An Approach to the Physiologic Simulation of the Null-gravity State

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THE PROBLEM of "weightlessness" has shown itself to be one with which it is remarkably difficult to come to grips. The arrangement of the experimental conditions for the study of weightlessness, even for seconds of time, is costly, technically difficult to achieve, and subject to the criticism that such physiologic measurements as can be made in a given zero G ellipse represent responses not to a simple experience, but rather to the entire complex of accelerative change demanded by the flight profile.

In casting about for some method for study of the physiologic effects of prolonged weightlessness, our consideration inevitably was arrested by the similarities and differences to be observed between the condition of a body floating in space and that of a body floating in water. A comparison of the two states requires a brief examination of the forces acting in each case. It is particularly important that a distinction be observed between the kinds of forces involved, determined by the way they act on a given body.

H. Haber[2] has classified mechanical forces as gravitational, inertial, and external. He points out that gravitational and inertial forces are, by the general theory of relativity, two sides of the same coin. Certainly they have this in common: they both behave as *field* phenomena. The action of these field forces is in sharp contrast to that of external forces. External forces act at the surface of matter and are transmitted from molecule to molecule through the mass. Because they are non-uniform with respect to the mass as a whole, external forces produce inequalities of pressure within the mass. In non-rigid bodies the external forces thus become forces of deformation. The measure of the deformation which a body produces in a restraining medium when acted upon by a field of force is what we call weight. The restraining medium is an external force. Weightlessness, therefore, is simply the absence of any external forces acting.

The human body can sense only the deformation which forces produce and is totally unaware of the presence of any unopposed field force acting on it. For example, a body in free fall being accelerated in the earth's gravitational field has no way of sensing its accelerated motion except by visual reference until an opposing external force such as air friction or the solid surface of the earth itself clearly points it out.

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The special organs for detecting the presence of external forces are the pressure receptors of the skin, viscera, and musculo-skeletal system, and the vestibular mechanism of the inner ear. If the sensory input from these receptors could be obliterated it is reasonable to suppose that the resulting physiologic adjustments normally made in response to such information would not be made. And it is the absence of these adjustments, or the physiologic concomitants of the weightless state that is of interest in space medicine. To what extent, then, can such sensory input be extinguished in the normal human subject?

Visual input is readily eliminated by covering the eyes. The afferent impulses from the exteroceptors of the skin can be neutralized effectively by placing the body in water of uniform, comfortable temperature. The special exteroceptive end-organs such as the Meissner and Pacinian corpuscles and the nerve endings around the hair follicles are sensitive only to deformation, and as long as the support of the body —the restraining medium in which it floats—is distributed over its entire surface, no skin deformation occurs.

In the hypothetical situation of a mass of homogeneous, non-rigid tissue suspended in a liquid such as water the tissue behaves virtually as part of the fluid, maintaining a pressure gradient throughout its mass, the equivalent of that of the water surrounding it. The human body, however, is not a single homogeneous tissue. When it is suspended in water, deformations will occur in the tissue because of the differential effect of gravity upon tissues of varying density. The question may be asked, however, to what extent these slight deformations, occurring deep in the body mass, are sensed by the nervous system.

The otolith mechanism of the inner ear is designed to sense precisely this kind of differential stress. But how sensitive is it? A search of the literature turned up surprisingly little information on this subject. The work of Lowenstein and Sand,[3] using the dogfish, can hardly be extrapolated to man because of the high level of efficiency these organs can be presumed to have developed in creatures which depend so heavily upon them for special orientation. Graybiel[1] attempted to establish a threshold of sensitivity of these organs in man, using a human centrifuge and observing the oculogravic illusion. In 1928 Quix,[4] using human subjects on a gimballed frame described a position in space in which apparently no sensory input originated from the otolith mechanism. He called this position the *tache auveugle*, or blind spot, of the otoliths and described the position as supine, with head dependent. Graybiel noted the phenomenon with his subjects when they were suspended in the head-down position.

It was considered by the author that if this "blind spot" phenomenon could be verified, a method existed for subjecting the human body to conditions approaching minimum input from all the organs of special sense having to do with gravitational effects and spatial orientation. In other words, a physiologic condition approaching that observed in the null-gravity state could be simulated by obscuring vision, immersing the subject in a water bath to eliminate tactile and proprioceptive cues, and positioning in the supine, head-down orientation. The chief advantage of this approach would be that the conditions could be maintained for comparatively long periods of time.

In September, 1956, at the U. S. Air Force School of Aviation Medicine, a small project was undertaken to investigate, in a preliminary way, the matter of spacial orientation during immersion in water. The specific goals of the experiment were to examine the blind spot of Quix and if possible, to establish approximate values for the threshold of sensitivity of the otolith organ to change in position.

The use of a swimming pool was arranged and the pool filled with water to a depth of about seven feet. A tilt-table was placed on the bottom of the pool. A large protractor, calibrated in degrees, measured the angle of tilt. The subject wore a visual occluder consisting of a skin-diver's mask in which a sheet-metal disk had been substituted for the glass plate. Respiration was attained by means of a portable high-pressure air-lung device with a regulator integral with the mouthpiece. The subject was strapped to the tilt-table using an aircraft safety belt. The table was hand-moved slowly by an observer through varying angles of tilt, an attempt being made to keep any change of acceleration at a value less than the threshold of stimulation of the semi-circular canals. The subject was required to signal the instant he was certain that his position had changed from the original position, and to indicate the direction of change. Starting positions varying from 0° to 190° with the vertical were used in a random fashion.

The humble experimental setup, using hastily assembled equipment, was not sufficient to provide any finely quantitative results. It did provide acquaintance with the problems which will be involved in the design of a more refined apparatus.

Three principal subjects were used, all of whom had previously acted as subjects for in-flight null-gravity experiments in T-33 or F-94C aircraft. All were impressed with the subjective similarity between the conditions of zero-gravity in flight and those of suspension in water. All observed a rapid loss of sense of position after submersion. In general, large changes in the position of the tilt-table could be made before they were positively identified by the subject. The mean change required was 17° with a standard deviation of 8°. In almost every experiment the clues to change of position were factors unrelated to vestibular sense, but rather to the crudeness of the setup—factors such as changing pressures within the middle ear and sinuses, bubbles passing over the skin, change of water temperature, or uneven movement of the tilt-table.

The blind spot described by Quix was not positively identified, although it was noted that beginning from a vertical head-down position (180°) very large movements of the table (of the order of 100°) did occasionally take place before their direction could be identified. The experiments were terminated by an unforeseen complication—the simultaneous development of bilateral acute otitis externa in the three main participants. The technical problems which were encountered appear capable of ready solution in the development of an experimental setup for further study.

Although it is not claimed that the condition of the body floating in water is identical to that of the body floating in space, the theoretical similarities are such that the physiologic study of human subjects under water may be of value. The condition may represent the nearest approach to prolonged weightlessness capable of close study until the day of the manned satellite.

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Pavlov and Poetic Justice

The information which Soviet scientists have already acquired from the dog which was a passenger in Sputnik II will lay a sound foundation for solving these new problems of nutritional and respiratory physiology. Without this precise knowledge man cannot embark on travel into outer space. There is a kind of poetic justice which conceded to the Russian scientists the initial success in this sphere. The sending of a dog as the first satellite traveler was only possible by training it to feed on signal. The basis for this training was created by Pavlov, a Russian, and one of the greatest physiologists of all time. His work on the conditioned reflex in animals (especially dogs) was, in a sense, a prophetic contribution to the most recent achievement of Russian science.—EDITORIAL: The Challenge of Space, *Medical Proceedings* (Johannesburg, South Africa), December 21, 1957.