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EFFECTS OF WEIGHTLE[redacted]S ON MAN

DURING U. S. SUBORBITAL AND ORBITAL FLIGHTS

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Introduction

The major scientific objective of the NASA's Project Mercury was the investigation of man's capabilities to live and perform useful functions in a space environment and under conditions which he encounters during his entry into and return from space. The environmental conditions of particular interest were weightlessness and the accelerations associated with liftoff, flight, and reentry. A wealth of information has been gained through two suborbital and four orbital manned flights, which were conducted during a 24-month period from May 5 1961, to May 1963. (References 2, 3, 14, 15, 22-27, 29, and 32) Since weightless periods of very different durations occurred, the results attained are arranged and analyzed accordingly in this study. Moreover, an attempt will be made to extrapolate the effects of longer periods of weightlessness from these data. This will be based on a comparison of personal experiences, performance, as well as on changes in vital signs, blood and urine chemistry, and serum and plasma enzymes, which were associated with weightlessness.

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Suborbital Flights, MR-3 and MR-4

The flight profile of the MR-3 and MR-4 spacecraft is shown in Fig. 1. The duration of the weightless periods was about 5 minutes, starting with spacecraft separation and terminating with the onset of reentry G forces. The weightless condition was briefly interrupted by a 23-second period of retrofire, when an acceleration of about 1 g was produced. Launch accelerations of approximately 6 g preceded, and decelerations of about 11 g at reentry followed the period of weightlessness. Two short accelerations of about 4 g and 12 g with rates of onset less than 200 G per second occurred during main chute deployment and impact, respectively. The cabin was pressurized at about 5.5 psia. Inflight physiologic measurements concerned heart rate, EKG, respiration, and rectal temperature.

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Personal experiences. Personal experiences of test subjects proved to be valuable criterion measures for the assessment of weightlessness effects in previous experiments. (Reference 4) In the Mercury suborbital flights, both pilots experienced about the same sensations during weightlessness; and they had to make a special effort to notice the weightless condition. Astronaut Shepard reported as follows: "I said to myself, 'Well, O.K., you've been weightless for a minute or two, and somebody is going to ask you what it feels like'. . . In other words, I wasn't disturbed at all by the fact that I was weightless. I noticed a little bit of dust flying around, and there was one washer over my left eye. . . I was not uncomfortable and I didn't feel like my performance was degraded in any way. No problem at all." (Reference 22)

Astronaut Grissom noticed a brief tumbling sensation at launch vehicle cutoff. Thereafter, the absence of gravity produced no specifically recognized symptoms. No disturbances in well-being or abnormalities of sensation, thought or intellectual functions were noted. Movements, speech, and hearing were unaffected by weightlessness, and the entire sensation was similar to floating. Hence, both pilots were able to operate the complex vehicle without reduction in performance.

Special senses. Special senses, that is, vision, hearing, and vestibular functions, appeared to be intact throughout the flight. Near, distant and color vision were normal. Vivid contrasting color was reported during observation of sky and earth. Hearing was adequate according to pilot report and voice communication. Both astronauts were able to discern angular accelerations during spacecraft turnaround as well as linear accelerations in flight; but they did not think that they could feel the accelerations produced in controlling the spacecraft. Neither pilot became disorientated.

Vital signs. A comparison of the vital signs of the astronauts is given in the Appendix, Table I. In addition to inflight measurements, the data obtained immediately before and after the exposure were used in this and the following tables. While body weight decreased, body temperature and pulse rate showed a considerable increase. In both cases, the pulse

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rates climbed during launch to relatively high values, were sustained for about one minute, and then declined during the early part of weightlessness. By and large, pulse rates in the weightless period were somewhat elevated and erratic. Respiration rate followed a similar pattern. Astronaut Shepard maintained a breathing rate at a range from 15 to 20 breaths per minute during countdown. A peak of 40 occurred during launch, and it declined to 20 near the end of the weightless period. Unfortunately, the MR-4 respiration sensor did not work during flight. It was during the weightless phase that the pilot was most active, manipulating the spacecraft's attitude control system and making external observations. With the exception of occasional sinus tachycardia and arrhythmia (Grissom), the electrocardiograms displayed no irregularities of rate or wave form.

Biochemistry. Laboratory studies prior to and after the flights concerned urine, blood and enzyme analyses. Their results are shown in the Appendix, Tables II to V. There were increases in calcium (Tables II and III), glucose, norepinephrine (Table III), white blood cells (Table IV), and peptidase, aldolase and isomerase (Table V). The changes in biochemical reaction were almost identical to those observed in centrifuge runs and procedure training exercises on the ground. (Reference 23) The clinical and laboratory tests revealed no significant differences from the normal values; and the functional changes consistent with general stress and fatigue effects were small and within the expected range.

Summary. Physiologic and psychologic responses to 15 min. of suborbital flight were normal. Five minutes of weightlessness (interrupted by 23 seconds of retrofire) did not seem to have caused any specific reaction. Acceleration-weightlessness transition produced physiological responses within the limits of intact functions. It is concluded that the changes in response were caused by the emotional and acceleration stresses rather than by the relatively short periods of weightlessness.

Orbital Flights, MA-6 and MA-7

The two manned orbital flights, MA-6 and MA-7, extended the periods of weightlessness to about 4½ hours. Hence, the immediate effects of zero-G was studied in greater details by inflight experiments. The biosensors used to monitor the physiological state of the pilots were essentially the same as those used in the suborbital flights, but a blood-pressure measuring system (BPMS) was added. The accelerations during powered flight varied from 1 g to 6.7 g in 2 minutes and 10 seconds (booster-engine cutoff), and from 1.4 g to 7.7 g in the following 2 minutes and 52 seconds (sustainer-engine cutoff). Maximum accelerations of 7.7 g were generated at reentry with a gradual buildup and return to 1 g over a period of 3 minutes and 30 seconds. Main chute deployment and impact produced about the same forces as experienced in suborbital flights. Cabin and suit pressure levels were stable at approximately 5.7 and 5.8 psia, but suit inlet temperature increased slightly and caused overheating and dehydration of the pilots. (References 24 and 25)

Personal experiences. Both astronauts reported that the weightless state was pleasant and, in several respects, easier to bear than the 1-G condition (Carpenter: "A blessing--nothing more, nothing less," (Reference 25)). Zero-G facilitated the sitting in the spacecraft since there were no pressure points, and the use of the camera and feeding tubes because they had no weight and could be left hanging in the air when not needed. The men adapted very rapidly to weightlessness and they soon took advantage of the situation. They were always oriented with respect to the earth. There was no over-reaching or lack of coordination. The somatic sensations were normal, eating and drinking were accomplished without difficulties, and taste and smell sensations were undisturbed. Deceleration at retrofire was experienced by Glenn as "moving back to Hawaii," by Carpenter as a stop. The reentry acceleration was as expected and similar to that experienced in centrifuge runs. There had been some questions as to whether the tolerance to the reentry stress might be reduced after the exposure to weightlessness, but the astronauts noted no difference between their experience on the flight and on the centrifuge.

Special senses. Both pilots reported normal visual functions during weightlessness. Two small eye charts were attached to the instrument panel with letters of decreasing size and with a "spoked wheel" pattern to check visual acuity and astigmatism. No change from normal was apparent. The astronauts were able to track the sustainer stage without difficulty. In a special experiment on depth and color vision, Carpenter described correctly the distance, color, and brightness of the objects and encountered no disturbances other than failure of equipment. Using only eye movements, Astronaut Glenn tracked a rapidly moving light spot generated by the finger-tip lights. He had no difficulties during this task and no sensations of dizziness or nausea. Hearing was unaffected by weightlessness.

A brief tumbling sensation forward was reported by Glenn just after SECO. This sensation ended promptly and was not associated with vertigo. No disturbances in spatial orientation were reported, nor were any symptoms suggestive of vestibular disturbances described by either pilot. The effects of head rotation in zero-G were investigated: Rapid head movements in the three geometrical planes produced no sensations of dizziness. Moreover, oculogyral tests were made in which turning rates of the spacecraft were related to subjective sensations and eye movement photographs. The results were of the same order as those obtained during preflight tests. (Reference 12) Modified caloric and equilibrium tests administered before and after the flight showed no significant variations on either of the two astronauts. (Reference 12)

Vital signs. Biomedical data obtained by the MA-6 and MA-7 flights are also summarized in the Appendix. If we compare preflight values with inflight and postflight data, we find that body weight decreased, whereas body temperature, pulse rate, and probably pulse pressure showed an increase (Table VI). During reentry acceleration and parachute descent, heart rate and respiration were elevated within acceptable physiological limits. To provide data on cardiovascular response, the MA-6 pilot exercised by pulling on a bungee cord once per second for 30 seconds. As a result, pulse rate increased from 80 per minute to 124 per minute but returned to 84 per minute within 2 minutes. The blood pressure was 129/76 before and 129/74 after exercise. This response is within the previously observed values in the procedures trainer. Generally, heart rate showed a return trend toward resting preflight values with increasing exposure to weightlessness while respiration was unaffected.

Biomedical observations. Inflight experiments concerned the reactions of the gastro-intestinal functions. Food chewing and swallowing were accomplished with ease. Intestinal absorption tests using xylose excretion rates yielded normal results in the MA-6 flight. Bladder sensation and function while weightless were normal, and the pilots urinated without difficulty shortly before reentry. The acceleration-weightlessness transition periods did not produce any recognized physiological deteriorations. Specifically, reentry acceleration after $4\frac{1}{2}$ hours of weightlessness did not produce any unexpected symptoms, and the physiological data remained within functional limits. Audiogram, EEG, EKG, chest X-rays, equilibrium, neuromuscular coordination, and mental status of the two men were entirely normal after flight.

Biochemistry. In the first three flights, a number of enzymes were studied to evaluate variations of muscle or liver activity resulting from the biodynamic changes or from the prolonged semi-immobilization of the astronaut. Since neither the MR-3, MR-4, nor the MA-6 pilot showed significant changes in transaminase or aldolase activity, the number of tests was reduced in the MA-7 flight. Of the dehydrogenases examined none has shown any consistent change. In the MA-6 flight, the lactic acid level was increased, but a decrease was observed in the MA-7 flight. The only biochemical changes consistent with those of the previous data are the decrements in the pH level and specific gravity of urine (Table VII), sodium and urea nitrogen in the blood (Table VIII), and neutrophiles (Table IX). Consistent increments were found in hemoglobin, and white blood cells (Table IX), phosphohexose isomerase and probably lactic dehydrogenase (Table X). There was a slight lowering of blood calcium, but the potassium values were stable. Since the calcium excretion data are contradictary for the two men, it has been suggested that the decrease in blood calcium is not indicative of a general calcium mobilization. (Reference 25)

Summary. A review of the detailed biomedical examinations of the MA-6 and MA-7 pilots who each experienced approximately $4\frac{1}{2}$ hours of weightlessness reveals neither psychological, physiological or biochemical evidence of any detrimental effect. As demonstrated by the numerous inflight reports, task performance, and onboard film as well as by the various laboratory tests, the mental, emotional, physical and psychomotor responses were consistently appropriate. Psychiatrically, before, during and after the flight, both astronauts exhibited entirely normal behavior.

Orbital Flights, MA-8 and MA-9

The orbital flights MA-8 and MA-9 are of particular importance, since the periods of weightlessness constituted by far the major parts of the entire operation including preflight preparations and recovery. In the MA-8 flight, a weightless period of about 9 hours was obtained, the MA-9 pilot experienced more than 34 hours of zero-G. The biomedical instrumentation was the same as used in the previous orbital flights, but body temperature was recorded orally in the MA-9 flight at certain intervals. Biomedical measurements were taken during the entire flight period, of which the first hour and 35 minutes and the last few hours were recorded continuously. Recording of physiological data through the midportion of the flight was intermittent and arbitrary.

Personal experiences. The astronauts rapidly adjusted to weightlessness and described it as pleasant and relaxing. Although sensations of floating, drifting and traveling upsidedown were occasionally experienced, orientation was maintained throughout the flights. After the proper visual perspective was established, the changing views from the capsule were not disturbing and the random orientation was of no concern. No nausea or vomiting occurred in either flight. Eating, drinking, sleeping and dreaming were normal. The assigned inflight tasks were performed without difficulty and hampered only by engineering flaws. During both missions, the men monitored the spacecraft systems, reported accurately and clearly on the status of their systems, and took over the control of the craft when this was required. Subjectively, the astronauts could tell little difference between the work performed under 1-G and under zero-G; the effort of zero-G being, if anything, slightly easier. This included the calibrated physical exercises. The accelerations produced by retrofire, reentry, parachute opening, and impact were less severe than expected and very well tolerated. (Reference 26)

Special senses. As was the case in the previous flights, vision, hearing, and vestibular functions were normal. Details of ground features, such as villages, fields, roads, houses, and smoke from chimneys, were reported which were thought to be far beyond the resolution of the human eye. Since other visual tests (balloon and flashing light experiments) indicated normal visual functions, a magnifying effect of the clear atmosphere, when looking through it from satellite altitudes, cannot be excluded. There were no mental aberrations or hallucinations. Head movements had no effect on well-being or orientational ability. A pointing test during flight as well as modified caloric tests and retinal photography after flight revealed no significant changes from preflight results.

Vital signs. The physiological data are summarized in the Appendix, Tables XI to XV. There was a pronounced increase in heart rate (pulse) particularly during launch and the calibrated work periods; but it fell to a resting rate during weightlessness and below this level during sleep. Respiration was also elevated during launch and the initial period of weightlessness but declined and showed occasional elevations mostly due to emotional excitations. The mean inflight heart rates were slightly higher and the respiration rates slightly lower than the corresponding preflight values. Systolic blood pressure increased during weightlessness and fell below normal values during the postflight phase. Diastolic blood pressure data are inconsistent, but pulse pressure was high in the weightless state, (Table XI). Reentry, although assisted (MA-8) or accomplished (MA-9) by manual control, was physiologically uneventful. However, an orthostatic rise in heart rate accompanied by a drastic fall in blood pressure was observed shortly after landing. Both astronauts felt "light headed" upon egress from the capsule, and Schirra's feet were swollen and reddish-purple particularly during standing.

Biomedical observations. The EKG's were characterized by slight variations of R-wave to R-wave intervals which were greater than that caused by sinus arrhythmia and unrelated to physical activity (MA-8), and a "wandering pacemaker" (MA-9). The reasons for these changes are unknown. Eating, drinking, digestion, and urination were normal. At no time did the pilots have any nausea, vomiting or gastro-intestinal problems. The only real discomfort was associated with the pressure suit. Painful and slightly swollen red areas developed over each patella, which were caused by the suit when the knees were flexed. These symptoms persisted for several days after the longest flight. There was no evidence of abnormal mental or emotional responses to weightlessness for the duration of these missions.

Biochemistry. Marked increases in response concern K, Ca, and Cl (Tables XII and XIII), hematocrit, white blood cells, neutrophiles (Table XIV), and some of the dehydrogenases (Table XV). Consistent decreases were noted in urine pH-level, Cl and Na (Table XII), lymphocytes (Table XIV), phosphohexose isomerase and leucylamino peptidase (Table XVI). A comparison of the hormonal responses of the MA-8 and MA-9 pilots is not possible because of incomplete data.

Summary. Cardiovascular and respiratory functions during weightlessness and normal inflight activities were similar to those observed in the 1-G environment. Personal experience as well as objective performance criteria indicated the intactness of the human system. No significant changes were found in comprehensive preflight and postflight physical examinations and biochemical tests. The significance of the consistent changes in response and the orthostatic hypotension observed at the end of the mission warrant further discussion.

Discussion

The identification of weightlessness effects in the Project Mercury flights presents some difficulties because of the great difference in the duration of the zero-G periods, the small number of persons exposed to these conditions, and the multitude of factors involved which do not allow a statistical evaluation. Table 1 shows a time summary of the flight conditions including weightlessness. From this table it is evident that the effects of the weightless episode will play a more or less dominant role in the psychologic and physiologic response of the astronaut. It is also clear that the results of post-flight examinations may reflect the total amount of stress encountered during flight, and in particular during reentry and landing, rather than the response to zero-G. This is especially true for the data obtained during and after the short flights. Thus, the MR-3 and MR-4 data may be biased more by the increases of G than by its decrease. In considering these difficulties, emphasis was placed on the evaluation of inflight criteria; and of the preflight and postflight data, only the measurements taken closest to the weightless period were used. Moreover, an inversion of results obtained in short and long flights was not considered as a contradiction but interpreted as a possible reversal of a trend from increased to decreased G-effects.

The personal experiences of the astronauts, information on sensory functions and performance criteria were not tabulated for this discussion since numerical data were scarce. However, these reports provide valid information because of the pilot's ability to observe the symptoms and to relate them to weightlessness by rationalization in situ. (References 5 and 19) This, of course, implies that the processes involved were not affected by weightlessness. The Mercury astronauts unanimously experienced weightlessness as a tolerable and even pleasant environmental condition. They have consistently demonstrated during flight that vision, hearing, taste, smell, and equilibrium were not disturbed by zero-G. Cognative and other mental functions, such as learning, thinking, reasoning, memorizing, writing, computing, communicating and navigating were efficiently performed. Finally, the men were not only able to maintain routine proficiency under weightless conditions but they also controlled their spacecraft properly during post-weightlessness accelerations at reentry and impact. Hence, there is enough reason to expect that normal mental, emotional, sensory and motor functions will be maintained during weightlessness regardless of duration of exposure.

In order to arrive at some conclusion about the effect of weightlessness on human physiology, a summary of the trends observed in the vital signs is given in Table 2. An inspection of this table shows a high degree of consistency in the physiologic response of the organism. However, we must add a word of caution, for consistency in the trend of a certain function must not necessarily be indicative of a specific zero-G effect, nor express any relationship to weightlessness at all. For example, body weight usually decreases as a consequence of physical stress; in contrast, weightlessness per se is a physically stressless condition. Body temperature increased through overheating of the pressure suit. Hence, neither body weight nor temperature responses can qualify as criteria of weightlessness despite (or better, because of) their consistent trends in the Mercury experiments.

Of particular interest is the consistency in cardiovascular responses. The increase in heart rates observed in the MR-3 and MR-4 pilots is most probably due to the stress and excitement of the space flight situation, but it may also be interpreted as a "weightlessness effect" during the longer exposures. There was also a consistent increase in systolic blood pressure and pulse pressure in these flights. Postflight tilting tests and Flack tests showed the presence of moderate orthostatic hypotension and tachycardia, but compensation was achieved without syncope.

It has been theorized that the removal of gravity will result in cardiac slowing and relaxation of peripheral vascular resistance. (References 6, 8, 18) A gradual decrease in both systolic and diastolic blood pressure was found during water-immersion induced hypodynamics. (References 9, 10, 13)

The discrepancy between these findings and the Mercury cardiovascular results are not resolved. It may be assumed that the combination of the various factors, such as recumbent position, excessive sweating, immobilization, and situational stress disturbed the circulatory reflex pattern of the astronaut causing the mild but consistent tachycardia and hypertension during flight. (Reference 7) The most noteworthy element of the physiological parameters observed during the weightless periods was the evidence which confirms the pilots' subjective experience of fairly strenuous activities throughout the major portions of the flight. During the period, when the astronauts were resting quietly or asleep, essentially no medical data were attained. In contrast, many of the recording periods caused or were associated with activity or excitement. Consequently, mean heart rate values for the duration of the entire flight are probably biased toward the high side of the true mean. Moreover, the range of the preflight data, in particular heart rates, is rather wide, which limits the establishment of an "abnormal range" of responses.

The respiration rate of the astronauts during weightlessness shows an inversion from the short to the longer flights. This is in agreement with a measured oxygen consumption of 18 liters per hour and a respiratory quotient of 0.83 for the longest coasting periods. Hence, the mean metabolic rate during prolonged weightlessness equaled that of a non-fasting man under resting and 1-G conditions.

The results of the urine and blood chemistry tests are listed in Tables 3 through 6. There seems to be a mobilization of the skeletal minerals in the MA-7 pilot, but for the other pilots the data are inconclusive, although there are indications of an increased urinary potassium excretion (Table 3). There is also a trace of hypercalcemia (Table 4) and peripheral blood changes, of which the increase in hematocrit and monocytes may be related to weightlessness (Table 5). Enzyme activity data are still inconclusive. The peripheral blood values including electrolytes reveal that blood calcium was maximal in the immediate postflight period but returned to the preflight levels in less than one day. Such changes are only suggestive because of their very low magnitude and may have resulted from a number of causes including dehydration, loss of weight, immobilization, situational stress, and laboratory variations. Postflight hypercalcuria never exceeded preflight variations under normal and stress conditions.

The consistent biomedical changes observed in the Mercury flights are listed in Table 7. Of the inflight data, only the changes in cardio-vascular and pulmonary functions and in potassium excretion may reflect weightlessness effects. Of the postflight data, the increases in white blood cells, hemoglobin, and phosphohexose isomerase seem to reflect a general stress response of the organism, but the changes in hematocrit, monocytes, and blood calcium may be closer related to weightlessness. Tilt studies of EKG responses after stress have clearly indicated that forced recumbency, inadequate food and water intake, loss of body weight, disturbances of the blood supply in the legs, and soaking of the skin create difficulties in interpreting these results. (References 16 and 17) It is well-known that immobility, stress, dehydration, and decreased blood volume can cause the same symptoms as were observed during the Mercury flights. (References 20, 21, 28, 32)

In order to assess the effects of weightlessness on reentry tolerance, the changes in heart rate and respiration rate during launch and reentry are compared in Table 8. The differences between the data obtained at peak accelerations of the two events and the preflight, countdown and inflight values are given in per cent and entered in columns 6, 7, 11 and 12 of this table. If the cardiac and pulmonary functions were affected by weightlessness, the values in columns 9, 11 and 12 should increase with increasing time of exposure. Moreover, a special "post-weightlessness acceleration effect" as described by von Beckh should manifest itself by larger values in these columns than in columns 4, 6 and 7. (References 29 and 31)

An inspection of Table 8 shows that the heart rates measured at launch exceeded those caused by peak reentry accelerations (column 4 vs. 9) although the latter accelerations were higher. This same relationship is ture not only for the preflight differences from the maxima (column 6 vs. 11), but also for the countdown versus inflight changes (column 7 vs. 12), which are based on the cardiac rates measured during weightlessness. The highest values were obtained during drogue chute deployment, descent, retrofire, and orbital insertion (column 13). These figures reflect the combined effects of physical and emotional stress. The respiration rates and their percentage increments do not show this consistency. This can be explained by the fact that the pilots often hold their breath to counteract high acceleration stress, thus reversing the respiration rates. How much weightlessness contributed to the changes in cardiac and pulmonary response is still a moot question.

Finally, the percentage differences between inflight heart and respiration rates and their maxima during reentry seem to increase with increasing flight duration (see column 12). Although this correlation is not well established yet and seems to be less pronounced with longer exposure times, its physiologic implications demand serious consideration for longer space flights.

Conclusions

The data obtained from Project Mercury were analyzed with regard to the effects of weightlessness on man. The following conclusions can be drawn:

1. Weightlessness does not seem to have any psychological effects on man. Operational and experimental performance were maintained on the highest level through all phases of the missions.
2. Consistent trends of response changes during the flights were best reflected by the vital signs. Cardiovascular, pulmonary, and metabolic changes were found which may be associated with weightlessness.
3. A mild mineral mobilization resulted in increments of urinary potassium excretion and hypercalcemia.

4. Consistent changes in blood chemistry concerned increments in white blood cells, hemoglobin, hematocrit, and monocytes. The pH-level of the blood decreased.
5. Serum and plasma enzyme pre- and postflight tests yielded inconclusive results in most cases.
6. A correlation between duration of weightlessness and response change of cardiac and respiration rates during reentry stress seems to exist.
7. Orthostatic hypotension and orthostatic tachycardia were observed after the longest flights.
8. All of the response changes observed during or after the flights can be interpreted as symptoms of physical, psychological and situational stress caused by a variety of factors including or regardless of weightlessness. (References 1, 11, 29, and 21)
9. All abnormalities attributed to weightlessness during the Mercury flights were well within the tolerance limits of the human organism. There are no psychological or physiological contra-indications to embarking on longer spaceflight missions. (Reference 26) The factors, which caused the adverse effects observed during the two longest flights (i.e. orthostatic hypotension and increase of reaction to reentry stress), must now be investigated in a more appropriate and systematic manner. This can best be done in a manned earth-orbiting laboratory.

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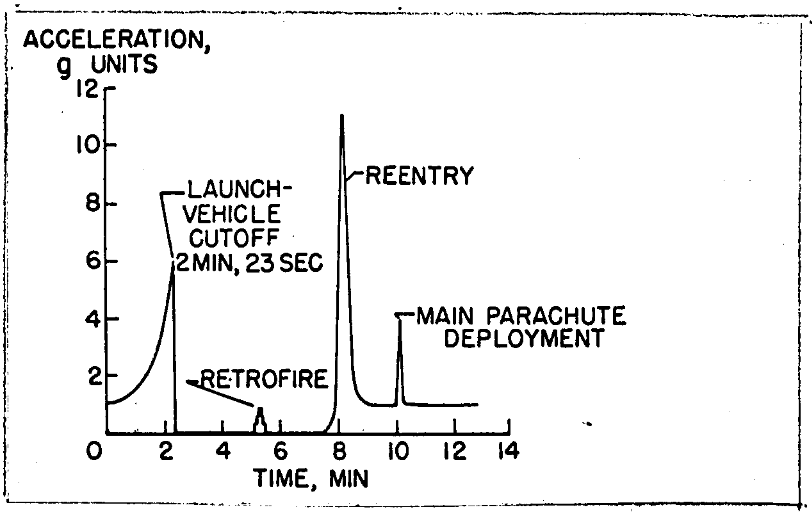

Figure 1: Acceleration-Time History
of MR-3 and MR-4 Flights

TABLE 1

TIME SUMMARY OF VARIOUS ACTIVITIES AND
DURATIONS OF WEIGHTLESS PERIOD

Flight	Preflight preparations	Weightlessness	Reentry & recovery	Total
MR-3	8 hours	5 min.	1 hour	9 hours
MR-4	8 hours	5 min.	2 hours	10 hours
MA-6	7 hr 30 min.	$4\frac{1}{2}$ hr.	40 min.	11 hr 10 min
MA-7	6 hr 30 min.	$4\frac{1}{2}$ hr.	4 hr 10 min.	14 hr 30 min
MA-8	5 hr 35 min.	9 hours	40 min.	15 hr 15 min
MA-9	4 hr 10 min.	34 hours	40 min.	38 hr 50 min

TABLE 2

VITAL SIGNS*

	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Remarks
Body weight	-	-	-	-	-	-	Decrease
Body temperature	+	+	+	+	+	+	Increase
Pulse (heart rate)	+	+	+	+	+	+	Increase
Respiration rate	+	+	-	+	-	-	Decrease
Systolic pressure	+	-	+	?	+	+	Increase
Diastolic pressure	+	+	-	?	-	+	Inconsistent
Pulse pressure	+	-	+	?	+	+	Increase

* + Increase
- \- Decrease
- 0 No change
- ? No data available

TABLE 3

RESULTS OF URINE TESTS*

	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Remarks
Specific gravity	-	-	-	-	0	0	Inconsistent
Albumin	0	0	0	Trace	0	0	No change (?)
Glucose	0	0	0	0	0	0	No change
Ketones	0	0	0	0	0	0	No change
Bile	0	0	0	0	?	?	No change
pH	0	-	-	-	-	0	Decrease
Na	+	-	-	+	-	?	Inconsistent
K	-	-	-	+	+	?	Increase
Ca	+	?	-	+	-	?	Inconsistent
Cl	-	+	-	+	-	?	Inconsistent

* + Increase
- Decrease
0 No change
? No data available

TABLE 4

BLOOD CHEMISTRY*

	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Remarks
Na (serum)	0	-	-	-	-	+	Inconsistent
K (serum)	+	-	-	+	+	0	Inconsistent
Ca (serum)	+	?	0	-	+	+	Increase (?)
Cl (serum)	+	-	+	-	+	0	Inconsistent
Proteine (total)	+	-	+	-	0	-	Inconsistent
Albumin (serum)	0	+	0	-	?	?	Inconsistent
Alb/Glob (serum)	+	-	-	-	?	?	Inconsistent
N urea (serum)	-	?	-	?	?	?	Inconclusive
Glucose	?	+	-	?	?	?	Inconsistent
Epinephrine	0	0	0	0	?	?	Inconclusive
Norepinephrine	+	+	?	?	?	?	Inconclusive
P	?	?	?	?	?	+	Inconclusive

* + Increase
- \- Decrease
- 0 No change
- ? No data

TABLE 5

PERIPHERAL BLOOD TESTS*

	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Remarks
Hematocrit	-	-	+	+	+	+	Increase
Hemoglobin	+	+	+	+	?	+	Increase
WBC	+	+	+	+	+	+	Increase
RBC	-	0	-	+	?	+	Increase (?)
Lymphocytes	+	-	+	+	-	-	Decrease (?)
Neutrophiles	-	+	-	-	+	+	Increase (?)
Band	0	?	?	?	?	?	No change
Monocytes	-	-	0	+	+	+	Increase
Eosinophiles	-	+	+	+	+	-	Increase (?)
Basophiles	0	-	-	+	0	0	Inconsistent

* + Increase
- Decrease
0 No change
? No data available

TABLE 6

SERUM AND PLASMA ENZYME TESTS*

	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Remarks
Lactic acid	?	?	+	-	?	?	Inconsistent
Phosphohexose isom.	+	+	+	+	-	?	Increase (?)
Leucylamino peptid.	+	+	-	+	-	?	Inconsistent
Lactic dehydrogenase							
Incubated: 20°-25°	?	?	?	+	-	?	Inconsistent
Incubated: 30°	?	?	?	+	?	?	Increase (?)
Heat stable	?	?	-	+	+	?	Increase (?)
Heat stable: %	?	?	-	0	+	?	Inconsistent
Urea stable	?	?	?	+	?	?	Increase (?)
Urea stable: %	?	?	?	+	?	?	Increase (?)
Cholesterol: total	?	?	?	?	+	?	Increase (?)
Cholesterol esters: %	?	?	?	?	+	?	Increase (?)
Malic dehydrogenase	-	+	?	?	+	?	Inconsistent

* + Increase
- Decrease
0 No change
? No data available

TABLE 7

CONSISTENT BIOMEDICAL CHANGES*

	Index	MR-3	MR-4	MA-6	MA-7	MA-8	MA-9	Result
Inflight	Body temperature	+	+	+	+	+	+	Increase
	Heart rate	+	+	+	+	+	+	Increase
	Systolic blood pr.	?	?	+	?	+	+	Increase
	Pulse pressure	?	?	+	?	+	+	Increase
	Potassium (urine)	?	?	-	+	+	?	Increase (?)
	Respiration rate	+	+	-	+	-	-	Decrease
	pH - level	?	?	-	-	-	?	Decrease
Postflight	White blood cells	+	+	+	+	+	+	Increase
	Hemoglobin	+	+	+	+	?	+	Increase
	Hematocrit	-	-	+	+	+	+	Increase
	Monocytes	-	-	0	+	+	+	Increase
	Calcium (serum)	+	?	0	-	+	+	Increase
	Isomerase (phosphohexose)	+	+	+	+	-	?	Increase
	Body weight	-	-	-	-	-	-	Decrease

* + Increase
- \- Decrease
- ? No data available
- 0 No change

TABLE 8: COMPARISON OF CARDIOVASCULAR AND PULMINARY DIFFERENCES BETWEEN ACCELERATION STRESS AT LAUNCH AND AT REENTRY.

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Flight	Preflight values	Count-down	Max.at launch	Δg	ΔPreflight m %[1]	ΔCount-down %[2]	Inflight	Maxim.at reentry	Δg	ΔPreflight in %[3]	ΔInflight %[4]	Maximum values
Heart Rate	MR-3	68	80	138	5	104	72.5	108	132	12	79.5	22.2	
	MR-4	68	96	168	5	149.5	74.9	150	163	12	139	8.6	(171)[xx]; (173)[x]
	MA-6	68	70	114	6.7	65.8	63.0	86	109	7.7	60.2	26.7	(134)[x]
	MA-7	57	62	96	6.7	50.9	54.8	70	84	7.7	47.4	20.0	(104)[x]
	MA-8	64	72	112	6.7	89.2	68	76	104	7.6	62.5	36.8	(121)[xxx]
	MA-9	72	73	154	6.7	114.	112.5	89	140	7.6	94.4	57.4	(184)[x]
Respiration Rate	MR-3	16	20	40	5	150	100	20	30	12	87.6	50	32.2
	MR-4	12	22	28	5	133.3	27.25	28	32	12	167	14.3	
	MA-6	14	16	-	6.7	-	-	12	19	7.7	35.7	58.3	47
	MA-7	15	15	20	6.7	33.3	33.3	14	19	7.7	26.7	35.7	(24)[x]
	MA-8	20	20	37	6.7	85.0	85.0	19	43	7.6	115	126.3	
	MA-9	19	16	30	6.7	57.9	87.6	15	28	7.6	47.4	86.6	

[1] difference between preflight values and maximum launch acceleration values in per cent

[2] difference between countdown values and maximum launch acceleration values in per cent

[3] difference between preflight values and maximum reentry acceleration values in per cent

[4] difference between inflight values and maximum reentry acceleration values in per cent

[x] values during drogue chute deployment and descent

[xx] values during retrofire

[xxx] values during insertion

APPENDIX

BIOMEDICAL DATA SUMMARY

TABLE I

VITAL SIGNS

	Preflight		Inflight		Postflight		Change in Response
	MR-3	MR-4	MR-3	MR-4	MR-3	MR-4	
Body weight, lb.	169.3	150.7	-	-	167.3	147.2	Decrease
Body temperature, °F	99	97.8	99.2	99.2	100.2	100.4	Increase
Pulse per minute	68	68	108	150	100	160-104	Increase
Respiration per min.	16	12	20	-	-	32	Increase
Blood pressure, mmHg	120/78	128/75	-	-	130/84	120/85	Inconsistent
Pulse pressure, mmHg	42	53	-	-	46	35	Inconsistent

TABLE II

RESULTS OF URINE TESTS

	Preflight		Postflight		Changes in response
	MR-3	MR-4	MR-3	MR-4	
Sample vol., ml	100	135	400	110	-
Specific gravity	1.020	1.020	1.013	1.010	Decrease
Albumin	Neg.	Neg.	Neg.	Neg.	None
Glucose	Neg.	Neg.	Neg.	Neg.	None
Ketones	Neg.	Neg.	Neg.	Neg.	None
Occult blood	Neg.	Neg.	Neg.	Neg.	None
pH	6.6	6.6	6.6	6.4	Decrease
Na	137	142	178	70	Inconsistent
K	143	35	49	19	Decrease
Ca	1.4	-	5.2	-	Increase
Cl	203	55	87	130	Inconsistent
Microscopic check	Rare white blood cells		Occasional red and white blood cells		Inconsistent

TABLE III

BLOOD CHEMISTRY FINDINGS

	Preflight		Postflight		Changes in response
	MR-3	MR-4	MR-3	MR-4	
Sodium (serum), mEq/l	137	142	137	140	Decrease
Pottassium (serum), mEq/l	4.4	4.1	4.6	3.5	Inconsistent
Calcium (serum), mEq/l	4.7	-	5.4	-	Increase
Chlorine (serum), mEq/l	102	97	106	95	Inconsistent
Protein (total serum), gram/100ml	7.4	7.4	8.3	7.3	Inconsistent
Albumin (serum), gram/100ml	4.0	3.25	4.0	4.2	Increase
Globulin (serum), gram/100ml	3.4	4.15	4.3	3.1	Inconsistent
Urea nitrogen, mg/100ml	15.4	-	15.2	-	Decrease
Glucose, mg/100ml	-	94	-	136	Increase
Epinephrine (plasma), μg/l	0.0	0.1	0.0	0.1	None
Norepinephrine (plasma), μg/l	5.2	5.1	12.9	16.5	Increase

TABLE IV

PERIPHERAL BLOOD FINDINGS

	Preflight		Postflight		Changes in response
	MR-3	MR-4	MR-3	MR-4	
Hematocrit, per cent	45	42.5	40	42.2	Decrease
Hemoglobin, gram (Sahli)	13	14.1	13.5	14.4	Increase
White blood cells, per cc	6500	6500	9800	7200	Increase
Red blood cells, millions/cc	5.1	4.8	5.0	4.8	None
Differential blood count					
Lymphocytes, per cent	33	46	42	40	Inconsistent
Neutrophiles, per cent	56	46	51	54	Inconsistent
Monocytes, per cent	8	5	6	4	Decrease
Eosinophiles, per cent	3	1	1	2	Inconsistent
Basophiles, per cent	0	2	0	0	Decrease

TABLE V

SERUM AND PLASMA ENZYME TESTS

	Normal range, units	Preflight		Postflight		Changes in response
		MR-3	MR-4	MR-3	MR-4	
Transaminases:						
SGOT	0-35	23	19	22	21	Inconsistent
SGPT	0-20	0	6	6	6	Increase
Esterase acetylcholine	130-260	195	225	210	205	Inconsistent
peptidase leucylamino	100-310	360	370	415	375	Increase
Aldolase	50-150	28	6	38	13	Increase
Isomerase phosphohexose	10-20	5	42	15	86	Increase
Dehydrogenases:						
lactic	150-250	185	190	170	250	Inconsistent
malic	150-250	225	235	190	275	Inconsistent
succinic	Neg.	Neg.	Neg.	Neg.	Neg.	None
alpha-ketoglutaric	Neg.	Neg.	-	Neg.	-	None
isocytric	0-10	-	3	-	6	Increase
L-glutamic	0-10	-	11	-	3	Decrease
Alk phos		-	4	-	3	Decrease

TABLE VI

VITAL SIGNS

	Preflight		Inflight		Postflight		Changes in response
	MA-6	MA-7	MA-6	MA-7	MA-6	MA-7	
Body weight, lb.	171 7/16	154	-	-	166 2/16	148	Decrease
Body temperature, °F	98.2	97.4	98.7	99.9	99.2	97.6	Increase
Pulse per minute	68	60	86	70	76	78	Increase
Respiration per min.	14	12	12	14	14	-	Inconsistent
Blood pressure, mmHg	118/80	120/78	129/70	-	105/60	116/78	Inconsistent
Pulse pressure, mmHg	38	42	59	-	45	38	Increase

TABLE VII

RESULTS OF URINE TESTS

	Preflight		Inflight		Postflight		Changes in response
	MA-6	MA-7	MA-6	MA-7	MA-6	MA-7	
Volume, cc	135	250	800	2.360	295	155	---
Spec. gravity	1.019	1.015	1.016	1.003	1.024	1.013	Decrease
Albumin	Neg.	Neg.	Neg.	Trace	Neg.	30	Increase
Glucose	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	None
Ketones	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	None
Bile	-	Neg.	-	Neg.	-	Neg.	None
pH	6.2	6.0	6.0	5.0	6.0	5.0	Decrease
Na, mEq/l	225	20.1	157	85.6	103	45	Inconsistent
K, mEq/l	64	4.9	27	16.7	59	21	Inconsistent
Cl, mEq/l	223	13	152	88	100	51	Inconsistent
Ca, mEq/l	11.2	1.0	6.9	3.9	3.5	3.7	Inconsistent
Osmolarity	1010	179	613	313	599	295	Inconsistent

TABLE VIII

BLOOD CHEMISTRY FINDINGS

	Preflight		Postflight		Changes in response
	MA-6	MA-7	MA-6	MA-7	
Sodium (serum), mEq/l	160	141	146	137	Decrease
Pottassium (serum), mEq/l	4.6	4.0	3.9	4.4	Inconsistent
Calcium (serum), mEq/l	4.3	4.8	4.3	4.1	Decrease
Chlorine (serum), mEq/l	9.8	107	104	105	Inconsistent
Proteine (total serum), g/100 ml	6.6	6.9	6.9	6.4	Inconsistent
Albumin (serum), g/100 ml	3.8	3.6	3.8	3.2	Decrease
Albumin - Globulin ratio-(serum)	1.4	1.1	1.2	1.0	Decrease
Urea nitrogen (serum) mg/100 ml	15.5	-	10.5	-	Decrease
Glucose, mg/100 ml	109	-	(96)	-	Decrease
Epinephrine, plasma, μg/l	0.1	0.2	0.1	0.2	None
Norepinephrine, plasma, μg/l	18	-	-	6.3	Inconsistent

TABLE IX

PERIPHERAL BLOOD FINDINGS

	Preflight		Postflight		Changes in response
	MA-6	MA-7	MA-6	MA-7	
Hematocrit, per cent	39.5	42	46	50	Increase
Hemoglobin	14.1	13.8	16.1	16.0	Increase
White blood cells/cc	4,650	11,600	8,200	12,500	Increase
Red blood cells, millions/cc	4.96	(5.2)	4.82	5.6	Inconsistent
Differential blood count					
Lymphocytes, per cent	37	19	47	27	Increase
Neutrophiles, per cent	57	79	47	65	Decrease
Monocytes, per cent	3	1	3	3	Increase
Eosinophiles, per cent	1	1	2	4	Increase
Basophiles, per cent	2	0	1	1	Inconsistent

TABLE X

SERUM AND PLASMA ENZYME TESTS

	Preflight		Postflight		Changes in response
	MA-6	MA-7	MA-6	MA-7	
Lactic acid, mg	36	35	185	28	Inconsistent
Phosphohexose isomerase	0	7	24	20	Increase
Leucylamino peptidase	300	270	250	300	Inconsistent
Lactic dehydrogenase					
Incubated, 30°c	-	334	-	367	Increase
Incubated, 20° to 25°c	-	250	-	525	Increase
Heat stable	95	167	60	183	Inconsistent
Heat stable, per cent	39.6	50	19.7	50	Decrease
Urea stable	-	165	-	250	Increase
Urea stable, per cent	-	49	-	68	Increase

TABLE XI

VITAL SIGNS

	Preflight		Inflight		Postflight		Change in response
	MA-8	MA-9	MA-8	MA-9	MA-8	MA-9	
Body weight, lb.	176 3/4	147	-	-	172 1/4	139 1/4	Decrease
Body temperature, °F	97.6	97.4	98	99	99.4	99.4	Increase
Pulse per minute	64	72	76	89	82	77	Increase
Respiration per minute	20	19	19	15	-	16	Decrease
Blood pressure, mmHg	117/80	112/79	126/69	119/81	112/78	91/66	See text
Pulse pressure, mmHg	37	33	57	38	34	25	See text

TABLE XII

RESULTS OF URINE TESTS

	Preflight		Inflight		Postflight		Change in response
	MA-8	MA-9	MA-8	MA-9	MA-8	MA-9	
Volume, cc	-	-	292	-	233	-	-
Spec. gravity	1.010	1.025	1.010		1.018	1.019	Increase
pH	6.0	6.0	Acid	?	Acid	6.0	Decrease
Na, mEq/l	103	184	86	177	107	137	Decrease
K, mEq/l	47	68	49	51	58	70	Increase
Cl, mEq/l	127	212	106	185	103	150	Decrease
Ca, mEq/l	8.5	8.25	6.1	15.0	4.8	19.8	Increase*
Osmolarity	593	-	595	-	848	-	Increase

*Based on MA-9 data only

TABLE XIII

BLOOD CHEMISTRY FINDINGS

	Preflight		Postflight		Change in response
	MA-8	MA-9	MA-8	MA-9	
Sodium (serum), mEq/l	152	144	150	153	Inconsistent
Pottassium (serum), mEq/l	3.9	5.2	4.1	5.2	Increase
Calcium (serum), mEq/l	5.2	4.22	5.9	4.67	Increase
Chlorine (serum), mEq/l	102	104	108	104	Increase
Proteine (total sum), g/100ml	8.0	6.6	8.0	6.3	Decrease
Albumin (serum), g/100 ml	-	-	-	-	
Albumin/Globulin ratio (serum)	-	-	-	-	
Urea nitrogen (serum), mg/100ml	-	-	-	-	
Glucose, mg/100ml	-	-	-	-	
Epinephrine, plasma, μg/l	-	-	-	-	
Norepinephrine, plasma, μg/l	-	-	-	-	
Phosphorus mg/100ml	-	4.4	-	4.5	Increase

TABLE XIV

PERIPHERAL BLOOD FINDINGS

	Preflight		Postflight		Change in response
	MA-8	MA-9	MA-8	MA-9	
Hematocrit, per cent	44	43	47	49	Increase
Hemoglobin g/100ml	15	15.0	(14.5)	16.5	Inconsistent
White blood cells, per cc	9,800	6,500	(10,350)	9,200	Increase
Red blood cells, million/cc	5.0	4.79	(4.7)	4.80	Inconsistent
Differential blood count:					
Lymphocytes, per cent	34	36	(31)	20	Decrease
Neutrophiles, per cent	62	60	(63)	75	Increase
Monocytes, per cent	3	3	(4)	5	Increase
Eosinophiles, per cent	1	1	(2)	0	Inconsistent
Basophiles	0	0	(0)	0	None

TABLE XV

SERUM AND PLASMA ENZYME TESTS

	Preflight		Postflight		Change in response
	MA-8	MA-9	MA-8	MA-9	
ctic acid, mg	-		-		-
Phosphohexose isomerase	28		22		Decrease
Leucylamino peptidase	550		460		Decrease
Lactic dehydrogenase					
Incubated, 20° to 25°c	250		225		Decrease
Heat stable, 60°c	60		75		Increase
Heat stable, per cent	24		33		Increase
Malic dehydrogenase	275		325		Increase
Cholesterol, total, mg/100ml	225		290		Increase
Cholesterol esters, per cent	70		74		Increase