Effects of Weightlessness in Ballistic And Orbital Flight

A Progress Report

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THE MAIN biological interest in the achievement of orbiting space flight centers about the controversial question of the effects of the weightless state.[1] To date, there has been no difficulty in tolerating the noise, vibration, and acceleration associated with launch and with reentry.[2-4] For example, as can be seen in Figure 1, none of the accelerations in the various Mercury flights exceeded limits eminently tolerable for the supine posture. Launch values, with the exception of the escape rocket firing in MR-2, were less than 8g and reentry less than an 11g peak with a maximum time above 6g of no more than 45 seconds. Even with the unscheduled escape rocket firing of the MR-2, the momentary 17g launch and subsequent 15g reentry peaks were well tolerated. The oscillatory accelerations were, in all cases, less than 1.0g through the entire frequency range, including those from 1 to 20 cycles per second. Sound levels at no time exceeded tolerance, and impacts on the ocean using the pneumatic bag deployed with the heat shield were so mild that the protective crushable honeycomb structure under the couch remained uncompressed.

The normally functioning spacecraft environmental control system maintained suit inlet temperatures at less than 75° F. throughout flight. The only significant heat stress was after landing when the heating effect of the fan caused suit inlet values to rise above the already warm (75-85° F.) ambient air of the tropical ocean. This air has a high humidity and will, at these temperatures, maintain heat balance only in resting conditions. Radiation has been no problem in the Mercury flights to date, for the capsule no more than skims the atmosphere far below the Van Allen zones. It is not surprising then that the results of the postflight physical examinations and the evaluation of pilot performance have been negative.[2-4] It is important to note that the data on Figure 1 refer only to the Mercury-Redstone and Mercury-Atlas spacecraft-booster combinations. Another larger vehicle could have different and, perhaps, less tolerable launch acceleration, vibration, and noise characteristics. The characteristics of the environmental control system employed, including its freedom from toxic gases is also peculiar to these particular systems. Nevertheless, it can be stated that the Mercury environmental stress data is fully compatible with normal pilot performance. This leaves the question of the effects of the weightless state, a question which was first raised in the closing days of World War II by Gauer and Haber.[1]

The present paper will review what has been learned about the effects of weightlessness, now that manned orbiting spacecraft are realities. Gauer and Haber's original paper, which was written in 1946,[2] remains a classical summary of the possible effects of the weightless state. In it, they speculated concerning the possible consequences of day to week-long exposures such as would be met during a flight to the moon or even Mars. Their concern centered about the

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questions of orientation. Postulating an individual free to float, they argued that vision would then provide the only means of orientation. There would be grossly altered and deficient information from the joints, tendons, muscle, and skin, i.e., the kinesthetic sense would be disturbed. The labyrinth would provide none of the usual orienting information from the otoliths in the utricle. Gauer and Haber[1] and later Haber and Gerathewohl[5] predicted difficulties because of the gross discrepancy anticipated between vision and the sensations from the labyrinth. It was thought that the utricular receptors might over-respond to the small inertial effects of head movement when there was no overriding force of gravity to pin them down.

SPACECRAFT ENVIRONMENTAL PARAMETERS

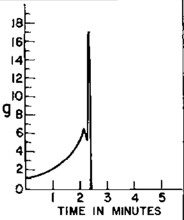
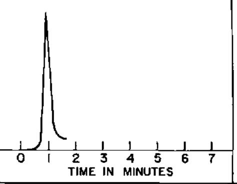
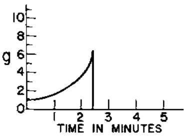
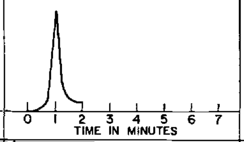
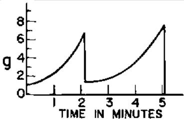
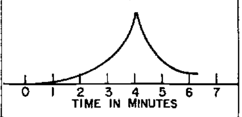
FLIGHT	ACCELERATION		VIBRATION LEVEL (0 TO 20cps)	TEMP. °F MAXIMUM
	LAUNCH	REENTRY		SUIT INLET
MR-2			LESS THAN 1g	66
MR-3			LESS THAN 1g	75
MR-4				57.5
MA-5			LESS THAN 1g	76
MA-6				75

Fig. 1. Chart indicating Mercury spacecraft environmental parameters.

Furthermore, since the actual relation between the gravity force and the sensation experienced by the organism had not been determined experimentally, Gauer and Haber chose to cite the Weber-Fechner law, which states that the sensation experienced by the organism is not directly proportional to the intensity of the particular stimulus but to its logarithm. Haber and Gerathewohl extrapolated the Weber-Fechner relationship to values below 1g, using this value as corresponding to zero sensation.

Gougerot immediately challenged these contentions arguing that the threshold for null sensations[6] of gravity would not be 1g but would probably change with reduced gravity to which he thought the organism would adapt rapidly, setting a new threshold as is the case with a continuous background of sound. However, as Haber and Gerathewohl themselves pointed out,[5] "the analysis of phenomena in a gravity free state had of necessity, to depend on assumptions and conclusions by analogy and only experiments will decide." Subsequent work with exposures to weightless flight in aircraft, lasting for no more than 30 seconds, have confirmed Gougerot's idea of adaptability. Thus, Simons reports the rapid reorientation of a man walking with "sticky" Velcro on his feet along a strip on the roof of the cabin. To these subjects, the erstwhile ceiling now appeared to be down;[7]

and, in a later study, Gerathewohl has concluded that it was probable that only small changes in sensations were produced at values below 1g.[8]

The early speculation further assumed that "in the absence of gravity there would necessarily be a sensation of falling in space."[1] But, as Gerathewohl has recently pointed out,[9] even the brief aircraft experiments did not support this. Both Gerathewohl[9] and Von Diringshofen[10] report merely a floating feeling. Nor have aircraft experiments revealed the predicted difficulty with hand-eye coordination in the seated pilot with full visual references. It would seem that rapid adaptation to the weightless state occurs.

Because of the brief periods of weightlessness available in aircraft studies, it has not been possible to differentiate accurately between the effects of vision and kinesthetic sense in determining orientation. Such refined analysis must await more careful tests in orbiting spacecraft. However, it is interesting that experiments by Gerathewohl with cats in which they were held on their backs until they had been weightless for several seconds led to abolition of the righting reflex.[11] The impression was gained that they relied on vision for orientation.

Destruction of the labyrinth before exposure to the weightless state in the celebrated turtle experiment of von Beckh[12] prevented the onset of confusion in the animal when suddenly exposed to weightlessness. Having already lost his gravireceptors, the labyrinthectomized animal experiences no new situation to which he must suddenly accommodate. Von Beckh's normal turtles missed their target when suddenly weightless, but the labyrinth damaged animal showed no reduction in accuracy unless he was deprived of vision by hooding.[12]

Early Studies with Ballistic Rockets.—Ten years ago, the first results of a four-year, nine-flight investigation of the physiological and performance effects of the subgravity state during rocket flight were published by a team of American investigators and engineers in this journal.[13] The work, in which Dr. Gauer collaborated as an advisor, was in part an attempt to answer Gauer and Haber's questions concerning the subgravity state.[1] Monkeys and mice were used, first in captured V2's and later in Aerobee upper atmosphere research rockets specially assigned for these biological studies. The monkeys were placed in chairs and on couches and the electrocardiogram, respiration, systemic arterial and venous pressure were recorded by telemetry. It was concluded that the weightless state had no significant effect upon these physiological indices. Motion picture observations of performance were also made on a labyrinthectomized mouse and upon one trained to climb over a barrier in a slowly rotating, smooth-walled drum. Thus, an attempt was made to disassociate visual and kinesthetic from labyrinthine information: in one case by labyrinthectomy; in the other by providing a perch for the one animal and no possible orienting support for the other. As long as gravity was present to provide orientation, the animals behaved normally. With loss of gravity, the suddenly deprived animal became disoriented. Thus, the labrinthectomized animal did better than his normal control and the animal provided a perch did not display random behavior as did the one without foothold in the drum.

The results were promising, but ballistic rockets offered too short a period of weightlessness to justify further studies and the project was terminated with the above mentioned report which concluded that "the weight of evidence suggested that in currently attainable durations of two to three minutes, the subgravity state will not lead to any serious psycho-physiological difficulties. Investigation of the effects of subgravity states lasting for hours or days must await the development of orbital rockets." Since this event was still several years away, the group turned to other studies after sketching out the requirements for a long-term experiment using a mouse drum.[14]

Subsequent to this first group of V2 and Aerobee ballistic rocket studies, Russia has accomplished further work using dogs. In a review article by Galkin, et al,[15] results are presented from fourteen dogs, some alert and some anesthetized, which were submitted to dynamic weightlessness for a few minutes. The conclusion was drawn that, during weightlessness, the pulse rate and respiration of the alert animals were stimulated by the launch to high levels but decreased after the first two to three minutes of weightlessness and within four to five minutes had returned to their preflight levels. Significantly, in the anesthetized animals, pulse rate, respiration, and blood pressure did not differ during the period of weightlessness from their resting control values.

There were four American ballistic rocket flights of biological interest with a few minutes of weightlessness in the late 1950's. Two were with unanesthetized mice[16] and two with monkeys.[17] No performance data were obtained, but it was observed that the pulse and respiration rates approached prelaunch values during the weightless state.

Orbiting Flights other than the Mercury Series.—Workers in the USSR have successfully recorded data from at least six dogs in two 90-minute and four 24-hour orbital flights. In addition, they have reported the orbiting flight experiences of four men. How far do these hour-to-day-long flights go toward answering Gauer and Haber's questions?

Sisakyan[18] reviewed the data on the alert trained dogs and reported that following the emotional arousal of launch; pulse, respiration, and blood pressure settled to "normal values"; and, in ninety minutes, the pulse and respiration were "comparable to preflight data." During weightlessness, "all physiological functions approached the original level" and it was concluded that this "condition could be tolerated for as long as a day." A food and water supply was provided and body movements were monitored, both by actuation of a counter and by television.[19] Beischer[20] quotes the Russian investigators as observing that "no noticeable deviation in the condition and regulation of the main physiological functions from the usual level recorded under laboratory conditions occurred in the animals." However, in a recent article, Gazenko and Yadovsky do make a passing reference to "a certain unstability of the pulse rate and respiratory pattern suggesting a mild autonomic disturbance."[21]

The first human subject to be in orbit remained there for one and one-half hours. During this time, he reported no difficulties "in the sensory or motor sphere."[21] The second subject made several observations that relate to Gauer and Haber's original questions.[1] He described the usual sensation of tumbling at booster cutoff, prior to initiation of the weightlessness state. Despite this evidence of normal labyrinthine response, he reports no falling sensation during weightlessness. He had no difficulty with hand movements or the use of controls. He ate three meals successfully and slept, at first fitfully, then for several hours. He was able to perform exercises, write notes, and remain, according to his account, clear-headed and cognizant of his situation.[22]

However, after the sixth orbit, the subject reported "unpleasant" sensations of vestibular character which were felt stronger and stronger, especially when he sharply turned his head."[21] After some sleep, these symptoms decreased but did not disappear before the beginning of the "reentry overloads." It is further stated that "the sensation of some discomfort accompanied a considerable portion of the flight and resembled seasickness."[21]

In evaluating the severity of the symptoms, it is worth noting that, according to his account given to the press, the subject ate breakfast, considered shaving, discussed problems connected with reentry, and elected to parachute instead of staying with the capsule.[22] Nevertheless, the first subject's sensations raised interesting questions which, according to the accounts given to the press have had light thrown on them by the four and three-day orbiting flights of the Vostok 3 and 4. The reports from these flights describe the subjects' freedom from any symptoms, attributing this to a "new" "diversified" training program. It was stated that they had no nausea or other symptoms suggestive of motion sickness throughout these prolonged flights. Their condition at recovery was described as excellent and the pilot of Vostok 3 states that he "did everything during flight as though he was on the ground." The reports point to no major incapacitation by periods of weightlessness lasting up to four days.

Methods in the Mercury Flights.—The techniques employed to gather biological data during the Mercury flights have been described in the individual flight reports MR-2 and MA-5 (23), MR-3 (2), MR-4 (3), and MA-6 (4). To be considered are two animal and three manned flights. Three were ballistic firings, each yielding about six minutes of weightlessness (MR-2, 3 and 4) and two were orbital (MA-5 and 6), giving about 180 and 270 minutes, respectively. The first of the animal flights preceded the two manned ballistic shots and the other preceded the first manned U. S. orbital flight. Because the purpose of the animal flights was to verify the life support systems for the man, at attempt was made to use the same biosensors, and the animal couch was substituted for the pressure suit in the Mercury environmental control system.[23] The bioinstrumentation techniques employed are described in the individual flight reports[2-4,23] as well as in a special report by Wheelwright.[24]

Performance of the astronauts was determined by analysis of the voice records, by study of the onboard camera films, and by analysis of the manner in which the various tasks assigned them were accomplished. These included the working of the hydrogen peroxide jets controlling capsule attitude.[2-4] Behavior of the chimpanzee was assessed by means of operant behavior techniques. In the ballistic flight, a complex avoidance task, using two levers, was employed.[25] This consisted of the Sidman[26] avoidance procedure which required the subject to respond by pressing one lever continuously, or at least every fifteen seconds, to avoid an electric shock, and a discriminated avoidance task in which the animal was required to press a second lever within five seconds following presentations of a blue light, in order to prevent the occurrence of shock. This provided a measure similar to reaction time.

In the orbiting flight, a multiple schedule was employed which included three additional components:[27] a fixed ratio procedure in which the chimpanzee responded 50 times to obtain a pellet of food; a differential reinforcement of low rate procedure[28] which required the animal to pace his responses at least twenty seconds apart in order to obtain a water reward. An odd symbol discrimination task was used in which the animal selected the odd of three symbols (triangle, circle, square) (18 sets) displayed to the animal. Performance on the latter procedure was reinforced by shock.[29]

Results of the Mercury Flights.—Although the duration of weightlessness in the three ballistic flights (MR-2, 3 and 4) under consideration was only six minutes, this was already ten times as long as had been routinely achieved in aircraft weightless studies.

The animal data from the MR-2 flight showed his unimpaired efficiency.[23] Respiration rate returned to normal preflight values during weightlessness, after the rise which followed firing of the escape rocket at the end of the powered phase of flight. Heart rate followed the same pattern and returned towards normal resting values during the six minutes of weightlessness, as was described by the Russian workers.

Reactions to the four blue lights, presented during weightless flight, were all well within the preflight range. On the Sidman avoidance task, the subject responded at his normal rate of approximately once a second until at the 18g peak escape-loading acceleration, when he received a shock for failure to respond within the twenty second period. During the entire weightless state, his rate was normal, falling off only after the reentry acceleration. Postflight recovery examination revealed nothing that could be attributed to the weightless state.[23]

The human results suggested that pulse and respiration actually reverted towards normal during weightlessness. Performance was unaffected and control accuracy was unimpaired.[2,3]

Neither the human nor the animal data in the ballistic flights showed any impairment as a result of the weightless state.[3,23] What then of the animal and manned orbital flights? Does the longer duration of exposure lead to symptoms?

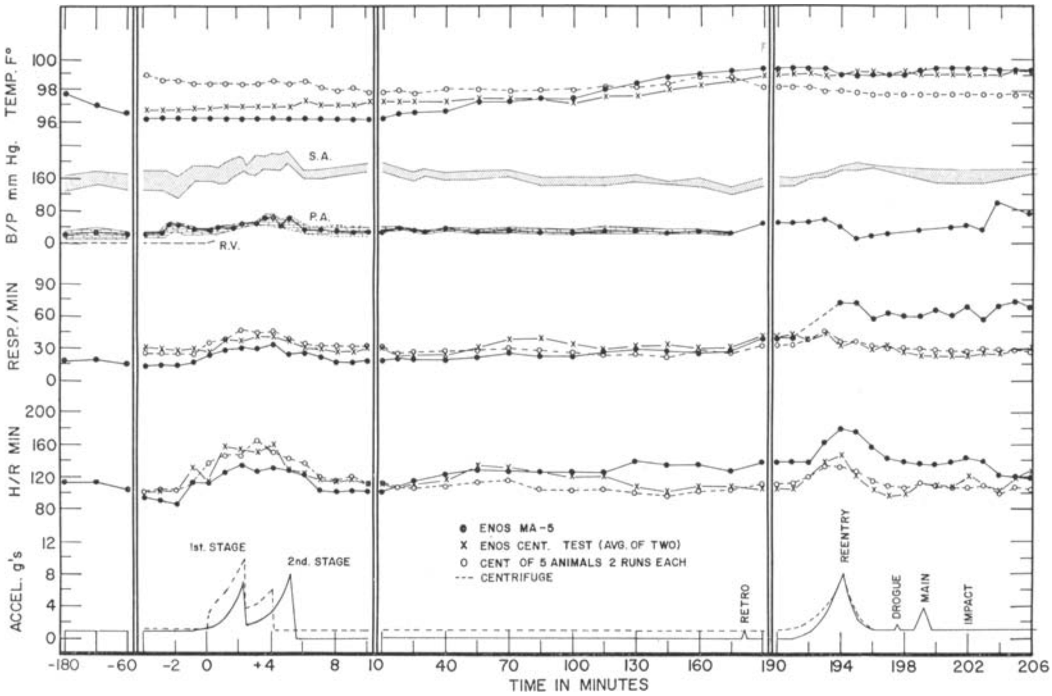


Fig. 2. Physiological data from the MA-5 chimpanzee flight. At the bottom: acceleration transverse to the subject in g's. Dotted lines represent centrifuge trials. The heart rate, in beats per minute, shows the parallelism of centrifuge and flight data. Respiration shows an increase during and after reentry, possibly due to the oscillation of the spacecraft. PA shows mean values (solid circles) and pulse pressure in the pulmonary artery. RV represents the pressure in the right ventricle during diastole which was obtained during countdown and, briefly, during flight. SA represents systemic arterial pressure as recorded by direct catheterization. Note high values during three hour control period prior to launch. Temperature during flight approximately parallels centrifuge experience.

Mercury Orbital Flight Data.—Figure 2 shows the cardiovascular and respiratory data obtained during the animal orbiting flight.[23] They are compared with control values determined on the centrifuge during simulated Atlas orbiting flights.

Body temperature remains well within acceptable limits, only reflecting moderate changes in inlet and capsule wall temperatures. Systemic arterial pressure is high in this animal, but this is a sustained high resting value as the three hours of on-the-pad record indicates. It rises further following launch but, with the three hours of weightlessness, falls back to prelaunch on-the-pad values. Further comparative studies have been made of this animal on the centrifuge. It appears to have developed vascular hypertension during the months preceding flight[23] and will be studied further. Pulmonary arterial pressure runs at slightly elevated values and is not changed by weightlessness.

Premature ventricular contractions occurred during orbiting flight. As is discussed by Henry and Mosely,[23] the presence in the right ventricle and orifice of the pulmonary artery of a fine polyethylene tubing, intended to measure thoracic inferior vena caval pressure, was probably responsible for these events, which were without effect upon the animal's performance.

Respiration rate is unchanged by weightlessness, but rises following reentry in comparison with centrifuge data. This rise may represent a response to apprehension engendered by the oscillations of the capsule during reentry and when on the descending parachute; these oscillations were not reproduced in the centrifuge runs.[4] Pulse rate, like respiration, is relatively unaffected during launch and the first hour of weightlessness.

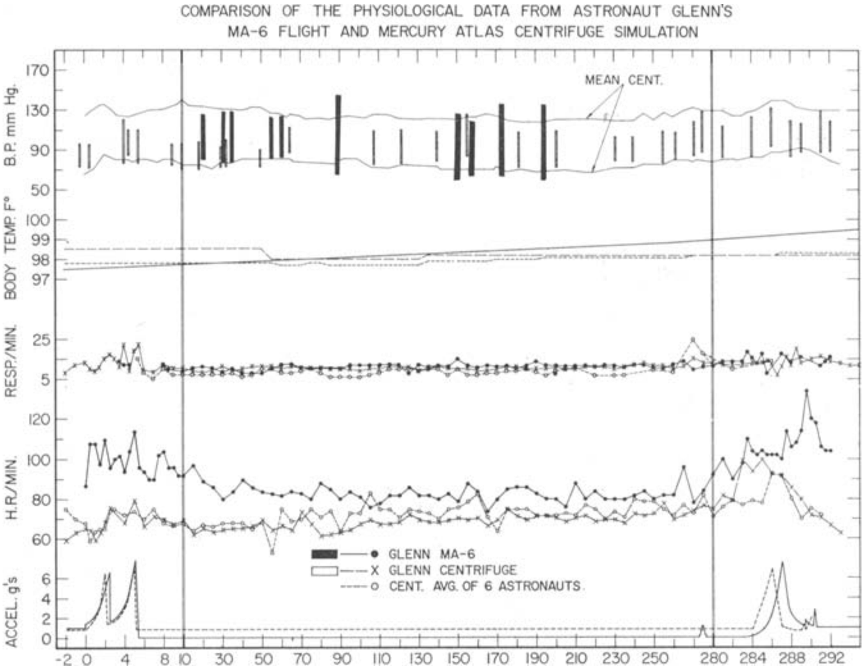


Fig. 3. Physiological data from the MA-6 flight. At bottom: acceleration transverse to the subject in g's. Dotted line represents centrifuge runs. The heart rate shows a return towards resting preflight values during weightless state. Respiration is unaffected by weightless state. Body temperature stays within normal values during flight (solid line). Blood pressure during the flight (solid bars) differs from centrifuge controls (open bars) showing a greater pulse pressure. Continuous lines represent mean of systolic and diastolic centrifuge blood pressure observations on six astronauts.

Figure 3 shows the comparable data from the manned orbital flight of MA-6.[4] The flight data are again contrasted with those from centrifuge studies in which the subject and other astronauts participated. Blood pressure, as measured with the autosphygmomanometer, is presented for the subject's centrifuge run by the open bar data and for the orbiting flight with a solid bar.[4] The mean systolic and diastolic values for the six astronauts tested on the centrifuge is represented by the continuous envelope. The rather large pulse pressure during orbiting flight is interesting, but not outside the range of normal physiological variation. It may in part represent a warming of the body with consequent vasodilation of the skin. Body temperature records are clearly within tolerable limits. Respiration is quite uneventful and the pulse rate, during the flight, shows the acceleration over control values that might be expected in view of the significance of the flight. It is interesting that the reentry acceleration does not lead to the highest pulse rate, as might have been expected if the prior four and one-half hours of weightlessness were having an adverse effect. Rather, the peak pulse rate is during the ensuing period of oscillation of the spacecraft on the drogue chute.

Performance of the animal during the orbital flight is shown in Figure 4 which summarizes the detailed reports of Rohles, Grunzke and Reynolds on the MA-5 flight.[23,30] The five components of the performance schedule are shown in relation to the accelerations of launch, the period of zero g, and the reentry acceleration.

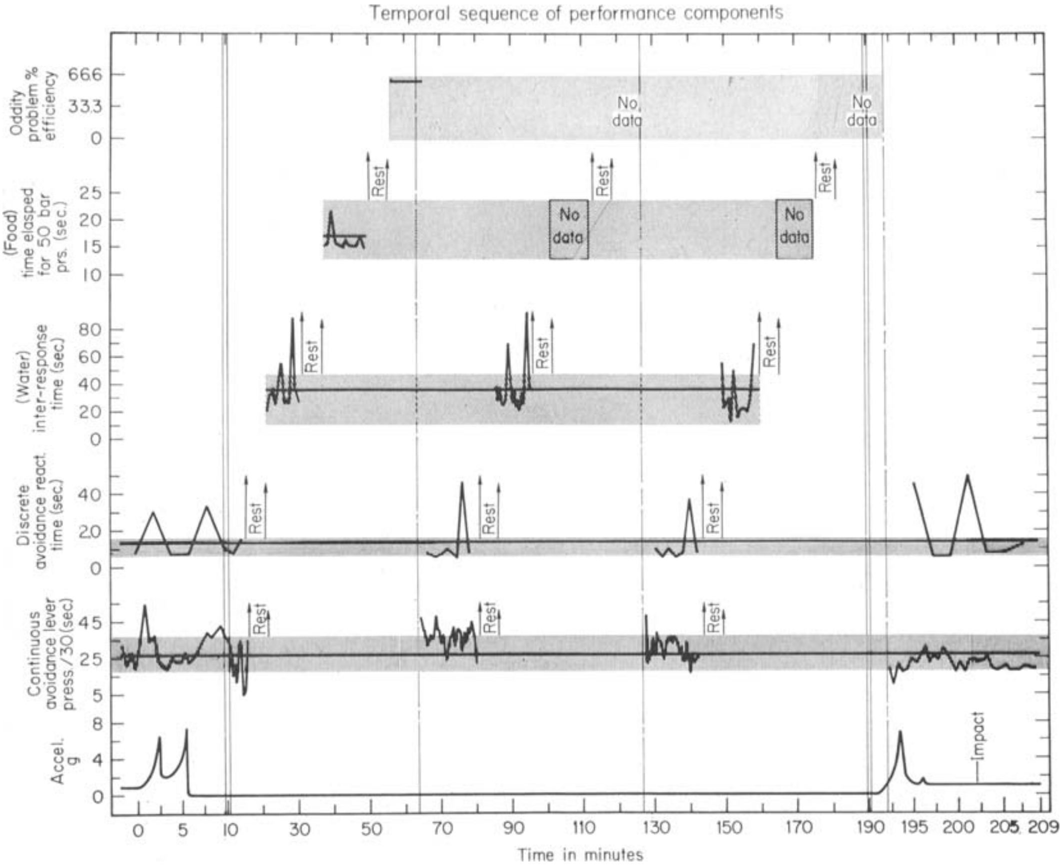


Fig. 4. Performance data obtained during MA-5 chimpanzee flight. At bottom: Acceleration transverse to the subject in g's. For each of the performance tasks indicated on the ordinate, the shaded bands indicate one standard deviation in each direction from the preflight mean. Transverse heavy line is arithmetic mean of flight performance. Time out periods are shown by two vertical arrows.

The sequence of presentation of each of the performance tasks is presented here, as well as "time out" or rest periods, indicated by the vertical arrows. The inflight mean (heavy horizontal line) is overlaid on the animals preflight performance. The shaded band represents one standard deviation on either side of the preflight mean and is based on many hundreds of measurements on this animal. It will be observed that the inflight mean falls within one standard deviation of the preflight mean, for all performance measures. The degree of control maintained over the animal is indicated by the absence of responding during "time out" periods.

With regard to the motivational status during flight, it can be stated that no major alterations in behavior occurred, whether the performance was reinforced by food, water, or aversive stimuli. It is also of interest that performance on schedules such as fixed ratio and DRL, in which the animals' own responses play a major role in maintaining the behavior, is not adversely affected by the weightless state in which proprioceptive and other internal stimuli are presumably altered.

Figure 5 shows the performance of the astronaut during the period of manual control systems check of the orbiting vehicle.[3] It is evident that he was performing within the standard attained in his previous experience with the simulator as represented by the shaded band.[4] The detailed flight report gives much additional evidence of the orbital astronaut's continued high level of performance, and his clear introspection revealed no subjective disturbance as a result of the weightless state. Thus, the voice reports were consistently accurate, confident, and coherent throughout the weightless state. The voice quality conveyed a sense of continued well-being. His prompt responses to ground transmissions and to sounds from the spacecraft indicated that he experienced no decrement in hearing ability. Visual acuity was maintained, and the fact that his reports of visual perceptions were accurate was confirmed by in-flight photographs.[4]

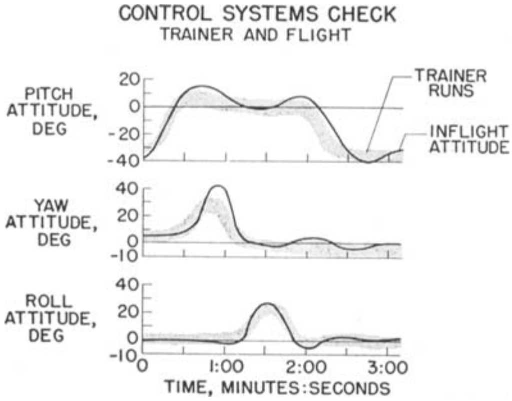


Fig. 5. Control systems check during the MA-6 flight. Solid line contrasts performance with mean of runs in the trainer (shaded bands).

The weightless state was associated with no disturbances in spatial orientation. Voluntary, rapid head-turning movements induced no unpleasant sensations suggestive of vestibular disturbance. This, despite the fact that the report of a brief sensation of tumbling forward occurring after sustainer engine cutoff and a feeling of backward acceleration with retrorocket firing, showed that his vestibular sensitivity was not abnormally depressed. Weightlessness did not disturb the act of food chewing and swallowing or micturition. Indeed, to the MA-6 astronaut, the four and one-half hours of weightlessness were described as a "pleasant" sensation and his physiological functions and performance during the period appeared to have been essentially undisturbed.[4]

The results of the MA-7 flight confirmed those of the MA-6. The subject experienced no ill effects from four and one-half hours of weightlessness. Indeed, he was relieved of the discomfort of the pressure suit. He experienced no nausea, ate and drank without difficulty and, in general, found the weightless aspects of the flight an enjoyable experience.[31]

DISCUSSION

Detailed comments on the significance of the Mercury Flight data available to date will be found in the individual flight reports.[2-4,23] When evaluating the results, consideration should be given to the fact that the primary objectives of the pioneering Mercury project were not those of scientific data collection. Furthermore, the closing remarks of Graybiel and his associates concerning the difficulties of this type of experiment are pertinent.[17] They comment on "the prodigious effort that went into the collection of relatively few data and the almost innumerable opportunities for human error and material failure." Taking these points into consideration, there is gratifying concordance between the results that were achieved and the data of other workers, both in the United States and Russia. There is also very satisfactory correlation between the performance information and the physiological data. This has often been missing in the past, even in experiments conducted under far more favorable circumstances.

It is important to recognize the potential limitations of the data from the Mercury studies due to the fact that they have been carried out in subjects that were firmly held in place and, consequently, had good spatial orientation and kinesthetic sense of their position. Furthermore, they were excellently oriented by visual sense being thoroughly familiar with the capsule interior and, in the case of the animal, with the pressurized couch. However, when combined with the work of the past fifteen years with humans and with animals, in parabolic aircraft flights[8-11] with water immersion tanks,[32-36] and with ballistic rockets,[13,20] the work with orbiting rockets has made it possible to frame a further interim answer to the questions raised by Gauer and Haber[1] and to say that no significant disturbance has occurred in properly oriented subjects subjected to the weightless state for periods up to hours. Indeed, the subjects of the Vostok III and IV appear to have practiced acts of fine hand-eye coordination such as threading a needle when floating detached in the spacecraft: it appears that orientation is feasible even when not firmly held into a seat.

Conceptual analysis of the weightless state has suggested several problems which may be encountered during and following a prolonged exposure to zero g which lasts longer than the periods that have, so far, been available to us. Answers are being found to these problems as the capability for prolonged flight rapidly develops. The first condition suspected is that of "space sickness" due to changes in utricular afferent information and to conflicting visual and proprioceptive stimulation. Whether problems of this nature will develop and whether adaptation will occur is currently receiving energetic attention.[37-39] The slow rotating room is being employed by Graybiel for investigating the Coriolis effect that arises when an attempt is made to replace gravity by radial acceleration.[38-41] Since acclimatization to labyrinthine disturbances due to wave motion occurs within a few days, it is reasonable to hope for a similar acclimatization to any disturbing influences of weightlessness. Reports of the three and four-day Russian flights support this thesis with their statement of freedom throughout from any symptoms such as nausea or loss of appetite.

Another question that has been raised is that of the possible "hypodynamic" effects of weightlessness on the circulatory system and the extent to which it may lower tolerance to subsequent reentry acceleration.[35,36] Disturbances of this nature would not occur immediately but would take several days. Hopefully, the effects will not differ significantly from those accompanying prolonged bed rest or the use of a water tank, but a major immediate objective should be to determine ways of preventing any deterioration by means, for example, of pressure cuffs on the limbs,[42] or pressure breathing. In actual flights, determination of the changes should be readily observable by using simple cardiovascular performance tests. However, the loss of blood volume and the changes of vascular reactivity that may accompany the weightless state would not necessarily lead to a significant disturbance in the tolerance of the transverse acceleration of reentry; for, in this condition, the hydrostatic columns are effectively in abeyance. The limiting condition is rather the blood distribution in the lungs. Here again the reports of the Vostok III and IV flights are of interest. It appears that reentry accelerations after three and four days of weightlessness were tolerated without loss of consciousness. Tolerance was attributed to preflight centrifuge training, regular in flight exercises and "special" exercises during the orbit just preceding reentry.

It has also been suggested that the digestive processes may become disturbed during the weightless state.[43] This certainly is an area of interest which must be followed closely. Tests of function of the gastrointestinal tract need not be elaborate in order to detect gross disturbances. It should only be necessary to be sure that all food given is eaten, to record symptoms such as malaise or loss of appetite, to follow nitrogen and inorganic ion balance, and the course of excretion of a marker pill such as carbon black and a non-metabolized sugar such as Xylose, in order to have reasonable clinical assurance whether this system has or has not functioned properly in the weightless state. It is significant that the Xylose absorption test carried out in the MA-6 flight showed normal results.[4] The available reports of the three and four-day Vostok flights support the briefer Mercury experiences. The Russians were reported as eating solid food at regular "mealtimes" throughout the flights without nausea or other digestive upset or loss of appetite.

As the duration of weightlessness extends from days to weeks, further questions concerning the effect of the prolonged condition upon the bones and muscles arise. As Lawton[44] points out, adequate exercise of the muscles should not only keep this system in tone but also, by the stimulating pull exerted on the bones, should prevent atrophy. Future studies carried out in prolonged flights will show whether this is indeed the case.

Another area of interest, in which it has been proposed that the weightless state might lead to disturbance, is the question of restful sleep and the diurnal rhythm that plays so large a part initiating it. The mechanisms of sleep have received much attention recently. The work of Jouvet[45,46] and Candia, Favale, Guissani and Rossi[47] suggests two fundamental phases: light sleep characterized by EEG synchronization, moderate muscular tonus and a resting waking blood pressure level; and rhombencephalic or "deep" sleep characterized by EEG desynchronization, complete muscular relaxation and a marked decrease of the blood pressure. There is evidence that dreaming occurs during "deep" sleep and that a certain amount of dreaming is important to the organism.[48] It would be of great interest to determine whether the weightless state in any way disturbs this sleep pattern and the diurnal rhythm associated with it. The statements in the press that the pilots of the last three Vostok flights "slept well in outer space" and on schedule for approximately seven hours each day "without disturbing dreams" suggests that for periods up to four days the weightless state does not grossly disturb this function.

While it would seem probable that weightlessness, per se, would not pose any threats to life, it may lead to subtle, or perhaps gross, changes in efficiency at the behavioral level. It is unknown whether there would be increased susceptibility in the weightless state to the sensory deprivation syndrome[40] were the subject left relatively unoccupied and, perhaps, floating for days or even months.[50] It is unlikely that man in space will, in the immediate future, be faced with situations in which there will not be the distraction of compelling tasks to prevent the development of symptoms. However, the development of behavioral techniques requires extensive study, not only for the prevention of symptoms, but for constructing an environment which will support optimum functioning and efficiency.

Hence, while not overlooking the possible disadvantages of zero gravity, it should be the aim of research, not so much to dwell on its deleterious effects nor merely to record the effects of passive exposure to it, but to design experiments in which our subjects interact with it so as to explore its unforeseen advantages—advantages which the first orbiting explorers have so vividly recounted.

SUMMARY

1. Data on weightlessness from work with aircraft and ballistic and orbiting rocket flights is briefly evaluated and described in relation to the results of the Mercury MR-2, 3, 4, MA-5, 6, and 7 flights. It is concluded that:

(a) A person firmly attached to his work place can carry out complex visual-motor coordination tasks proficiently for prolonged periods.

(b) Orientation is little problem if visual or tactile references are present.

(c) Respiration, digestion, eating and micturition appear to be unaffected by exposure to the weightless state for periods of hours to days.

(d) Weightlessness does not cause gross changes in the circulation within the course of a few hours and reentry has been tolerated after several days.

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The results presented in this report comprise a complex team effort that required, in addition to those cited as authors, the collaboration of a large number of people in the most varied branches of engineering and biological sciences.

Acknowledgment of some of those responsible is to be found in the technical documents describing the individual flights. It is only possible

to say that the unstinting cooperation of the entire group is remembered with appreciation as one of the most stimulating features of the Mercury project.

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