocrits were performed in duplicate. Plasma and whole blood volumes were determined by the dilution of RISA during 2 hr of immersion in five additional subjects. Absolute or quantitative changes in plasma volume and relative plasma volume changes were determined.

*Results:* After 25 min of immersion, the mean decrease in hemoglobin concentration for the five subjects is 0.66 ±0.06 gm. The mean change in hemoglobin concentration for the five subjects after 25 min of office activity control is a decrease of 0.10 ±0.11 gm. At 240 min the mean immersion hemoglobin has increased 1.7 ±0.24 gm compared to a control decrease of 0.12 ±0.21 gm. After 360 min of immersion the mean hemoglobin concentration is increased 1.28 ±0.18 gm compared to a control decrease of 0.22 ±0.29 gm.

After 25 min of water immersion the mean plasma volume has increased 9 percent relative to the baseline or zero time, while the 25-min control value has increased 2 percent. After 360 min of immersion the plasma volume has decreased 11 percent from the baseline or zero time value compared to a control increase of 4 percent.

*Conclusion:* Changes in plasma volume of five subjects was measured during 6 hr of complete water immersion and during 6 hr of office activity control by hemoglobin and hematocrit dilution and radio-iodinated serum albumin (RISA) techniques. The mean plasma volume increased 9 percent the first 25 min of immersion and then decreased over the next 4 to 6 hr to approximately 11 percent less than zero time value. The repeated injection and sampling of RISA is not a suitable technique for the measurement of acute changes in plasma volume. The mechanisms of the water immersion diuresis and post-immersion orthostatic intolerance are discussed and inferences made to human exposure to weightlessness.

142. McCally, M. Body fluid volumes and the renal response of human subjects to water immersion. AMRL-TR-65-115, Aerospace Medical Research Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 1965.

*Author's abstract:* Immersion of human subjects in water is used to simulate various aspects of the aerospace environment, including weightlessness. However, little is known of the physiological, cardiovascular, and renal response to immersion. Such data are necessary before responses to immersion can be related to other environments such as aerospace. The excretion of water and solute by the kidney is the fundamental mechanism for preserving the constance of the mammalian extracellular fluid. The mechanisms by which the kidney is notified to retain or excrete water and solute in response to changes in the environment have been defined in considerable detail in recent years. The response of the kidney to water immersion of human subjects, as measured by water and solute excretion, provides a fascinating model for the study of body fluid volume regulation. The Ama divers of Japan and Korea represent specific problems of body fluid volume regulation during immersion as dictated by the depth, duration, temperature, and respiratory mechanics of their particular immersion pattern. This report includes (1) a brief review of the physiological mechanisms of body fluid volume regulation as we now understand them, (2) a description of the renal responses to neutral or indifferent temperature immersion, (3) a consideration of the role of pulmonary mechanics and water temperature in the renal responses to immersion, (4) a summary of the possible mechanisms of the immersion diuresis, and (5) speculations about the renal response to Ama diving.

143. McCally, M. and G. W. Barnard. Modification of the immersion diuresis by hypnotic suggestion. *Psychosomatic Medicine* 30:287-297, 1968.

*Authors' abstract:* Seven moderately hydrated male subjects experienced 1 hr of exposure to six conditions of chair rest, immersion, and hypnosis on separate dyas. Head-out, neutral-temperature immersion produced significant diuresis characterized by increases in free-water clearance, osmolar clearance, and sodium excretion. Tubular reabsorption of sodium was not altered by immersion or hypnosis. Hypnotic suggestion of thirst significantly inhibited the diuretic response to immersion, principally by increased antidiuretic hormone activity. The estimated glomerular filtration rate was increased during immersion and reduced by the hypnotic suggestion of thirst. These data support the suggestion that appropriate hypnotic suggestion can significantly modify environmentally induced alterations in physiological performance.

144. McCally, M. and J. Goldman. Free fatty acid response to tilting following immersion. Aerospace Medical Association Preprints. 1965, p. 182.

*Authors' abstract:* It has been demonstrated that plasma FFA levels may be used as an indicator or assay of the plasma noradrenaline response to tilt. Therefore, in this study the integrity of sympathetic nervous system function following water immersion was evaluated by measuring plasma free fatty acid responses to passive tilting after immersion. Six healthy males between the ages of 20 and 35 were used as subjects. The subjects fasted overnight and were given one can of Nutrament$^{R}$ at 8 AM and one at noon on the day of the experiment. All tilts were performed after 30 min of quiet rest on the tilt table in the horizontal position and consisted of a 30-min tilt to 60° from the horizontal with a foot board support. Bloods were drawn through an indwelling #20 needle inserted prior to the equilibration period and kept patent with a slow saline drip. The blood samples were anticoagulated with mixed oxalate, quickly spun, and the plasmas were then frozen at −20° C until free fatty acid and glucose determinations could be done. Three experimental conditions were studied. Condition I consisted of a tilt in a room at 24° C after 6 hr of normal office activity. Condition II substituted 6 hr of complete water immersion for the office activity in condition I. Condition III consisted of an identical tilt after 6 hr in the scuba suit but without an air helmet in an all-weather room. The impaired fatty acid response to tilting after immersion supports the hypothesis that diminished urinary excretion of noradrenaline during water immersion reflects decreased sympathetic nervous system activity which, in turn, contributes to the orthostatic intolerance noted after immersion. Blood pressure, heart rate, plasma free fatty acids, and plasma glucoses have been measured during a 30-min tilt to 60° following 6 hr of office activity (control), 6 hr of water immersion, and 6 hr of exposure to a thermal environment mimicking that of the immersion facility. Diastolic blood pressure response to tilting was not changed by any of the experimental environments. Systolic blood pressure rose during the post-thermal tilt and fell during the other tilts. The degree of fall was similar in both cases. Heart rate rose least during the post-thermal and most during the post-immersion tilts. Serum glucoses did not change in response to a tilt. Serum free fatty acids rose higher and faster during post-control and post-thermal tilts. The response to post-immersion tilt was biphasic with a pronounced early fall and a diminshed late rise. These changes were independent of plasma glucose levels which did not change. Possible significance and mechanisms are discussed.

145. McCally, M. and D. E. Graveline. Urinary catecholamine response to water immersion. AMRL-TDR-63-20, Wright-Patterson Air Force Base, Ohio, March 1963.

*Authors' abstract:* The urinary excretion of adrenaline and noradrenaline was measured by bioassay for 16 normal human subjects during 6 hr of complete water immersion. The excretion of adrenaline was moderately increased, possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($p < 0.01$) reduced during immersion. Six subjects were studied during passive vertical tilt following immersion. Orthostatic intolerance was demonstrated and the increase in pulse rate and decrease in pulse pressure were significantly different from the control tilt. The probable mechanisms of the reduced noradrenaline excretion during immersion and its relation to the postimmersion impairment of orthostatic tolerance are discussed.

146. McCally, M. and D. E. Graveline. Urinary adrenaline and noradrenaline response to water immersion. *Federation Proceedings* 22:508, 1963.

*Authors' abstract:* The mechanisms of the impaired cardiovascular response to passive vertical tilt seen after periods of prolonged bedrest or water immersion are unknown. The urinary excretion of adrenaline and noradrenaline by 16 normal human subjects during 6 hr of complete water immersion was measured by bioassay. The cat's blood pressure, sensitive to noradrenaline and the fowl's rectal cecum, sensitive to adrenaline, were used. The excretion of adrenaline was moderately increased ($p < 0.15 > 0.10$), possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($p < 0.01$) reduced during immersion. Six subjects were studied during passive vertical tilt following the immersion. The increase in pulse rate and decrease in pulse pressure were significantly greater than those observed during a control tilt. It is concluded that the reduced noradrenaline excretion during immersion is related the diminshed need for reflex vasomotor activity.

147. McCally M. and D. E. Graveline. Sympathoadrenal response to water immersion. *Aerospace Medicine* 34:1007-1011, 1963.

*Authors' abstract:* The urinary excretion of adrenaline and noradrenaline was measured by bioassay for 16 normal human subjects during 6 hr of complete water immersion. The excretion of adrenaline was moderately increased, possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($p < 0.01$) reduced during immersion. Six subjects were studied during passive vertical tilt following immersion. Orthostatic intolerance was demonstrated and the increase in pulse rate and decrease in pulse pressure were significantly different from the control tilt. The probable mechanisms of the reduced noradrenaline excretion during immersion and its relation to the post-immersion impairment of orthostatic tolerance are discussed.

148. McCally, M., L. J. Thompson, and J. W. Heim. Post-immersion orthostatic intolerance and protective techniques. *Federation Proceedings* 25:461, 1966.

*Authors' abstract:* Six hours of head-out neutral temperature immersion by six human subjects produces significant orthostatic tachycardia and hypotension during a 70° vertical tilt compared to a chair rest control ($p < 0.05$), as previously reported. This defect may relate to plasma volume contraction during the immersion diuresis, alterations in capacitance vessel reactivity, or disturbance in catecholamine metabolism. Four "protective" techniques were assayed for ability to prevent post-immersion orthostatic intolerance: (1) four extremity venous occlusive tourniquets, (2) antidiuretic hormone (ADH) injection, (3) positive pressure breathing (15 mm Hg), and (4) elastic gradient leotard. The leotard donned after immersion just prior to tilt provided significant protection ($p < 0.01$) and restored the tilt-table response to the control range. Venous tourniquets inflated to 80 mm Hg 1 min on, 1 min off, provided partial protection. ADH and positive pressure breathing prevented immersion diuresis but did not significantly alter post-immersion orthostatic intolerance.

149. McKenna, W. J., P. M. Griffin, N. R. Anthonisen, and H. A. Menkes. Oscillation mechanics of the submerged respiratory system. *Aerospace Medicine* 44:324-326, 1973.

*Authors' abstract:* We studied the oscillation mechanics of subjects immersed to the neck in a swimming pool. As the subjects stood erect in air or water lung volume was altered by varying pressure at the mouth. Oscillations (3.5 to 10 cps) were superimposed on that pressure. Neither resonant frequency nor total respiratory resistance showed any change with water immersion. At all lung volumes resonant frequency varied from 5 – 6 cps in one subject to 6 – 8 cps in another subject. Neither resistance nor inertia of the water surrounding the chest had any significant affect on the measurements. It is concluded that immersion per se produced no significant load on the respiratory system.

150. McKenzie, R. E., B. Hartman, and D. E. Graveline. An exploratory study of sleep characteristics in a hypodynamic environment. School of Aviation Medicine, USAF, Brooks Air Force Base, Texas, Rept. No. 60-68, Oct. 1960.

*Authors' abstract:* Sleep characteristics were evaluated as part of an exploratory study of the effects of prolonged weightlessness, as produced by the body immersion technic. Electroencephalographic techics were used to monitor and assess sleep states. Four-hour sleep periods on seven successive days were scored in 5-min blocks by a rating procedure similar to several described in the literature. Three kinds of changes in sleep characteristics were seen: (a) a reduction in the total amount, (b) a constriction in the range of sleep states, and (c) a progressive improvement in the stability of sleep states. The most characteristic sleep state during immersion is one which falls between drowsiness and light sleep.

151. Mirolyubov, G. P. The influence of gravity effects from landing on animals immersed in water. *Problemy Kosmicheskoy Biologii* 13:206-214, 1969.

*Author's abstract:* The enhancement of an organism tolerance to the action of impact stresses has now become an urgent problem owing to the development of space flights.

The method of liquid immersion makes it possible to raise appreciably the tolerance limits of overloads occurring at the landing.

The effect of hydraulic pressure at the moment of impact overloads can bring about changes in the functions of cardiovascular and respiratory systems and some disturbances in the organism which form a certain complex of symptoms that can be observed upon the action of an impact pressure wave.

The protection of an organism against hydraulic pressure occurring at the impact moment makes it possible to withstand overloads up to 1.000 units quite satisfactorily.

152. Molnar, G. W. Survival of hypothermia by men immersed in the ocean. *Journal of the American Medical Association* 131:1046-1050, 1946.

*Author's abstract:* The recorded times of immersion of shipwreck survivors, on file in the Bureau of Medicine and Surgery, U. S. Navy, were plotted against the sea-water temperatures. A curve was drawn above the highest recorded times of immersion; the curve rises steeply for water temperatures above 60° F. Analysis of data on body cooling led to the conclusion that this curve represents a limit of tolerance which probably few men can exceed and many cannot approach.

Tolerance to water at temperatures below about 68° F is limited by the loss of body heat at a rate which exceeds heat production. The internal temperature gradient cannot be maintained, and the rectal temperature falls at a rate which becomes increasingly greater the lower the water temperature. Once the rectal temperature falls below about 95° F, heat production decreases. Respiratory and circulatory irregularities appear and death ensues.

153. Moore, T. O., E. M. Bernauer, G. Seto, Y. S. Park, S. K. Hong, and E. M. Hayashi. Effect of immersion at different water temperatures on graded exercise performance in man. *Aerospace Medicine* 41:1404-1408, 1970.

*Authors' abstract:* Eight subjects performed graded leg exercise at loads from light to forced maximal in air and totally submerged in water at 30°, 22°, and 16° C. There was no significant decrement in performance between the air and immersed environments. Heart rate, minute volume ($\dot{V}_E$), oxygen consumption ($\dot{V}_{O2}$), and carbon dioxide production had high linear correlation coefficients with imposed workload. $\dot{V}_E$ and $\dot{V}_{O2}$ were higher in water under all workloads and at the two lower water temperatures. Heart rate was the same at rest under all conditions, but significantly less at high workloads in 16° C water when compared to air. It is concluded that monitoring a diver's heart rate will cause underestimation of workload in surface-equivalent terms at high loads in water of low temperature. The data confirm and extend information on underwater work to lower temperatures and higher workloads.

154. Morris, D. P., Jr., D. E. Beischer, and J. J. Zarriello. Studies on the G tolerance of invertebrates and small vertibrates while immersed. *Journal of Aviation Medicine* 29:438-443, 1958.

*Authors' abstract:* Animals whose habitat is water can be exposed in their natural abode to extraordinary high G forces for prolonged periods of time. Euglena gracilis survived exposure in the ultracentrifuge at 212,000 G for 4 hr. The limiting conditions for small fishes (Lebistes reticulatus) were 10,000 G for 30 sec. The chance of survival for small terrestrail mammals is increased in the submersed state. In this condition mice while on oxygen survived a force of 1,300 G for 60 sec.

155. Morway, D. A., R. G. Lathrop, R. M. Chambers, and L. Hitchcock, Jr. The effects of prolonged water immersion on the ability of human subjects to make position and force estimations. NADC-MA-6115, Aviation Medical Acceleration Laboratory, Johnsville, Pa., July 24, 1963.

*Authors' abstract:* Twelve subjects using underwater breathing apparatus were immersed in water for 18 hr. Each subject's responses to two general psychomotor tasks: (1) the ability to reach and position the arm and hand accurately and (2) the ability to estimate a prelearned level of force, were measured before, during, and after water immersion. Analysis of variance performed upon the target aiming task showed no significant difference in the horizontal aiming component. However, a highly significant ($P < 0.01$) bias upward was observed in the vertical aiming component. Comparisons between trial means using the Duncan q' test indicates that the bias upward declined as a function of immersion time. An analysis of variance performed upon the force estimation data showed a significant interaction between trials within blocks and test conditions. Duncan's q' Test Ordered Means Comparison revealed no significant difference between the pre- and post-immersion force estimations. The mean estimation obtained during immersion was significantly different ($P < 0.01$) from the pre- and post-trials. The force data showed no tendency to adapt as a function of time immersed.

156. Myers, J. W. and J. A. Godley. Cardiovascular and renal function during total body water immersion of dogs. *Journal of Applied Physiology* 22:573-579, 1967.

*Authors' abstract:* Ten chloralosed dogs were studied during 2 hr of control followed by 2 hr of water immersion. Another 10 animals were studied during 4 hr of control conditions. During water immersion, a significant ($P < 0.05$) diuresis occurred due to an increase in the excretion fraction of sodium. Urea excretion and creatinine, PAH, and free water clearances were not significantly altered. Respiratory rate, heart rate, and cardiac output increased significantly ($P < 0.01$). Mean arterial pressure increased 11 mm Hg ($P < 0.06$). These data indicate that the observed diuresis was due to decreased tubular reabsorption of sodium and not due to changes in ADH activity. Water immersion probably augmented cardiac filling and increased end-diastolic volume, resulting in increases in cardiac output and mean arterial pressure. It is thought that the increased cardiac output and mean arterial pressure stimulated intra-arterial receptors which initiated decreased tubular reabsorption of sodium due to increased renal medullary blood flow and/or the action of a natriuretic hormone.

157. Ono, H. and J. P. O'Reilly. Adaptation to underwater distance distortion as a function of different sensory-motor tasks. *Human Factors* 13:133-139, 1971.

*Authors' abstract:* Adaptation to underwater distance distortion was investigated as a function of three sensory-motor tasks and exposure time. The tasks differed in terms of the extent to which visual feedback during the reaching response was provided. Eighteen experienced divers served as subjects. Each subject performed the three sensory-motor tasks and also observed another subject performing the tasks. Underwater distance perception was measured after each sensory-motor task and observing period. Adaptation occurred when the subjects performed the tasks but not when they were observing. The different sensory-motor tasks produced different amounts of adaptation. An argument is made that visually predirected reaching responses (no feedback) would produce greater adaptation than visually guided (feedback) reaching responses.

158. Ono, H., J. P. O'Reilly, and L. M. Herman. Underwater distance distortion within the manual work space. *Human Factors* 12:473-480, 1970.

*Authors' abstract:* An experiment was conducted to measure apparent distance of a target within arm's length above water and underwater. Eight experienced divers and eight novice divers wearing facemasks indicated apparent distances by reaching responses. The viewing conditions were (1) a target and a subject in air environment, (2) a target in water but a subject in air, and (3) a target and a subject under water. Apparent distances were smaller in conditions (2) and (3) than in (1). This difference is interpreted as being due to the dissimilar convergence and accommodation requirements in the various conditions. There was little difference between the experienced and novice divers.

159. Ovsiannikov, A. V. The motor present state in man in case of water immersion. *Fiziologicheskii Zhurnal SSSR imeni I. M. Sechenova (Moskva)* 58:305-310, 1972.

*Author's abstract:* The functional state of the segmental apparatus before voluntary movement was investigated in man during water immersion. H-reflex was used for the evaluation of excitability of spinal cord motoneurones. On the third, fourth, and fifth days of water immersion, the increase of antagonist motoneurone pool excitability began 30 msec before EMG, instead of the normal 60 msec. The absence of excitability increase in the interval 60-30 msec prior to movement is considered to be the consequence of disuse of the suprasegmental nervous structure, involved in the spinal mechanisms of postural readjustments.

160. Pape, R. W., F. F. Becker, D. E. Drum, and D. E. Goldman. Some effects of vibration on totally immersed cats. *Journal of Applied Physiology* 18:1193-1200, 1963.

*Authors' abstract:* A survey has been made of the physiological and pathological changes occurring when anesthetized totally immersed cats are exposed to vertical sinusoidal vibration. Twenty-five of 55 cats survived exposure to 15 G peak acceleration for periods averaging 47 min. A decrease in peak acceleration from 15 to 10 G caused a large decrease in mortality. Time of exposure, within the limits of 5-120 min, also affected mortality, but much less strikingly than acceleration. The heart rate and mean respiratory rate are little changed during severe vibration. Respiration becomes irregular, and the tidal volume is greatly depressed. At 15-G peak acceleration, electrocardiographic changes of ischemia and injury occur, especially in those cats which die later. The most significant gross pathological findings are pulmonary collapse and hemorrhage, involving especially the peripheral parts of the lower lobes, and gastrointestinal hemorrhage. The major changes appear to be related to vascular change, either by rupture, leakage, or changes in tone. The resulting ischemia contributes to tissue damage and death. There is both clinical and pathological correlation between the intensity of the forces applied and the response.

161. Paton, W. D. M. and A. Sand. The optimum intrapulmonary pressure in underwater respiration. *Journal of Physiology* 106:119-138, 1947.

*Authors' abstract:* Experiments have been made to find the most comfortable pressure of the respired air (eupnoeic pressure) when a subject is immersed. The effect of immersion on the vital capacity, on reserve, complemental and residual airs, minute volume, on tidal air and on the form of the respiratory cycle at various intrapulmonary pressures and grades of work were also studied.

The eupnoeic pressure is 5-10 cm below the external auditory meatus in the erect position at rest, increasing to 10-15 cm when there is hyperpnoea from any cause. In all positions other than the erect, eupnoeic pressure is at the level of the suprasternal notch.

The vital capacity is reduced during vertical immersion, is further reduced by negative intrapulmonary pressures, and is partially restored by positive pressures.

The reserve air is diminished during vertical immersion at eupnoeic pressure, with a corresponding increase in complemental air. In the horizontal position, at eupnoeic pressure, the volumes of reserve and of complemental air are similar to those in air. The residual air is slightly diminished by immersion vertically.

Deviations up to 15 cm less or 20 cm greater than eupnoeic pressure are without effect on minute volume, on tidal air, and on the shape of the respiratory cycle in the steady state.

The origin of the eupnoeic pressure and its relation to the partial collapse of the thoracic cavity following immersion are discussed.

162. Pierce, B. F. and E. L. Casco. Crew transfer in zero G as simulated by water immersion. General Dynamics/Astronautics, GDA-ERR-AN-502, April, 1964. 22 pp.

*Purpose:* To determine the feasibility of using an underwater weightlessness procedure for the performance of a specific problem of a crew transfer from a reentry capsule to a space station through a U-tube of given dimensions for the proposed space capsule.

*Procedure and methods:* A tunnel mockup arrangement of the U-shaped transfer tube was placed in a large swimming pool. A subject in pressure suit equipment and assisted respiration gear then made several attempts to pass unassisted and assisted through the tunnel.

*Conclusions:* There was sufficient room for the subject to maneuver safely through the transfer tube. At an inflation pressure of 1 psi in a Mark IV suit the mobility decrement nearly approximated the effects of full pressurization. Procedures for developing capabilities in simulating weight lessners was highly successful. Water immersion was found to be a relatively simple and inexperienced method of obtaining usable data concerning man-equipment problems in a weightless environment.

163. Pierce, B. F., R. L. Wolf, and E. L. Casco. The use of space suits in water immersion studies. A collection of papers on Spacesuits and Human Performance. Report No. 4 Aug. 1965. General Dynamics/Convair, San Diego, Calif.

*Authors' conclusions:* Since weightlessness represents one of the most important aspects of the outer space environment to which man will be subjected, and since it is precisely this condition that is the most difficult to duplicate in earth-bound laboratories, every technique for simulating its effects is worthy of serious consideration. Water immersion has been demonstrated as being a satisfactory method of simulating various physical effects of zero gravity. It has disadvantages compared to such techniques as air-bearing devices or parabolic flights in aircraft. Thus the hydrodynamic drag forces of water affect the acceleration and velocity of moving bodies differently than does a frictionless environment, although there are methods of minimizing this difference. However, water immersion has the advantages of being relatively simple and inexpensive, and of being minimally restrictive in volumetric and time-duration considerations.

Since the spacesuit will be an influential element in the space environment, and since the suit-man unit will be affected by weightlessness, it is imperative to include the suit in any tests representing conditions in which it would normally be worn. With techniques now available, underwater spacesuit operations have already provided the answer to practical, manned-space-vehicle design problems. The procedures and equipment currently under development are intended to increase the efficacy of the weightless-simulation by water-immersion technique as well as to broaden its applications.

164. Reeves, E., E. L. Beckman, and R. E. Deforest. Physiological effects resulting from different types of fluid replacement during water immersion. *Aerospace Medicine* 34:264, 1963.

*Authors' abstract:* With the advent of man into prolonged space travel, the problems of zero G have become increasingly important. The most convenient method of studying the weightless state for any length of time in the Earth's gravitational field is by means of water immersion. This method of investigation also has lent itself to the study of the problems of survival at sea because of the magnitude of the diuresis which results from water immersion.

Four subjects were studied while floating immersed to the neck level in water of 95° and 85° F. Replacement of urinary loss was by two fluids (a) Metrecal (a balanced dietary liquid) and (b) Sanalac (a powdered milk product). Nonreplacement of fluid loss was also studied during immersion for each temperature. Data were collected concerning body temperatures, pulse, respiration, blood pressures, oxygen consumption, blood morphology, urinary output, and electrolyte changes in serum and urine.

165. Reeves, E., J. W. Weaver, J. J. Benjamin, and C. H. Mann. Comparison of physiological changes during long term immersion to neck level in water at 95°, 85°, 75° F. MF011, 99-1001 Rep. 9. Naval Medical Research Institute, Bethesda, Md. Aug. 1966. 24 pp.

*Authors' abstract:* This experiment was designed to evaluate the physiological changes which result from immersion of subjects in water to neck level for 24 hr at water temperatures of 95°, 85°, and 75°F. It had previously been determined that immersion of subjects in water below 95° F resulted in a heat loss from the body which was compensated by an increase in metabolic rate. Other changes in blood morphology and blood electrolytes had been shown to occur concomitantly with increased urinary excretion of water and electrolytes. Since the previous studies had been carried out over a relatively short period of time, the present experiments were designed to evaluate such changes over a 24-hr period, not only at 95° F water temperature but at lower water temperatures as well. It was found that the three subjects increased their metabolic rate when immersed in 85° F water and were able to maintain a "normal" deep-body temperature over the 24-hr period. When immersed in the 75° F water, the increased oxygen consumption due to shivering was insufficient to maintain deep-body temperature. In addition, the physiological discomfort of immersion at 75° F and "the spirital failure" of those subjects caused the experiments to be terminated within 12 hr. The changes in the morphology and electrolyte content of the blood together with the hemoconcentration were associated with increased urinary water and electrolyte excretion and were progressive with time.

166. Rennie, D. W. Body heat loss during immersion in water. In: *Human Adaptability and its Methodology*, edited by H. Yoshimura and J. S. Weiner. Tokyo: Japan Society for the Promotion of Sciences, 1966. pp. 36-41.

*Purpose:* To determine heat loss and body insulation values of Korean diving women and non-diving men.

*Procedure and methods:* Hatfield gradient calorimeter discs were used to measure skin heat flux in 15 women (6 diving Ama and 9 nondiving control women). Six laboratory staff also acted as subjects in a separate series of experiments. Subjects were immersed for 3 hr in water of critical temperature (defined as the lowest water temperature the subject could tolerate for 3 hr without shivering).

*Results:* Skin heat loss from the Ama was 45.3 kcal/hr/0.86 $m^2$ compared to 36.4 for nondivers. Ama also had higher metabolic rates than nondivers. Skin heat loss for the Ama was higher for any given area; however, skin heat loss was equally divided between the trunk and limbs for both groups.

In laboratory staff members immersed for 3 hr in water at 30°–35.5° C, skin heat flux and finger blood flow decreased proportionately in the cooler water. However, the reduction in forearm blood flow was not accompanied by a decrease in steady-state heat flux. The latter was due to the small contribution of limb circulation to limb heat loss at critical water temperature.

Convective heat transfer was also studied via arm occlusion experiments. Following 15-20 min of arrested circulation in 35° C water, a prompt reduction in heat flux occurred; however, in 32° C water no such decrement was observed. This heat flux from the nonperfused Ama represented direct loss of metabolic heat from underlying tissue. Total average heat flux from the forearm rose only 50 percent from the circulation and 50 percent from convective even in 35° C water, but water below 32° C almost exclusively from conduction.

*Conclusion:* During immersion in water temperatures near 30° C heat loss continues at an undiminished rate. A reduction in convective heat transfer is replaced by an equal conduction component. Limb heat loss in cool water does not reflect limb circulation but limb metabolic rate.

167. Rennie, D. W., P. di Prampero, and P. Cerretelli. Cardiac output of man in water. Proceedings of the International Union of Physiological Sciences, Washington, D. C., 1968. p. 364.

*Authors' abstract:* The effect of head-out water immersion on the interrelationships among cardiac output ($\dot{Q}$), oxygen consumption ($\dot{V}_{O_2}$), and heart rate (f) were studied in resting and in exercising subjects (water temperature: 22°–36° C). Expired air $O_2$ and $CO_2$ tensions were recorded continuously. The 92 percent $N_2$ – 8-percent $CO_2$ rebreathing method was used to measure $P_{\bar{v}O_2}$ and $P_{\bar{v}CO_2}$ for calculations of $\dot{Q}$. Cardiogenic oscillations of $P_{EO2}$ were used to assess the degree of inhomogeneity of $\dot{V}_A/\dot{Q}$ within the lungs. At water temperatures below 34° C, $P_{\bar{v}O_2}$, f, and $\dot{Q}$ were reduced 20 to 25 percent below air controls ($P < 0.01$) in subjects at rest. During leg work up to 650 kg-m/min, f remained 20 to 40 beats/min less and $\dot{Q}$, 1 to 1.5 L/min less in water than in air at equal values of $\dot{V}_{O_2}$. In warmer water and f and Q responses to exercise were the same as in air. Cardiogenic oscillations of $P_{EO_2}$ averaged 8 mm Hg in air but disappeared altogether in water, regardless of temperature. We conclude that $\dot{Q}$ and f are reduced in water in response to cold stress and that the more even distribution of $\dot{V}_A/\dot{Q}$ in water is a consequence of mechanical factors which lead to a more uniform distribution of pulmonary blood flow.

168. Robinson, S. and A. Somers. Temperature regulation in swimming. *Journal of Physiology (Paris)* 63:406-409, 1971.

*Purpose:* To compare the metabolic and thermal responses of well trained men during swimming and treadmill exercise.

*Procedure and methods:* Three men aged 20-24 yr who finished in second or third places in the Olympic Games (two Olympic champions and one world record holder) acted as subjects during swimming tests. For comparative purposes, one track man ran on the treadmill at the same metabolic rate as the swimmers.

Each man swam free style for 1 hr in three different water temperatures, averaging 21°, 29°, and 35.5° C. Rectal and skin of the back (surface and subcutaneous) temperatures were recorded. Oxygen consumption was estimated from previously determined $\dot{V}_{O_2}$ – speed curves obtained at steady-state rates. Swimming speed varied from 0.9 to 1.2 m/sec. On the treadmill, the runner ran for 1 hr at 9.3C db, 6.6wb, and 25Cdb, 16Cwb; air movement was 60 m/min. Rectal and six skin temperatures were recorded. The open circuit method was used to determine $\dot{V}_{O_2}$ twice during each run.

Cutaneous weight loss was calculated as the difference between total body weight loss and pulmonary weight loss.

*Results:* For comparative purposes, the responses of two swimmers in 29° C water were compared with those obtained on the runner at 9° C. Metabolic rates were comparable. During the second half hour of work, skin temperatures were similar: 28.8° C for the runner and 29.3° C for the swimmers. In the swimmers, however, rectal temperature during work was not significantly different from that obtained at rest while the runner experienced a 1° C rise in rectal temperature. Subcutaneous temperatures were also lower in the swimmers. The runner sweated more than the swimmers, 1300 vs. 1100 g/hr.

The 1-hr swim in 21° C water was very stressful. In the three slowest swimmers (333-400 kcal/m$^2$/hr), rectal temperature declined from 37.5° to 37.1° C. In the two fastest swimmers (480-510 kcal/m$^2$/hr) rectal temperature rose from 37.3° to 37.9° C. Cutaneous weight loss was virtually absent in the second half hour of these swims.

*Conclusions:*

At equivalent metabolic rates, convective cooling during swimming in 29° C water was more effective than low velocity air movement during running in 9° C air and prevented an excessive rise in core temperature.

The data suggested that the optimal water temperature for competitive distance swimming events up to 20 min is between 21° and 33° C with 29° C being close to optimal since heat conductance was adequate with only moderate sweating at this temperature.

169. Ross, J. C., G. D. Ley, R. F. Coburn, J. L. Eller, and R. E. Forster. Influence of pressure suit inflation on pulmonary diffusing capacity in man. *Journal of Applied Physiology* 17:259-262, 1962.

*Authors' abstract:* Previous investigations of the effect of inflation of a pressure suit on pulmonary diffusing capacity ($D_L$) have been reported from our two laboratories, one (Indianapolis) finding an increase and the other (Philadelphia) finding no change. The present investigation was carried out in Philadelphia, using some of the same subjects and pressure suits in order to reconcile the contradictory results. The earlier contradictory results were confirmed. The pressure suit used in the investigations at Philadelphia (suit P) covered the entire body below the nipples, whereas the suit used in the investigations at Indianapolis (suit I) extended cephalad only as far as the costal margin. When suit P was inflated in the present study, $D_L$ again did not increase significantly in two subjects. However, when the upper part of the suit was folded down so that the thoracic cage was not covered, inflation of the suit did produce a significant increase in $D_L$. Inflation of suit P when it covered the chest made it difficult for a subject not to perform a Valsalva maneuver during breath holding and caused more decrease in alveolar volume (VA) than when it was inflated in the folded-down position. In two subjects studied, we found no difference in air trapping with inflation of suit P in the two positions. The discrepancy between the results of the two earlier studies appears to have resulted from the different

construction of the two pressure suits used. We conclude that pressure-suit inflation in man will produce an increase in $D_L$, presumably by means of pulmonary congestion.

170. Ross, J. C., T. H. Lord, and G. D. Ley. Effect of pressure-suit inflation on pulmonary-diffusing capacity. *Journal of Applied Physiology* 15:843-848, 1960.

*Authors' abstract:* Pressure-suit inflation over the lower body produces acute pulmonary hypertension. An increase in pulmonary capillary blood volume, Vc, with this procedure should theoretically increase pulmonary-diffusing capacity, $D_L$. Lewis and co-workers *(Journal of Applied Physiology* 12:57, 1958) found no increase in $D_L$ with suit inflation. The subject was reinvestigated with measurement of the increase in central venous pressure, CVP, produced and with a study of effect of alveolar volume, VA and the Valsalva maneuver on the results. $D_L$ was determined in five seated and seven supine subject at small and large VA, both before and during suit inflation and also with a Valsalva under each condition. Suit inflation significantly increased $D_L$ (13 percent) with an increase in 21 of the 22 comparisons. Mean $D_L$ was 16 percent lower when VA was decreased 34 percent. The Valsalva maneuver significantly decreased both control and suit inflation $D_L$. Results show that with controlled VA and no Valsalva and when CVP was definitely increased by the procedure, $D_L$ significantly increased with suit inflation, probably indicating that the pulmonary capillary bed was passively dilated.

171. Rublowsky, J. Man in a tub. *Space World* 1:15, 1960.

*Author's abstract:* An editorial account is presented of how one man spent 7 days immersed to the neck in a warm-water bath to test the effects of prolonged simulated weightlessness in man. Blood pressure, heart rate, respiratory rate, metabolism, and body temperature were monitored. Excessive muscular weakness and incoordination occurred in a progressive manner. Physiologic debilitation is discussed.

172. Sandalov, Yu. A. Preliminary physical training as a factor increasing tolerance to water immersion. *Kosmicheskaya Biologiya i Meditsina* 4:59-64, 1970.

*Purpose:* To determine the effectiveness of preliminary physical training for increasing human body tolerance to water immersion.

*Procedure and methods:* Nine healthy men (22-32 yr of age) with initially low levels of physical fitness were physically conditioned twice weekly (90-100 min/period) for 3 months. Measures of endurance, strength, speed, cardiovascular and respiratory measures were determined before and after 24 hr of water immersion prior to and following physical conditioning.

*Conclusions:*

Before conditioning: Indices of strength, static and general endurance were decreased following water immersion. The rate of treadmill recovery increased, but running at maximum rate after water immersion was accompanied by a higher heart rate. After water immersion, work efficiency decreased, oxygen demand was increased by 16.5 percent, and oxygen debt by 28 percent.

After conditioning: Strength measurements were essentially unchanged. Treadmill running speed increased after water immersion. Oxygen demand and debt were also unchanged. Oxygen utilization factor increased 6 percent. Before water immersion, heart rates during work were lowered but water immersion produced higher heart rates. It is concluded that highly conditioned men withstand hypokinesia better than unconditioned men.

173. Sass, D. J. Visceral motion in water immersed cats during whole body vibration. Aerospace Medical Association Preprints, 1968, pp. 260-261.

*Purpose:* To determine the degree of heart motion during vibration when abdominal motion is minimal.

*Procedure and methods:* Anesthetized cats were vibrated at 4.5 to 2-Hz frequencies in the upright position with vertical sinusoidal motion. Water immersion was used to reduce thoraco-abdominal motion without interfering appreciably with respiration. A simple radiographic technique was used to record relative visceral motion during vibration.

*Conclusions:* Water immersion successfully reduced abdominal visceral movements so that diaphragmatic movements were minimal as indicated by relatively stabilized visceral contents during vibration. In limiting diaphragm motion there is very little heart motion during vibration along the longitudinal body axis. Thus, thoracic trauma due to heart oscillation in the long axis may be considerably reduced by abdominal restraint.

174. Sass, D. J. Mechanisms of injury due to intense $\pm G_z$ vibration in water-immersed cats. *Journal of Applied Physiology* 26:819-826, 1969.

*Author's abstract:* This paper describes the pattern and developmental sequence of injury in cats produced by intense $\pm G_z$ vibration. Anesthetized cats were positioned upright in a water-immersion restraint and vibrated in the long axis of the body with vertical sinusoidal motion. Frequency and peak acceleration varied between 3.5 and 20 Hz and ±1 and $\pm 15\ G_z$, respectively. Exposures at ±4 G or less were for 30 min, but at the higher accelerations the time ranged between 15 sec and 30 min. Autopsies were performed immediately after vibration. The major injury occurred in the lung, and resembled lung injury due to blast, impact deceleration, and chest-wall impact. The common mechanism seems to be excessive transpulmonic pressure resulting from abrupt change in thoracic volume. In an earlier investigation in this laboratory, supine cats were subjected to $\pm G_z$ vibration in a water-immersion restraint. Pulmonary collapse and hemorrhage were the major injuries and were attributed to the heart pounding the lungs against the chest wall. Comparison of the results of the two studies indicate that body position in relation to the direction of vibration is a critical factor in the mechanism of vibration injury.

175. Sass, D. J. Roentgenographic study of relative heart motion during vibration in water-immersed cats. *Journal of Biomechanics* 6:219-225, 1973.

*Author's abstract:* Anesthetized cats were subjected to constant-amplitude (10 mm peak-to-peak) whole-body vibration in either the prone (±Gx), left lateral decubitus (±Gy), or upright positions (±Gz) to determine whether or not the heart could be forced to undergo large-amplitude translational motion relative to other intrathroacic structures and show resonance phenomena as described by others. The animals were totally immersed in water within a rigid transparent assembly to minimize vibratory motion of the chest wall and abdominal viscera which could transmit translational forces to the heart. With the animal thus tightly coupled to the vibration table, motion of the heart would be due only to its inertia and to the mechanical properties of its intrathoracic supports. Radiopaque 2-mm beads were implanted in the cardiac apex, domes of the diaphragm, and in the chest wall, and the amplitude of motion of each bead was measured in serial roentgenograms as the frequency and peak acceleration of the vibration were increased stepwise from 3 Hz (±0.2 g) to 20 Hz (±8 g). In contrast to the results of roentgenographic studies of heart motion due to vibration reported by other animals less well restrained, in the present study, motion of the heart due to whole-body vibration was minimal, less than 3 mm at the cardiac apex, and resonance was not detected.

176. Sass, D. J., P. Corrao, and A. K. Ommaya. Brain motion during vibration of water immersed rhesus monkeys. *Journal of Biomechanics* 4:331-334, 1971.

*Authors' abstract:* Three rhesus monkeys were subjected to sinusoidal vibration in the long axis of their brain and body at ±5, ±10, and ±15 G peak linear accelerations, while totally preventing vibration-induced motion of body parts relative to each other (e.g., head on neck) by water immersion. A roentgenographic technique was used to visualize the motions of the skull relative to motions of isodensity radio-opaque pellets imbedded 2 mm below the cortical surface within the brain. No brain motion relative to skull motion could be detected under these conditions of pure linear or translatory head motion. These data support the hypothesis that rotational head motions are of greater significance than translation for brain injury during impacts.

177. Segar, W. E. and W. W. Moore. The regulation of antidiuretic hormone release in man. I. Effects of change in position and ambient temperature on blood ADH levels. *Journal of Clinical Investigation* 47:2143-2151, 1968.

*Authors' abstract:* The studies reported here were designed to alter blood distribution by thermal and by positional change to test this thesis.

Human blood ADH levels have been shown to vary with position: a mean value of 0.4 ±0.6 (SD) μU/ml was obtained while the subject was supine, a value of 1.4 ±0.7 μU/ml while sitting and 3.1 ±1.5 μU/ml while standing. In 79 control subjects, sitting comfortably for 30 min in a normal environment, a blood ADH level of 1.65 ±0.63 μU/ml was found. It is suggested that subjects assume this position during experiments in which blood is drawn for measurement of ADH levels.

In eight seated subjects, the ADH level rose from 1.6 ±0.4 to 5.2 ±0.8 μU/ml after a 2-hr exposure at 50° C and fell to 1.0 ±0.26 μU/ml within 15 min at 26° C.

Six subjects with a mean ADH level of 2.2 ±0.58 μU/ml sat quietly in the cold (13° C) for 1 hr, and the ADH level fell to 1.2 ±0.36 μU/ml. After 15 min at 26° C, the level rose to 3.1 ±0.78 μU/ml. The serum sodium and osmolal concentrations remained constant during all studies.

Water, sodium, and total solute excretion decreased during exposure to the heat, whereas the urine to plasma (U/P) osmolal ratio increased. During cold exposure water, sodium and total solute excretion increased, and there was a decrease in the U/P osmolal ratio.

These data are interpreted as indicating that changes in activity of intrathoracic stretch receptors, in response to redistribution of blood, alter ADH secretion independently of changes in serum osmolality. The rapidity of change of blood ADH concentration indicates a great sensitivity and a prime functional role for the "volume receptors" in the regulation of ADH secretion.

178. Seireg, A., A. Baz, and D. Patel. Supportive forces on the human body during underwater activities. *Journal of Biomechanics* 4:23-30, 1971.

*Authors' abstract:* This study deals with the evaluation of the magnitude of the supportive forces and moments resulting from human activities in an underwater environment. A platform capable of monitoring all components of supporting forces and moments has been used in a water tank. Results from similar activities in air and water are presented. A mathematical model has been developed to verify the experimental results. The model can be utilized for the analysis of human body dynamics underwater.

179. Shurley, J. T. Profound experimental sensory isolation. *American Journal of Psychiatry* 117:539-545, 1960.

*Author's abstract:* A feasible and effective method has been described for studying a wide range of psychophysiological phenomena under circumstances permitting exceptionally effective isolation and demonstration of discrete elements in the complicated, interconnected patterns and sequences underlying even the simplest human act or experience.

A number of hypotheses relating to very fundamental issues can be erected from these observations and can be subjected to experimental testing. In due course, such experiments may contribute to a more adequate understanding of human behavior.

180. Sirotina, M. F. Changes in the morphological composition of the blood in underwater submersion of athletes. *Fiziologischnyy Zhurnal* 1:77-81, 1963.

*Author's abstract:* Short-term (10-15 min) submersion of aqualung divers in the sea leads to changes in the composition of the peripheral blood. In the majority of subjects, there was an increase in the number of leukocytes, red cells, and reticulocytes, and a slight increase in the number of thrombocytes, and accelerated sedimentation rate of the red cells.

The observed changes in the number of formed elements of the blood are manifestations of a redistribution reaction.

Submersion of aqualung divers to depths of 7-10 m was accompanied by a neutral phylic reaction of the white cells; submersion to depths of 20-35 m showed a predominant lymphocytic reaction.

181. Sloan, R. E. G. and W. R. Keatinge. Cooling rates of young people swimming in cold water. *Journal of Applied Physiology* 35:371-375, 1973.

*Authors' abstract:* Body temperature of the younger and thinner members of a group of boys and girls aged 8-20 yr fell by up to 3.2° C when they swam for up to 40 min in water at 20.3° C, at an energy expenditure of about 4.8 kcal/min. The rate of cooling correlated well regardless of age or sex with the individual's overall surface fat thickness on both trunk and limbs; the correlation was improved by making allowance for differences in surface area/mass ratio. Fat thickness was less and fall in body temperature more rapid in young than older swimmers, and in boys than girls, even after correction for surface area/mass ratio. Regional differences in fat distribution were less important, but older swimmers and boys, of given trunk fat thickness generally had less limb fat and cooled faster than younger swimmers and girls, of similar trunk fat thickness and surface area/mass ratio.

182. Smith, G. B. and E. F. Hames. Estimation of tolerance times for cold water immersion. *Aerospace Medicine* 33:834-840, 1962.

*Purpose:* To predict human tolerance to cold water immersion.

*Procedure and methods:* The routes of body heat during immersion in cold are primarily through conduction and convection. Physical laws of heat transfer were used to estimate body heat loss during immersion and to determine tolerance time.

*Conclusions:* The rate at which heat will be transferred from the body after initial contact depends primarily on the insulation afforded by the skin and peripheral tissues. Equations for estimating heat exchange take into account that the body core is the primary heat source since skin temperature rapidly approaches that of the water. Peripheral tissues have an insulative value of 0.61 clo, varying from 0.15 clo to 0.90 clo. Subcutaneous tissue and fat have a maximum clo value of about 0.90 clo. Since the insulative value of still water is about 1/25 that of still air, men dressed in water-permeable garments can be considered almost "nude" when immersed in cold water.

183. Sokolkov, V. I. Basal metabolism under conditions of simulated weightlessness. *Problems of Space Biology* 16:49-55, 1971.

*Author's abstract:* The effect of 24-hr water immersion on the level of basal metabolism and certain functions of external respiration of man was studied.

Three series of tests were conducted. In the first series, the test subjects were in a water medium. In the second series, they remained for 24 hr in bed. The third series was the control. In the first and second series, the food ration was the same.

Under conditions of water immersion, the indices of basal metabolism of the consumption of oxygen, of elimination of carbon dioxide, pulmonary ventilation, and the coefficient of the use of oxygen are higher than under conditions of staying in bed. This confirms that such models of weightlessness, such as hypodynamia (bed conditions) and water immersion, leads to different levels of metabolism.

184. Sokolkov, V. K. Some characteristics of external respiration and energy expenditures during orthostatic tests before and after eighteen-hour immersion. *Kosmicheskaya Biologiya i Meditsina* 4:52-58, 1970.

*Author's abstract:* External respiration, metabolism, and energy expenditures were studied during orthostatic tests before and after an 18-hr immersion experiment. Tilt tests at an angle of 90° were performed for 15 min. The subjects were classified into two groups on the basis of orthostatic tolerance. The first group included individuals with a high tolerance and the second included those with a reduced tolerance (regularly developing orthostatic collapses). During tilt tests the subjects in the second group exhibited statistically significant increases in pulmonary ventilation, oxygen consumption, release of carbon dioxide, and energy expenditures in comparison with subjects in the first goroup.

185. Stegemann, J., H.–D. von Framing, and M. Schiefeling. The effect of a six-hour immersion in thermoindifferent water on circulatory control and work capacity in trained and untrained subjects. *Pflügers Archiv* 312:129-138, 1969.

*Authors' abstract:* The influence of a 6-hr immersion in thermoindifferent water on the circulatory control was investigated by means of a tilt table in four trained and four untrained subjects. Furthermore, the maximal aerobic capacity, the performance-heart-rate index according to E. A. Müller and the maximal voluntary force of a muscle group were determined before and after immersion. The untrained subjects tolerated a period of 10 min in vertical position in both cases without abnormal effects. After immersion all trained subjects fainted, however, – showing the symptoms of vagovasal syncope – within a time of 6.1 ±1.8 min, after having been placed into the vertical position. Results were the same when the experiments were repeated. It was possible to prevent the fainting by oral application of Atropin half an hour before the tilt-table test was performed.

After immersion the heart rate showed remarkable waves in both groups during standing with duration periods of 12 to 60 sec. In the trained group the waves were more pronounced. Here the amplitude increased from the beginning of standing until fainting up to 80 beats/min. The aerobic work capacity decreased by the immersion by about 10 percent in the untrained and 20 percent in the trained group. The performance-heart-rate index rose about 14 percent in the untrained and 28 percent in the trained subjects. No significant changes in the maximal voluntary force could be observed.

186. Strauss, M. B., R. K. Davis, J. D. Rosenbaum, and E. C. Rossmeisl. "Water diuresis" produced during recumbency by the intravenous infusion of isotonic saline solution. *Journal of Clinical Investigation* 30:862-868, 1951.

*Authors' abstract:* Antidiuretic activity, ordinarily dimished by hypotonicity of the extracellular fluid, may also be diminished in the recumbent subject by isotonic expansion of the extracellular fluid volume. These results suggest that the receptors for expanded volume (or an associated factor) may have their locus in the cephalad portion of the body. Since the supra-optico-hypo-physeal system is believed to be largely involved in the control of water excretion and since it is so located, it may be suggested that the receptor cells, known to respond to changes in osmotic pressure, may also respond to hydrostatic pressure.

The fact that an equal expansion of extracellular volume in the sitting subject does not significantly diminish antidiuretic activity, although there is an equal or greater expansion of both plasma and extracellular volume, suggests that the distribution as well as the magnitude of the expanded extracellular volume is of importance.

187. Streimer, I. Human performance characteristics in a complex manual task underwater. *Human Factors* 14:95-99, 1972.

*Author's abstract:* Five subjects executed a complex maintenance task at a pool depth of 6 ft. Heart rate, oxygen uptake, and task accomplishment times were continuously monitored. The results indicate that significant performance degradations may be anticipated during the performance of manual work under water.

188. Streimer, I., D. P. Turner, and K. Volkmer. Task accomplishment times in underwater work. *Journal of Ocean Technology* 2:22-26, 1968.

*Purpose:* To determine performance and task accomplishment times during underwater work.

*Procedure and methods:* Three subjects, aged 24-35, executed a maintenance task that required 7 min in an air environment. The same task was repeated using Scuba diving gear while underwater at depths of 12-18 ft at a temperature of 62°–64° F.

*Results:*

The time for underwater work was 35 percent longer than in air. Upper-torso work increased 32 percent over air work while a 61 percent increase in time was noted for work involving gross body translations.

An alignment task required 78-100 percent more time in water than in air.

*Conclusions:* The work of breathing at increased depth may account for higher energy costs for work performance. The cool water temperature may have increased energy expenditure and produced some performance degradation. The data are available for conversion to engineering specifications for use in hardware and activity schedule development.

189. Streimer, I., D. P. W. Turner, and K. Volkmer. How effective are underwater workmen? *Ocean Industry Digest* 3:75-76, 1968.

*Purpose:* To examine human capabilities in underwater work and provide upper limits for performance.

*Procedure and methods:* Four divers, aged 23-38, wearing Scuba gear practiced maximal isometric or "breakway" forces while submerged and tractionless. Each diver performed three different tasks five times each, with a 2-min rest between trials.

*Results:* Torque production underwater was significantly less than that produced while normally active. Shaft rotation torque output values were higher.

*Conclusions:* The magnitude of the observed decrements in force-producing capabilities was found to be a function of the biomechanical nature of the task. Due to the viscosity of the medium, impulsive forces should probably be executed so that the diver works while offering the maximum body surface area at right angles to the force vector.

190. Syzrantsev, Yu. K. Effect of hypodynamia on nitrogen metabolism and importance of graded physical exercises for maintenance of the nitrogen balance. *Problemy Kosmicheskoy Biologii* 7:342-347, 1967.

*Purpose:* To study nitrogen metabolism of human subjects during exposure to hypodynamia, with and without the use of physical exercise.

*Procedure and methods:* Young healthy subjects (19) received activity restriction through bedrest, water immersion, and isolation in a confined space. The protein and diet constituents were identical during the control and experimental periods. Water immersion and bedrest were carried out in the horizontal position for 8 days.

*Results:*

Nitrogen excretion was significantly incresed (20-25 percent) during both bedrest and water immersion. Physical exercise reduced the nitrogen excretion, the greater the energy expenditure the greater the reduction in nitrogen excretion. No changes in nitrogen metabolism were observed during the first 3 days of hypodynamia and the greatest excretion was noted during the last days of the test.

Creatine and increased creatinine excretion occurred. The content of urea and free amino acids in the urine also increased.

*Conclusions:* The results confirm previous findings that increased nitrogen excretion in the urine and a negative nitrogen balance occurs during hypodynamia apparently as a result of muscle atrophy. A decrease in protein resynthesis is also evident.

Physical exercise at a level of 400 kcal is effective in maintaining body protein. However, a diet high in essential protein and vitamins is recommended.

191. Thompson, L. J. and M. McCally. Role of transpharyngeal pressure gradients in determining intrapulmonary pressure during immersion. *Aerospace Medicine* 38:931-935, 1967.

*Authors' abstract:* It is not clearly understood why immersed seated subjects prefer to breathe at a pressure which is negative relative to the chest rather than select a breathing pressure which is equal to the mean external pressure on the thorax.

The role of transpharyngeal pressure gradients in setting intrapulmonary pressures was studied in eight seated subjects, immersed in thermally neutral water (33°-34° C). When breathing through a mouthpiece or a facemask, subjects chose pressures which were negative relative to the sternal notch (range 0 to -8 cm $H_2O$). When a helmet alone was used, breathing pressures ranged from -5 to +20 cm $H_2O$, suggesting that when no transpharyngeal pressure gradient is present, discrimination in choosing a breathing pressure is reduced. When breathing from a mouthpiece inside a helmet, an increase in breathing pressure resulted in the subject choosing an increased helmet pressure, thus minimizing the transpharyngeal gradient (mean range 1 to 7.5 cm $H_2O$). A wide range of transthoracic pressure gradients (-30 to +40 cm $H_2O$) is subjectively more comfortable than a slight increase in transpharyngeal gradient (up to 7.5 cm $H_2O$).

192. Thompson, L. J., M. McCally, and A. S. Hyde. The effects of posture, breathing pressure, and immersion in water on lung volumes and intrapulmonary pressures. AMRL-TR-66-201, Wright-Patterson Air Force Base, Ohio, May 1967.

*Authors' abstract:* Lung volumes were measured by spirometry and single-breath helium dilution in five subjects under various combinations of posture, breathing pressure, and head-out neutral temperature immersion. Tidal volume was unaltered. Vital capacity was reduced significantly only by negative pressure breathing during seated immersion. Seated immersion decreased total lung capacity and functional residual capacity, but the supine posture underwater partially restored these decreases. Positive pressure breathing increased total lung capacity and residual volume for the seated subject in both air and water. A wide range of transthoracic pressure gradients is subjectively more comfortable than a slight increase in the transpharyngeal pressure gradient, suggesting that during immersion, intrapulmonic pressures are selected by the subject to minimize the transpharyngeal pressure gradient.

193. Tikhonov, M. A. Mechanics of respiration during simulation of weightlessness in an immersion medium. *Kosmicheskaya Biologiya i Meditsina* 6:53-56, 1972.

*Author's abstract:* Changes in lung capacity, air passage resistance, and dynamic compliance during water immersion were investigated in six healthy male test subjects. At the beginning of the immersion experiment, the functional residual capacity of the lungs decreased by an average of 7 percent and remained at that level until the end of the experiment. At the onset of the experiment, lung compliance also decreased by an average of 20 percent but tended to recover by the end of immersion. At the beginning of the experiment, air passage resistance increased by 65-80 percent and decreased slightly by the end of immersion. These changes may be caused by shifts in intrathoriacic pressure and redistribution of the circulating blood volume.

194. Trophy, D. E. The influence of activity and inactivity on orthostatic tolerance and plasma volume during water immersion for six hours with balanced pressure breathing. Aerospace Medical Association Preprints, 1965, pp. 271-272.

*Purpose:* To evaluate the effects of inactivity of bedrest and water immersion on orthostatic tolerance.

*Procedure and methods:* Five subjects were subjected to five separate environmental stresses for 6 hr each: normal (office activity), NA; recumbent active (bed-active), BA; recumbent inactive, BI; immersed recumbent active, IA; and immersed recumbent inactive, II.

*Conclusions:*

Subjects consistently exhibited diuresis during immersion, active and inactive. Recumbency did not seem to induce a diuresis that was significant with this number of subjects.

Plasma volume changes ($\Delta V$) during the four conditions studied were significant as follows:

a. Immersion active or inactive and bedrest inactive all resulted in a significant decrease in plasma volume ($P < 0.01$).

b. Immersion active or inactive caused a greater decrease than bedrest inactive ($P < 0.10$ and $P < 0.05$, respectively).

c. No significant difference between IA or II was observed.

d. Plasma volume losses were less than the urine losses, indicating loss of extravascular water.

No significant differences in tilt-table response was noted in the five conditions studied, for example, no deconditioning was demonstrated after 6 hr of bedrest or immersion.

Norepinephrine excretion was elevated to the same degree on being tilted despite the preceding condition (NA, B1, or II). It thus seemed the sympathetic nervous system was not "deconditioned" by 6-hr immersion. An interesting ancillary finding was that norepinephrine excretion was increased during water immersion contrary to the findings of Graveline. This might be due either to the breathing pressures involved or to the method of assay (flurometric in our case, biologic in Graveline's).

195. Torphy, D. E. Effects of immersion, recumbency and activity on orthosatic tolerance. *Aerospace Medicine* 37:119-124, 1966.

*Author's abstract:* The effects of water immersion for 6 hr without negative breathing pressures were studied in five subjects. Control conditions of normal activity and bedrest with and without activity were also studied to delineate the separate effects, if any, of activity, recumbency, and immersion.

Heart rate during the separate conditions as well as resting and tilted blood pressures were measured and statistically analyzed. No statistically significant decrement in heart rate and blood pressure response to tilting was found, although immersion resulted in a tendency toward increased heart rate and blood pressures as well as greater narrowing of pulse pressure with tilting.

The deficiencies of tilt-table testing are discussed and our findings on tilt angle and parameters dependent on degree of orthostatic stress presented.

196. Torphy, D. E. Effects of short-term bed rest and water immersion on plasma volume and catecholamine response to tilting. *Aerospace Medicine* 37:383-387, 1966.

*Author's abstract:* The urinary excretion of norepinephrine and epinephrine measured in five subjects when tilted to 44° after 6 hr of other normal activity, recumbent, (bedrest) inactivity, or immersed inactivity showed the same expected rise regardless of the preceding condition. This suggested that vasoconstrictive response to orthostasis, as evidenced by norepinephrine excretion, was not impaired by 6 hr of immersion.

Plasma volume measured before and after 6 hr of normal activity, recumbent (bedrest) inactivity, immersed activity, and immersed inactivity showed mean plasma volume changes of -114, -146, -284, and -290 ml, respectively, indicating recumbency reduces plasma volume and immersion reduces it further. Negative pressure breathing was not present during immersion. Fluid volume loss is considered as a possible primary cause of orthostatic intolerance following water immersion experiments.

197. Trout, O. F., Jr. A water-immersion technique for the study of mobility of a pressure-suited subject under balanced-gravity conditions. NASA TN D-3054, Jan. 1966.

*Author's summary:* A technique for simulating zero-gravity performance of an astronaut in a pressurized spacesuit by complete water immersion has been developed and investigated. The technique allows the pressure-suited subject to move in six degrees of freedom without the encumbrance of connecting lines or hoses or other supports and further permits performance simulation of long-duration tasks.

Experiments were made to demonstrate the relationships between the maneuvers performed by a pressure-suited subject under weightless conditions produced by water-immersion and zero-gravity aircraft flights and those performed under full-gravity conditions. An overall description of the test procedures, pressure suit and modifications, self-contained gas-supply breathing system, and methods for obtaining neutral buoyancy is provided.

The tests demonstrated that the simulation technique is useful for premission determination of critical operational characteristics relating to spacecraft and spacesuit design under conditions of zero gravity. In addition, the physical capabilities of man and his ability to perform useful work and maneuvers in a pressurized suit under simulated zero-gravity conditions can be demonstrated by this technique. Test variables included time, suit pressure, and simulation mode. Comparison of the subject's motion behavior between the aircraft and water-immersion tests showed that the water-immersion technique is valid where the velocities are low.

198. Trout, O. F., Jr. Water-immersion technique for simulation of ingress-egress maneuvers under conditions of weightlessness. In Selected Papers on Enviromental and Attitude Control of Manned Spacecraft. NASA TM X-1325 1967, pp. 79-87.

*Author's abstract:* A water-immersion technique has been developed whereby a pressure-suited subject, unrestrained by connecting lines and hoses, can simulate maneuvers under conditions of weightlessness in six degrees of freedom. This simulation has been applied to a series of ingress-egress experiments, and some of the results are described in this paper. The results of these experiments indicate that the technique has application to the study of human factors and capabilities in extravehicular space operations and to a determination of design criteria for advanced manned space vehicles and related equipment.

199. Trout, O. F., Jr. Water immersion simulation of extravehicular activities by astronauts. *Journal of Sapcecraft and Rockets* 4:806-808, 1967.

*Author's abstract:* Air-pressurized and water-pressurized suit systems are discussed in terms of performance during simulated weightlessness. Water immersion was used to re-examine extravehicular activities (EVA) that provided problems which had arisen during EVA operations of the Gemini 9-11 flights. Three training sessions for astronauts during water immersion were provided before the Gemini 12 flight. As a result of pretraining, frequent rest periods were provided during EVA operations and biomedical 100 percent monitoring was possible. It is suggested that simulation techniques can be a useful tool for developing EVA techniques for space.

200. Trout, O. F., Jr. Investigation of man's extravehicular capability in space by water immersion simulation techniques. AIAA Third Annual Meeting, Boston, Mass., Nov. 29-Dec. 2, 1966.

*Author's abstract:* In order to accelerate the development of man's extravehicular capabilities on future space missions, new economical terrestrial-based simulation techniques are required. One such development, which is proving to be a useful research tool, is the use of water-immersion techniques to simulate zero and partial gravity operations of the astronauts, study man's capabilities in space, determine man-machine interfaces, obtain design data, and to provide premission training. The technique is being applied to the study of ingress-egress operation through airlock systems, manual locomotion, maintenance and assembly processes, crew and cargo transfer functions, rescue operation, and repair tasks. Despite the limitations imposed by hydrodynamic drag and planing forces, hydrostatic simulation of zero gravity permits the pressure-suited subjects to operate in six degrees of freedom while providing total support for the body appendages. The simulation is not limited by supporting cables or attachments to the subject's body and is relatively insensitive to changes in center of gravity. Time is not a limitation since operations can be extended to several hours with sufficient breathing gas.

201. Trout, O. F., Jr. and W. J. Bruchey, Jr. Water immersion reduced-gravity simulation. *Human Factors* 11:473-488, 1969.

*Author's abstract:* A water-immersion technique for simulating zero- and partial-gravity conditions has been developed and employed to examine several extravehicular task areas in space. The technique allows the pressure-suited subject to move in six degrees of freedom unencumbered by connecting supports and simulates his biomechanical performance in weightless space. The technique is useful in examining the astronaut's capability to execute extravehicular work procedures, developing man-system engineering data, and as a training system. Several extravehicular task areas have been examined, including ingress-egress through airlock systems, manual self-locomotion, manipulation and maintenance tasks, and assessment of rescue procedures. Although limited in the study of rapid translatory tasks by the drag and damping effects of the water, the technique permits a perceptual equivalent simulation of complex manipulative tasks in real time. A description of the test procedures, equipment, and several typical tests is provided.

202. Tuttle, W. W. and J. L. Templin. A study of normal cardiac response to water below body temperature with special reference to a submersion syndrome. *Journal of Laboratory and Clinical Medicine* 28:271-276, 1943.

*Authors' conclusions:* On the basis of data collected from 68 college women, the following conclusions are drawn concerning the effects of submersion in water.

Submersion in water of swimming pool temperature causes a drop in the heart rate of normally adjusted persons.

The amount of the decrease in heart rate due to submersion varies directly with the resting heart rate.

Failure to experience a decrease in heart rate when submerged in water below body temperature is due either to a lack of emotional adjustment (fear) or to a failure to compensate physiologically.

Where emotional factors are controlled, failure to experience a significant drop in pulse rate during submersion in water below body temperature indicates sensitivity to the water.

It is suggested that the conditions causing a failure to make normal adjustments to submersion in water be called the "submersion syndrome."

203. Ulmer, H.-V., D. Böning, J. Stegemann, U. Meier, and W. Skipka. Pulse rate, blood pressure, blood volume, and oxygen uptake of sportsmen trained for endurance and of non-sportsmen during immersion in water. *Zeitschrift für Kreislaufforschung* 61:934-946, 1972.

*Authors' abstract:* Immersion in thermoindifferent water induces an orthostatic intolerance, which causes a collapse, especially of endurance-trained subjects. The mechanisms of this collapse are not well known; therefore, we immersed at times nine trained and untrained subjects in water of 35.5° C. We measured heart rate, blood pressure, and blood volume during an 8-hr immersion and during a control period of 8 hr lying on land. In a third series we measured the oxygen uptake, the influence of the temperature gradient air/water of 35.5° C, and the influence of the body position in water on heart rate and blood pressure.

The results do not show a greater decrease in blood volume of trained than of untrained subjects. The changes of heart rate and blood pressure are small, showing a circadian rhythm; but within the 8-hr period no tendency occurred toward the control values before immersion. Various temperature gradients air/water do not influence essentially the small increase of heart rate and decrease of blood pressure during immersion; small variations in body position seem to change the circulatory parameters more essentially. Oxygen-uptake during immersion does not differ significantly from the values before immersion.

The results show that the decrease of blood volume is not the essential factor of orthostatic intolerance after immersion, as suggested by other authors. Probably changes of the parasympathetic tone and the gain of the presso-receptor system are more essential factors. The small changes of the circulatory parameters during immersion of healthy subjects can be explained by a reflectoric vasodilatation caused by an increased intrathoracic blood volume.

204. Vanyushina, Yu. V. Functional changes in the cardiovascular system after exposure to hypodynamia. *Aviatsionnaya i Kosmicheskaya Meditsina,* 1963, pp. 92-94.

*Purpose:* To determine how the cardiovascular reflexes that resist gravity might change in human beings required to remain for a long period of time under circumstances that limit reflex impulses from muscles and the cardiovascular system.

*Procedure and methods:* Two series of experiments utilizing men aged 20-22 yr were performed. In the first series, six subjects were immobilized for 5.5 to 10.5 days in an armchair designed to give maximum muscular relaxation. In the second, three subjects remained in a tank of water for 5.5 to 11.5 days. Two orthostatic tests were used. One used tilting from the horizontal to vertical axis, the other involved the subject changing from a sitting to a standing position. Pulse and arterial pressure were measured every minute for 5-10 min.

*Results:* Before hypodynamia all subjects felt well and had pulse increases of 10-12 beats/min after orthostatic tests. Systolic blood pressure changed from −2 to +8 mm Hg, diastolic from +15 to +20 mm Hg. After hypodynamia pulse rate increased 20-49 beats/min. The longer experiments had greater impairments in blood pressure, a marked lowering of systolic pressure by 20 mm Hg or more after orthostatic tests.

Water hypodynamia produced more pronounced effects: extreme tachycardia (increased pulse by 50-74 beats/min) and drop in systolic pressure (26 mm Hg). Diastolic pressure tended to rise causing a marked decrease in pulse pressure (about 8-12 mm Hg).

Aschner's oculocardiac reflex revealed some sluggishness in cariovascular reflexes after hypodynamia.

*Conclusions:* The cardiovascular system adapts to the hypodynamic conditons. The adaptive mechanisms become weakened as determined by orthostatic tolerance. One reason for the decreased compensatory mechanisms may be dysfunction of the neuroreflex mechanisms which regulate cardiovascular activity. Means of preventing impairment of the cardiovascular system during hypodynamia are important.

205. Vanyushina, Yu. V., M. A. Gerd, and N. Ye. Panferova. The change of certain indices of the functional condition of the organism upon prolonged stay by man in the pose of "average physiological rest." *Problemy Kosmicheskoy Meditsiny*, 1966, pp. 88-89.

*Purpose:* To determine the physiological effects of water immersion and bedrest lasting 1.5 to 11.5 days on 21 healthy subjects.

*Conclusions:* Pulse and respiratory rates remained practically unchanged throughout the course of hypokinesia, while the systolic and diastolic blood pressure progressively declined. Biological activity of blood as tested on frog hearts was found to have a decreased chronotropic effect and an increased inotropic effect. Basal metabolism was reduced while R.Q. rose. Diurnal lowering of body temperature did not occur in some instances. Hand muscle strength and endurance were reduced. Sleep was superficial, brief, and often interrupted. Subjects displayed irritation and bad attitudes, especially during water immersion.

After completion of the tests, heart rate, arterial pressure, pulmonary ventilation, basal metabolism, R. Q., and sleep were restored to normal. Other functions did not return to normal in 3 to 5 days.

206. Vogt, F. B. Effect of extremity cuff-tourniquets on tilt table tolerance after water immersion. *Aerospace Medicine* 36:442-447, 1965.

*Author's abstract:* Tilt-table intolerance of four healthy adult young males was studied in two water-immersion experiments of 6-hr duration in an effort to reproduce a previous study reporting a protective effect from cuff-tourniquets applied to the extremities during immersion. Body weight, fluid intake, urine output, and leg circumference measurements were made and recorded. After the first period of 6 hr of water immersion, three of the four subjects experienced syncope during a tilt-table test. Compared to pre-immersion tilt tests, all subjects experienced marked changes in heart rate or blood pressure during tilting after immersion. A significant diuresis was not noted. During the second period of immersion, cuff-tourniquets were applied to the four extremities and inflated to a pressure of 60 mm Hg, with a 1-min-on, and 1-min-off cycle. Some degree of protection against tilt-table intolerance after immersion was provided in this test; none of the three subjects experienced syncope or showed the marked blood pressure changes they had shown on the previous immersion test without cuffs.

207. Vogt, F. B. Plasma volume and tilt table response to water immersion deconditioning experiments using extremity cuffs. *Aerospace Medicine* 38:460-464, 1967.

*Author's abstract:* The plasma volume and tilt-table response of six healthy adult male subjects was evaluated before and after six periods of water immersion deconditioning. The immersion periods were of 12-hr duration. A Latin Square experimental design was utilized employing six different treatments: (a) water immersion, no cuffs, (b) water immersion, no cuffs, (c) water immersion with arm cuffs, 1-min-off, (d) water immersion with arm cuffs, 2-min-on, 4-min-off, (e) water immersion with arm cuffs, 5-min-on, 10-min-off, and (f) water immersion with leg cuffs, 5-min-on, 10-min-off. The cuffs were inflated to an effective pressure of 60 to 70 mm Hg. The subjects were immersed in a sitting position, head out, with the water temperature maintained at 93° F. The results of the study indicate that cardiovascular deconditioning occurred during immersion as is evidenced by a decline in plasma volume and in tilt-table manifestations of orthostatic intolerance. There was no statistically significant difference in the tilt-table response or plasma volume changes for any of the experimental treatment conditions. The results thus indicate that in this group of subjects, under well-controlled experimental conditions, a protective effect was not noted with the use of extremity cuffs. The mechanism for the apparent protection afforded by cuffs in other experiments, and not in this study, is not evident.

208. Vogt., F. B. Tilt table and plasma volume changes with short term deconditioning experiments. *Aerospace Medicine* 38:564-568, 1967.

*Author's abstract:* The tilt-table response of nine experimental subjects was evaluated before and after short-term periods of deconditioning, including chair rest, bedrest, water immersion, and water immersion with cuffs. Twelve-hour deconditioning experiments were conducted utilizing the following eight experimental conditions: (a) water immersion, (b) water immersion, arm cuffs only, (c) water immersion, leg cuffs only, (d) water immersion, arm and leg cuffs, (e) bedrest, (f) chair rest, (g) water immersion with leg cuffs the last 4 hr, and (h) water immersion with leg cuffs 15 min/hr. In water immersion experiments, the subjects were immersed in a sitting position, head out, with a water temperature of 94° F. Cuffs were inflated in cycles, with inflation to 70 mm Hg for 2 of every 6 min. The results indicate that definite cardiovascular deconditioning occurred with water immersion, as evidenced in the plasma volume decline and the tilt-table response. There was a significant decline in plasma volume during all experimental conditions except chair rest. The results of this study do not indicate a definite protective effect from the use of intermittently inflated extremity cuffs.

209. Vogt, F. B. An evaluation of intermittently inflated extremity cuffs in preventing the cardiovascular deconditioning of bedrest and water immersion. NASA CR-92,085, 1967.

*Author's abstract:*

No significant protection against cardiovascular deconditioning associated with bedrest or water-immersion experiments could be attributed to the use of intermittently inflated extremity cuffs.

The use of pressure garments on the lower extremities provides a statistically significant protective effect against the manifestations of cardiovascular deconditioning resulting from bedrest or water immersion.

210. Vogt, F. B. and P. C. Johnson. Study of effect of water immersion on healthy adult male subjects: Plasma volume and fluid-electrolyte changes. *Aerospace Medicine* 36:447-451, 1965.

*Authors' abstract:* Four healthy adult males were studied during two water-immersion experiments of 6-hr duration. During the second experiment, cuff-tourniquets were applied to all four extremities of each subject to test the effect in preventing or lessening the cardiovascular deconditioning associated with water immersion. The use of the cuff-tourniquets was found to be partially effective. Repeated plasma volume, hemoglobin, hematocrit and serum sodium, potassium, osmolarity and protein determinations were performed and are reported. Fluid intake, urine output, and body weight measurements were made and are reported. An increased rate of transfer of intravascular protein as well as fluid and electrolytes into the extravascular compartment is suggested as one of the possible factors responsible for the symptoms observed during tilt-table tests after water immersion.

211. Voskresenskiy, A. D. and V. I. Sokolkov. Dependence between oxygen consumption and lung ventilation in orthostatic tests. *Kosmicheskaya Biologiya i Meditsina* 3:86-88, 1968.

*Purpose:* To determine changes in lung ventilation and gas exchange indices during orthostatic tests before and after water immersion.

*Conclusions:* Sixteen subjects were immersed in 34.5° C water for 18 hr. $\dot{V}_{O2}/\dot{V}E$ index (used as an index of lung ventilation efficiency) after immersion was considerably lower during 90° body tilt. In subjects with poor orthostatic tolerance, $\dot{V}_{O2}/\dot{V}E$ during tilting was higher than for subjects with good orthostatic tolerance. During orthostasis, prior to immersion, there were equal increments in $\dot{V}_{O2}$ and $\dot{V}E$ for subjects with poor and good tolerance. Following immersion, orthostasis was characterized by a lower $\dot{V}_{O2}/\dot{V}E$ ratio indicating a reduced efficiency of lung ventilation.

212. Walawski, J. and A. Kaleta. Observations on heart rates and cardiodynamics during prolonged weightlessness simulated by immersion method. Proceedings of the First International Symposium on Basic Environmental Problems of Man in Space. Wien: Springer-Verlag, 1965. pp. 179-185.

*Authors' abstract:* Among the numerous methods proposed for the investigation of physiological effects of weightlessness in laboratory conditions, the immersion method seems to be most advantageous. Although no true state of weightlessness is attained, nevertheless, long-term observation in subgravity are made possible in this way. Certain human experiments indicate that in such conditions slight disturbances in ECG and blood pressure may become manifest. These results were not confirmed by other authors. The aim of the present work was to investigate the effect of long-term weightlessness simulated by immersion on ECG and blood pressure in rabbits. The animals were under urethane narcosis to eliminate the influence of the central nervous system. The experimental animals were submerged in 1 percent solution of NaCl at temperatures ranging from 34° to 35° C. Respiration was made possible by tracheotomy tube connected with respiratory valve. Blood pressure from the carotid artery was registered kymographically using a mercury manometer. ECG electrodes were introduced under the skin of the fore and hind extremities. All incisions were sutured carefully to avoid contact of electrodes with the immersion fluid. The immersion period ranged from 12 to 24 hr.

No apparent changes were seen in the electrocardiograms. The heart rate registered hourly was about 230 per min and did not change during the whole observation period. No significant changes in ECG were observed. The conduction times remained in the normal range for rabbits. In some instances a slight depression of QRS complexes was noted. Sometimes QRS complexes were elevated even in final stages of the experiments. The arterial blood pressure remained during the whole experiment nearly at a constant level showing only slight deviations.

The results indicate that 24-hr weightlessness simulated by the immersion method does not induce any significant circulatory disturbances and is fairly well tolerated by rabbits. Supplementary experiments now under way using further physiological tests seem to confirm the foregoing conclusions.

213. Walawski, J. and Z. Kaleta. Some reactions of the circulatory system in the state of prolonged weightlessness produced by the immersion method. *Acta Physiologica Polonica* 14:373-377, 1963.

*Authors' abstract:* Among various physiological reactions observed in the state of weightlessness, the circulatory effects aroused special interest. A basic problem of the cosmic medicine at the present is the influence of a prolonged state of weightlessness on the organism. The immersion method is used mainly as it imitates the weightlessness in the laboratory conditions. So far the immersion method was applied in human experiments only. Not numerous bibliographical data encouraged the authors to investigate the influence of the relative weightlessness on the circulatory system of rabbits. Twenty rabbits were used for the experiments. The respiratory action, body temperature, arterial blood pressure on the kymographs, and electrocardiogram were recorded every half hour or every hour for 8-24 hr in rabbits under investigation. To evoke the state of weightlessness, the animals in light urethane anesthesia were immersed in a tank filled with 1-percent solution of sodium chloride at 34°-35° C. It was established that the rabbits can be maintained for 24 hr or even longer in the state of weightlessness. The relative weightlessness produced by the immersion method does not result in any circulatory disturbances. The fact that the circulatory reaction in anesthetized animals during the immersion do not differ from those in anesthetized animals during the rocket flights implies the possibility of the immersion method being of use as an experimental pattern for physiological investigations on prolonged weightlessness. The method is not free of drawbacks; nevertheless it makes possible the preliminary physiological investigations on the state of prolonged weightlessness and its effect on the organisms, which will then be proved during prolonged orbital flights.

214. Walawski, J. and Z. Kaleta. Vascular reactivity to neurohormones in subgravity simulated by immersion method. Second International Symposium on Basic Environmental Problems of Man in Space, Paris, France, June 14-18, 1965, pp. 222-228.

*Authors' abstract:* Dogs, anaesthetized with chloralose, were submersed in a NaCl solution at 35° C. Respiration was made possible by a tracheotomy tube connected with a respiratory valve. The vascular reactions, registered as systemic arterial blood pressure changes, were observed after adrenaline, noradrenaline, acetylcholine, histamine, and serotonin administration. The results indicate that a 24-hr period of subgravity simulated by the immersion method does not induce significant changes in vascular reactions to neurohormones.

215. Walker, J. L. C. Plasma 17 hydroxycorticosteroids in healthy subjects after water immersion of twelve hours' duration. *Aerospace Medicine* 38:459, 1967.

*Author's abstract:* The plasma 17 hydroxycorticosteroids were measured by the Nelson and Samuels method in six healthy subjects before and after water immersion at 93° F of 12-hr duration. The test was repeated several days after the first immersion. There was no significant difference in the concentration of 17 hydroxycorticosteroids in the plasma withdrawn before or after water immersion.

216. Weltman, G. and G. H. Egstrom. Heart rate and respiratory response correlations in surface and underwater work. *Aerospace Medicine* 40:479-483, 1969.

*Authors' abstract:* An exercise test battery composed of surface bicycling, surface and underwater weight lifting, surface and underwater block moving, and underwater pipe structure assembly was administered to two 7-man groups of divers. High rank-correlations were observed between levels of heart rate and inspiratory minute volume exhibited in various surface tests and the levels of these variables exhibited in strenuous underwater activity. A high degree of concordance was also observed among heart rate, inspiratory minute volume, and respiratory rate over the range of surface and underwater tests. Using the heart rate and respiratory volume measures, it was possible to order with respect to imposed workload tasks of known and unknown physical requirements. The main implications were that it is feasible to estimate underwater work capacity through surface tests, and that basic physiological measurements, particularly heart rate, taken during diving operations can permit reasonable estimation of imposed workload.

217. White, P. D., J. W. Nyberg, L. M. Finney, and W. J. White. A comparative study of the physiological effects of immersion and bed rest. Rept. DAC-59226, Douglas Aircraft Co., Santa Monica, Calif., June 1966.

*Authors' summary:* The purpose or the study was to compare the physiological responses of 10 subjects, each serving as his own control, during alternate 10-day periods of immersion and bedrest. Functional, diagnostic, and monitoring tests conducted before, during, and after the 10-day testing periods were used to follow physiological changes produced by these two analogs of null gravity and to quantitatively compare their effects. Fluid silicone was used as the immersion medium.

Neither immersion nor bedrest produced appreciable changes in Master's two-step test of exercise tolerance, resting oxygen consumption, tolerance to acceleration in the $+g_z$ direction, visual and auditory acuity, or in ECG and heart sounds recorded during tilt-table testing. There were no significant changes in microscopic or qualitative analysis of the urine for sugar, acetone, or protein; resting blood pressure, temperature, heart, and respiration rate; blood and urine chemistries or kidney and liver functions.

No serious complications were noted in any of the subjects during immersion or bedrest. Neither analog produced a free-water diuresis. The results of the study confirm the detrimental effects of prolonged immersion and bedrest on orthostatic tolerance and extracellular fluid volume. Both analogs brought about a deterioration in the mechanisms essential for adequate circulation in the erect position. This was shown by increased incidence of presyncopal reactions, by declines in pulse pressure, and by increased heart rate during tilt-table testing. Experimental conditions produced reductions in plasma, blood, and extracellular fluid volumes; declines in maximum oxygen consumption; and some impairment of postural equilibrium. Losses in body weight were progressive, the average was approximately 2 percent of initial weight. A negative free-water clearance was obtained in all subjects during immersion and bedrest.

Differential effects of the two environments are seen in orthostatic tolerance, fluid compartments, and renal function. The incidence of presyncopal reactions was higher and occurred earlier during immersion and during bedrest. Heart rates were higher and pulse pressures were lower during immersion than during bedrest. After 5 days of immersion and bedrest, the extracellular fluid decreased by 3 and 2 percent, respectively. After 10 days, the net decrease in fluid was 5 percent during immersion and 7 percent during bedrest. The conditions of immersion produced a larger loss in plasma volume after 5 days than did bedrest, but the net loss after 10 days was approximately the same for both environments. Changes in blood volume were parallel to those of plasma volume. Immersion produced an elevated urine flow, as evidenced by a comparison of urine outputs in the two environments and by higher urine outputs than fluid intakes during immersion. During bedrest the subjects produced a more concentrated urine, both with respect to individual electrolytes and solute load. During immersion the daily solute load excreted by the kidney was higher, urine output was larger, and osmolar clearance was higher.

The silicone fluid, immersion tanks, filtration, and cooling equipment met the requirements of the experiment. Except for two subjects, skin problems that developed during immersion were trivial. An effort to relate the occurrence of skin problems to bacteria, water, and contamination of the silicone was inconclusive. During a 6-month period following the study, the subjects were free of abnormal physical signs, symptoms, and skin problems.

218. Witherspoon, J. M., R. F. Goldman, and J. R. Breckenridge. Heat transfer coefficients of humans in cold water. *Journal of Physiology* (Paris) 63:459-462, 1971.

*Purpose:* To assess regional and total heat transfer on the basis of calculated convective coefficients and measured surface temperature gradients.

*Procedure and methods:* Heat-transfer coefficients were derived from combined forced and free convection equation and related to human cold-water immersion during active and inactive movement.

*Conclusions:*

Combined coefficients gave heat-transfer values less than those independently derived from forced or free convection coefficients and three times less than those measured in copper manikin studies.

The problems associated with surface gradient determinations are discussed.

219. Wood, E. H., E. F. Lindberg, C. F. Code, and E. J. Baldes. Effect of partial immersion in water on response of healthy men to headward acceleration. *Journal of Applied Physiology* 18:1171-1179, 1963.

*Authors' abstract:* Protection against the effects of headward acceleration afforded by immersion in water has been assayed in the human centrifuge on 15 trained subjects. Immersion in water to the xyphoid afforded an average protection of 1.1 ±0.1 G for vision and ear opacity and of 1.6 ±0.2 G for ear pulse and heart rate. Deeper immersion, to the level of the third rib at the sternum, increased the protection to 1.8 ±0.1 G for vision and ear opacity and to 2.8 ±0.2 G for ear pulse and heart rate. The protection afforded the various physiologic variables increased with the magnitude of acceleration tested. Protection against loss of consciousness may be greater than protection against blackout and is probably similar to the protection afforded the ear pulse and heart rate. The cardiovascular reactions produced by headward acceleration are qualitatively similar with and without water immersion. This finding does not support the concept that impediment to venous return is the primary determinant of man's tolerance to headward acceleration. Visual symptoms occurred at greater amplitudes of ear pulse, and presumably also at greater blood pressures at head level, during water immersion than during control runs.

220. Wood, E. H., E. F. Lindberg, C. F. Code, and E. J. Baldes. Photoelectric earpiece recordings and other physiologic variables as objective methods of measuring the increase in tolerance to headward acceleration ($+G_z$) produced by partial immersion in water. AMRL-TDR-63-106, Wright-Patterson Air Force Base, Ohio, Dec. 1963.

*Authors' summary:* The protection against the effects of headward acceleration afforded the human by immersion of water to the level of the xyphoid and to the third rib at the sternum has been assayed in 15 trained centrifuge subjects. Immersion in water to the xyphoid afforded an average protection of 1.1 ±0.1 G to vision and ear opacity and an average protection of 1.6 ±0.2 G to the ear pulse and heart rate. Increase in the level of the water to the third rib at the sternum increased the protection afforded in all subjects. The average increase in protection was 0.9 G. Immersion in water to the third rib afforded an average protection of 1.8 ±0.1 G to vision and ear opacity, and an average protection of 2.8 ±0.2 G to the ear pulse and heart rate. The protection afforded the various physiologic variables increases with the level of acceleration tested. The protection against loss of consciousness may be greater than the protection afforded against blackout and is probably similar to the protection afforded the ear pulse and heart rate. The cardiovascular reactions produced by headward acceleration with and without water immersion are qualitatively very similar. This finding does not support the concept that impediment to venous return is a primary determinant of man's tolerance to headward acceleration. Visual symptoms occur at higher ear pulse amplitudes and presumably also at higher blood pressures at head level during water immersion than in the control runs.

221. Zhdanova, A. G. Macrometric changes in the makeup of the human body in hypodynamia. *Arkhiv Anatomii, Gistologii i Embriologii* 49:29-34, 1965.

*Purpose:* To determine the effects of hypodynamia on the ratio of fat and nonfat tissues (body composition).

*Procedure and methods:* Specific gravity measurements were made by hydrostatic weighing in men aged 20-25 yr during 18 hypodynamic experiments lasting 2, 5, 7, or 10 days. Ten experiments were conducted during bedrest and eight during water immersion.

*Results:* Body weight changes were variable. In most subjects specific gravity decreased which was most notable during the 7- and 10-day experiments, i.e., the greater the length of hypodynamia, the greater the decrease in specific gravity and therefore increase in fat component. The latter was noticeable after only 2 days.

*Conclusions:* Development of adiposity, muscular atrophy, and dehydration occurred in most cases of hypodynamia. Data suggest an increase in body fat stores in hypodynamic environments.

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