Graybiel A, Kennedy R, Knoblock E, Guedry F, Mertz W, McLeod M, Colehour J, Miller E, Fregly A. ***Effects of Exposure to a Rotating Environment (10 RPM) on Four Aviators for a Period of Twelve Days.*** **Aerosp Med 1965; 36: 733-54.**

This study aimed to determine whether a select group of test subjects living in the Slow Rotation Room (SRR) could adapt to a rotational velocity of 10 RPM, which was considered the upper limit without disabling side effects. The SRR was 15 ft in diameter and 7 ft high and provided living and working space for four people. At 10 RPM, it imposed 0.24 G of centripetal force at the periphery. Four military officers (two Navy, two Marine), who had completed the aerobatic stage of flight training and were motion-sickness resistant spent 12 d in the SRR. Clinical symptoms, biochemical tests, and psycho-physiological performance were analyzed. The subjects' clinical responses were remarkably similar to those seen later in astronauts during spaceflight. The sudden transition from the normal stationary environment to the SRR had an immediate, strong impact on voluntary activity. Graybiel dubbed this response "canal sickness," characterized by ataxia and nausea that persisted for about 3 d. However, unlike spaceflight, the subjects in the SRR suffered from a fatigue syndrome throughout the remainder of the of the rotation period never fully adapted to the conditions.

The severity of the initial response to the SRR appeared to be related to the number of head movements made by each subject, but this variable was not controlled. No vestibular test or previous experience predicted the severity of the canal sickness. The only predictive variable was the anxiety dimension in the Rorschach test. Food and fluid intakes were reduced during the first few days of rotation, but eventually returned to normal. Urine output also varied in expected manners to preserve serum electrolyte homeostasis, apparently under the control of ADH. Emotional stress seemed to be an unimportant contributor, as no changes were observed in norepinephrine, and only minor fluctuations were observed in epinephrine throughout the experiment. Changes were observed in plasma LDH levels and in increased rates of glucose utilization, reflecting increased muscle metabolism. Psychophysiological tests indicated little change in performance during or after the SRR. Overall, it was concluded from this study that, while individuals can adapt to rotation rates of 10 RPM, additional countermeasures might be required to treat some of the neuro-adaptive side effects of the rotation.

BACKGROUND

Captain Ashton Graybiel, MC, USN was a pioneer in aviation medicine research. A Harvard-trained expert in cardiovascular medicine, he was assigned to Pensacola during World War II and initially brought his skills to bear on studying the effects of fatigue and cardiovascular fitness on the performance of military pilots. In the 1950's, he begin to study issues associated with the effects of weightlessness and acceleration on the human body. Among his accomplishments were early studies in parabolic flight, the unparalleled series of experiments with the SRR during the late 1950's and early 1960's (1-4), and a series of five seminal symposia he organized between 1965 and 1970 on "The Role of the Vestibular Organs in Space Exploration." These pioneering symposia brought together the world's best vestibular researchers, including physicians, psychologists, biologists, physiologists, engineers, and physicists, to discuss issues related to spaceflight. Dr. Graybiel, who has been called the "Father of Naval Aerospace Medical Research," directed the Naval Aerospace Medical Institute from 1945 to 1970 and then headed the biological sciences department of the newly formed Naval Aerospace Medical Research Laboratory (NAMRL) in New Orleans from 1970 to 1980.

Early in the U.S. manned spaceflight program, there was an enthusiastic optimism that human space exploration would proceed rapidly from low Earth orbit to Lunar and interplanetary travel. But there was also a huge void in our understanding of how human physiological systems would respond to prolonged weightlessness. Most early aerospace medicine experts presumed that as mission duration increased, artificial gravity (AG) would be required to protect the bone, muscle, cardiovascular, and sensory-motor systems from degeneration due to the lack of homeostatic mechanisms in the weightless environment (6).

Dr. Graybiel's research group in Pensacola was deeply involved in spatial disorientation research, working closely with NASA to understand how acceleration affects the vestibular, cardiovascular, and motor systems. They recognized that while AG may be the best way to prevent the health, safety, and performance issues associated with adaptation to long duration microgravity, the only practical means to provide AG would be centrifugal force generated by rotating the entire spacecraft. They also recognized that humans living and working in a rotating environment might experience significant side effects such as spatial disorientation, motion sickness, incoordination and the like. To determine how well, and under what circumstances, individuals could adapt to a rotating environment, Graybiel's research group undertook a series of experiments in which subjects lived in the SRR for various periods with different rotational velocities.

In earlier SRR studies (3), Graybiel had demonstrated the form of neurovestibular dysfunction he termed "canal sickness," characterized by the now-familiar symptoms of dizziness, headache, apathy, drowsiness, fatigue, and anorexia. Its primary signs included pallor, cold sweating, vomiting, inactivity, and ataxia, which gave way to secondary effects including biochemical changes and compensatory nystagmus. Canal sickness severity was individually variable, would decrease with adaptation and conditioning, and could be ameliorated in a limited way with countermeasures. Earlier studies had also shown that the severity of the canal sickness was directly proportional to the rotational velocity of the SRR, which was important because the cost of constructing a rotating spacecraft would increase with the radius, while the angular velocity required to achieve a given centrifugal force would decrease. The higher the tolerable angular velocity, the shorter the required radius and, consequently, the lower the cost of the vehicle. Loret (5) had shown that a rotating spacecraft would have to maintain a rotation of 4 RPM or less to prevent canal sickness and that this would give a centripetal force at the periphery of anywhere from 0.2 G (radius of 60 ft) to 1.0 G (radius of 180 ft).

COMMENTARY

by William Paloski, Ph.D., Professor – Health and Human Performance, University of Houston

In the 44 yr since this classic study was published, we have learned a lot about the neurological adaptation to rotating (and spaceflight) environments. Major contributions to the understanding of sensorimotor adaptation to space and other unusual environments have been contributed by laboratories at NAMRL, Brandeis, the Massachusetts Institute of Technology, Mt. Sinai, NASA, the Royal Air Force, and Universities in Paris, Munich, York, Amsterdam, Sydney, and elsewhere. We now have a better idea of the factors that drive the adaptive process, some of the underlying mechanisms of adaptation, how to treat adverse symptoms associated with AG, and human capacity for creating dual-adapted states. However, we still do not know of any reliable predictors for the susceptibility to AG side effects, nor have we developed countermeasures other than waiting for the process to run its course. Furthermore, few studies have looked at whole-body responses using the breadth of behavioral, biochemical, and psychophysical measures that were employed in Graybiel's studies. Future experiments of that scope will be critical for developing optimal approaches to applying artificial gravity as a multi-system countermeasure.

Not long after publication of this study, funding for AG work at Pensacola was put on hold until there was a more practical need. Since then, AG research programs have resurfaced periodically in the United States and other countries, but the cost and complexity of such programs have generally led to their cancellation as soon as the mission planners determined that other countermeasures would suffice for the current mission scenarios that they were developing. We've learned that humans can withstand far longer exposures to weightlessness

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than expected in the early days of human spaceflight. However, the 6-mo sojourns aboard the International Space Station approach the limits of human endurance to long duration weightlessness with non-AG countermeasures. Despite years of research, countermeasures that have been developed to prevent deconditioning do not prevent bone loss and only partially control muscle atrophy and cardiac deconditioning. The projected 30-mo Mars expedition may not be tolerable without AG. Thus, barring a major breakthrough in propulsion systems, it may now be time to make a sustained investment in completing the pioneering research begun nearly half a century ago by Dr. Graybiel and his visionary group.

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