N76 12683

CHAPTER 8
APOLLO FLIGHT CREW VESTIBULAR ASSESSMENT

by

J.L. Homick, Ph.D.
Lyndon B. Johnson Space Center

Earl. F. Miller, II, Ph.D.
Naval Aerospace Medical Research Laboratory

Introduction

The human vestibular system consists of two types of specialized sensory receptors located in the inner ear. The semicircular canals are structured to respond primarily to angular accelerations of the head. The otolith organs, closely related to the canals both anatomically and functionally, are highly sensitive to linear accelerations and to changes in the direction of gravity acting on the head. These two receptor mechanisms together provide sensory information essential to the perception of body position and movement.

Results of physiological and anatomical studies have shown that afferent fibers from these receptors project to a number of areas of the brain and the spinal cord and can interact with or influence neural activity in those areas. Thus, the reticular system, the autonomic nervous system, the eye muscles, and the voluntary skeletal muscles can be affected either directly or indirectly by vestibular activity. In laboratory and field investigations, it has been well documented that excessive stimulation of the vestibular receptors can lead to a variety of behavioral and physiological disturbances ranging from decreased alertness, voluntary restriction of physical activity, oculomotor impairment, nausea and, in extreme cases, vomiting. Discrepancies among visual, vestibular, and tactile-kinesthetic spatial perceptions can lead to stressful sensory conflict, which can also cause disturbances ranging from disorientation to nausea and vomiting.

Because a highly unusual gravito-inertial stimulus environment is present in space flight, concern was expressed early in the United States manned space flight program about vestibular problems that might occur during flight, particularly motion sickness. For this reason, antimotion-sickness drugs were carried onboard the first manned Mercury spacecraft. The drugs provided were Tigan and Marezine, in both oral and injectable forms. However, no symptoms occurred and neither of these drugs was required. The early Mercury crewmen were also instructed to perform head movements cautiously and to reach to different areas in the spacecraft. Again, no problems were reported.

Like the Mercury flight series, the Gemini flights, including those involving extravehicular activity, were free of significant vestibular problems. Results of quantitative preflight, inflight, and postflight tests performed during the Gemini 5 and 7 missions indicated that lifting the gravitational load from the otolith organs did not result in any disturbance of the integrative processes of the central nervous system that might have influenced the crewmen's spatial orientation. Also, there were no significant differences between preflight and postflight measurements of ocular counterrolling (Graybiel et al., 1967). A phenomenon that occurred during the Gemini Program, and that has been reported routinely by American flight crews since that time, was a feeling of "fullness of the head" upon entering weightlessness. Some astronauts described this sensation as a feeling of "hanging upside down." As a result, the idea was quickly adopted that these men had experienced an inversion illusion or a spatial disorientation. On the basis of better descriptions from the crewmen involved, the investigators are reasonably certain that this phenomenon was not an inversion illusion, but the result of a redistribution of extravascular and intravascular fluids.

The Apollo Program included several significant changes from Project Mercury and the Gemini Program in the type of vehicle and the type of mission being flown. The Apollo Command Module (CM) had a considerably larger habitable volume than had either the Gemini or the Mercury spacecraft. Therefore, for the first time in the American space program, crewmen were able to move about freely within the spacecraft. Beginning with the Apollo 9 flight, the CM and the Lunar Module (LM) were docked in flight, and crewmen were able to move back and forth between two vehicles for the first time. Beginning with the Apollo 11 flight, the first lunar landing, crewmen made transitions from zero g in flight to activity in one-sixth g on the lunar surface and back to zero g. With these changes, particularly the greater mobility permitted by the larger volume of the CM and the LM, the first serious vestibular problems became evident. The purpose of this report is to present and discuss all available information on vestibular system function during the Apollo series of space flights.

Methods

Qualitative Assessment Procedures

With one exception that is described in a following section, no systematic program to assess quantitatively the effects of space flight on crew vestibular function was pursued during the Apollo flight series. A major portion of the understanding of vestibular problems encountered during space flight is based, therefore, on qualitative information derived from a variety of sources. An attempt has been made to compile detailed motion experience histories for each astronaut in the Apollo flight series. These histories indicate whether or not an individual astronaut has ever experienced motion sickness in automobiles, in boats, during zero-g parabolic flight maneuvers, or during spacecraft egress exercises. In addition, heavy emphasis has been placed on subjective reporting by individual astronauts on the type and the magnitude of vestibular disturbances experienced during and following their missions.

Special Preflight and Postflight Laboratory Measurements

Because of the need to obtain more definitive information on the effects of exposure to the space flight environment on the vestibular system, procedures were implemented to perform preflight and postflight vestibular tests on the Apollo 16 and 17 crewmen. To accomplish a reasonably comprehensive evaluation of vestibular function, two types of tests were performed. Postural equilibrium tests were selected as a means of providing an assessment of a behavioral skill that is not only of practical importance, but also sensitive to altered vestibular inputs that may result from prolonged exposure to weightlessness. The second test used, caloric irrigation, complemented the tests of balance by monitoring for changes in semicircular canal activity as a possible cause of postmission dysequilibrium.

Postural equilibrium was tested by using a modified and shortened version of a standard laboratory method (Graybiel & Fregly, 1966). Each crewman was fitted with military-type shoes for this test, both preflight and postflight, to rule out differences in footwear as a variable in intersubject and intrasubject comparisons. Rails of four widths (1.90, 3.17, 4.45, and 5.72 cm) plus the floor provided the foot support for the standing crewman. A tape 10.16 cm wide and 68.5 cm long served as a foot-guide alinement for the floor portion of the test. Time, the performance measure of balance, began when the crewman, standing on the prescribed support with his feet in a tandem heel-to-toe arrangement, folded his arms. His eyes remained open in the first test series. In the second series, the time measurement was initiated after the crewman attained a balanced position and closed his eyes. Several practice trials were allowed on representative rails until the crewman demonstrated full knowledge of the test procedure and reasonable confidence in his approach to this balancing task.

The initial rail width for testing with eyes open was 3.17 cm. Three test trials with a maximum duration of 50 seconds each were given. If the time limit was reached in the first two trials, a third was not performed, and a perfect score of 100 seconds (100 percent of the required task) was recorded for the initial support width. If the crewman failed to obtain a perfect score, the two largest time values for the three trials were summed to obtain the final score. The choice of the second width depended on the individual's performance on the initial support width. If his score was greater than or equal to 80 percent, the next smaller support width was used; if less than 80 percent, the next larger was used. Testing on a third support width was required when both of the two prior width scores fell either below or above the 80 percent level. The testing with eyes closed followed the same procedure, except that a larger rail support (5.72 cm) was used initially. The eyes-closed test was executed in very dim laboratory light to initiate dark-adaptation of the crewman in preparation for the caloric test.

Electrodes for recording nystagmic eye movements were attached before the postural equilibrium test. After cleaning the appropriate skin areas with 95 percent isopropyl alcohol, silver chloride (Beckman) electrodes were placed at the outer canthus of each eye and the reference electrode was placed in the center of the forehead. A Tracor RN-243 electronystagmograph system was used throughout the caloric test to record corneoretinal potential changes. Electronystagmographic calibration of eye movements in degrees per centimeter was obtained with the crewman sitting in an upright position and fixating on two alternately flashing red lights placed at a distance from the center of eye rotation, providing a separation of 20° of arc. Eye movement calibration and all subsequent caloric testing were done in a dark room. The crewman then was reclined in a fixed Tracor torsion swing chair so that his head was approximately 60° from upright, and the line from his outer canthus to the tragus of the ear was vertical. Baseline measurements then were made for at least 40 seconds to determine the presence of spontaneous nystagmus. Two separate water baths were maintained at temperatures that ensured irrigating temperatures of 308.65°K (35.5°C) and 307.15°K (34.0°C) by a heater-mixer element. These temperatures were very accurately sensed by thermistors located near the exit nozzles of the irrigating syringes, and were maintained between tests by a continuous recirculation of water.

Calorization of each crewman proceeded according to the following schedule: right ear (RE), 308.65°K; left ear (LE), 308.65°K; RE, 307.15°K; and LE, 307.15°K. In each case, 155 to 160 cm^3 of water were directed onto the tympanic membrane for a period of 40 seconds. To maintain mental alertness, the crewman silently solved arithmetic problems throughout certain specified periods during the response period.

Following irrigation of each ear at 308.65°K and a period of continuous recording that indicated the disappearance of all nystagmic response, an additional period (140 seconds) of rest was instituted; this rest period was increased to 260 seconds following the 307.15°K temperature irrigation. After all caloric testing, eye movement calibrations again were made in accordance with the pretest procedure.

Preflight data were collected on the Apollo 16 prime and backup crewmen at 30 days before launch (F – 30). Postflight data were collected on all three prime crewmen three days following recovery (R + 3); two of the crewmen were tested again at R + 7. Preflight data on the Apollo 17 prime and backup crewmen were obtained at F – 30 and at F – 15. No postflight data were collected on any of the Apollo 17 crewmen.

Results

Inflight Disturbances

Motion sickness histories of individual Apollo crewmen, as well as motion sickness symptoms and vestibular related illusions experienced by Apollo crewmen during space flight, are summarized in table 1. All three Apollo 7 crewmen had positive motion sickness histories. During their mission, however, none of these crewmen – including the Lunar Module Pilot (LMP), who performed purposeful spinning and tumbling maneuvers in the Command Module – experienced any symptoms of motion sickness. While donning his space suit, the Apollo 7 LMP did experience a brief tumbling illusion once, as indicated in table 1. All three Apollo 8 astronauts had some history of motion sickness. During flight, soon after leaving their couches, all three crewmen experienced nausea apparently as a result of rapid body movements. For the Commander (CDR), these symptoms progressively worsened; and, shortly after waking from his first sleep period, he vomited. In this particular case, the severe symptoms experienced were in part caused by gastroenteritis. The antimotion-sickness drug, Marezine, was ineffective for the CDR, but it did alleviate the stomach awareness and nausea experienced by the other two crewmen.

Table 1

Illusions and Motion Sickness Symptoms Experienced by Apollo Astronauts

		Motion Sickness History			Illusions/Motion Sickness Symptoms in Space Flight			
Flight	Crewman	In Land, Air and Sea Vehicles	In Zero G Parabola	In Spacecraft Egress or Egress Training	Tumbling Illusions	Stomach Awareness	Nausea	Vomiting
7	CDR	X						
	CMP*	X	X	X				
	LMP*	X		X	X			
8	CDR	X				X	X	X**
	CMP	X	X	X		X	X	
	LMP*	X	X			X		
9	CDR							
	CMP			X	X	X		
	LMP*	X	X	X		X	X	X
10	CDR	X						
	CMP	X						
	LMP	X	X			X		
11	CDR	X	X	X				
	CMP	X	X	X				
	LMP	X	X					
12	CDR	X						
	CMP			X				
	LMP*							

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1 (Continued)

Illusions and Motion Sickness Symptoms Experienced by Apollo Astronauts

		Motion Sickness History			Illusions/Motion Sickness Symptoms in Space Flight			
Flight	Crewman	In Land, Air and Sea Vehicles	In Zero G Parabola	In Spacecraft Egress or Egress Training	Tumbling Illusions	Stomach Awareness	Nausea	Vomiting
13	CDR	X	X	X				
	CMP*					X		
	LMP*					X	X	X
14	CDR	X						
	CMP*							
	LMP*	X						
15	CDR			X				
	CMP*							
	LMP*		X		X	X		
16	CDR	X						
	CMP*	X	X					
	LMP*	X	X					
17	CDR	X	X			X		
	CMP*	X	X					
	LMP*	X	X			X		

(Modified and updated from Berry and Homick, 1973).

*No prior space flight experience.

**Concomitant illness.

The first clear episode of a severe vestibular related motion sickness problem occurred during the Apollo 9 mission. Because this incident is unique, a detailed account is given. The crewman involved, the LMP, had fewer flying hours than the average astronaut and a definite history of motion sickness. Also, he was making his first space flight. Because he was concerned about his previous history, he took one 50-mg Marezine tablet three hours before lift-off and another one 1-1/2 hours after orbital insertion. Upon rising from the couch later on the first day, he observed that when he turned his head rapidly, he experienced mild dizziness. The dizziness did not seem to interfere with his performance, and he was able to control it by executing all movements slowly and by turning at the waist instead of turning his head. He did not experience any nausea with the dizziness that was produced by head movements.

Shortly after donning his pressure suit for transfer from the CM to the LM at approximately 40:00 ground elapsed time, the Apollo 9 LMP vomited suddenly. The characteristic prodromal symptoms of motion sickness were not experienced. He was, however, able to retain the vomitus in his mouth long enough to use a disposal bag effectively. In the postflight medical debriefing, he could not recall whether he felt nauseated after vomiting or whether he experienced some relief. About four hours later, he vomited again after he had transferred to the LM. Again, the vomiting was sudden and was not preceded by much warning. Aspiration of the vomitus did not occur on either occasion. Just before vomiting the second time, he had been closing circuit breakers and cycling switches located in different areas of the cabin. Such activities require considerable movement within the LM. Immediately following the second episode of vomiting, he felt much better and noted a marked improvement in his ability to move around freely. The only residual symptom was a loss of appetite and an aversion to the odor of certain foods. Until the sixth day of the mission, he subsisted exclusively on liquids and freeze-dehydrated fruits (Apollo 9 Mission Report, 1969).

Because of great concern about the inflight problems of the Apollo 9 LMP, a decision was made to perform comprehensive vestibular tests on him at the Naval Aerospace Medical Institute, Pensacola, Florida. Functional tests of the labyrinth included audiometry, measurements of semicircular canal sensitivity (caloric irrigation and oculogyral illusion), ocular counterrolling, and ataxia/postural equilibrium. Provocative tests included the "dial test" (performance of head and arm movements in the slow rotating room), a coriolis motion sickness test (performance of programmed head movements while rotating in a chair), an off-vertical rotation test, and a cineramic motion picture.

On the basis of these tests, it was concluded that the Apollo 9 LMP had normal function of the vestibular apparatus. The provocative tests, including parabolic flight test data, indicated that he had no greater than average susceptibility to motion sickness. Furthermore, he showed an ability to adapt or to gain increased tolerance with repeated exposures to provocative stimuli.

As a result of the Apollo 9 vestibular problem, increased attention was given to developing techniques for predicting and preventing any such future occurrences. Insufficient time prevented individual crewmen from engaging in any special preflight vestibular adaptation activities. However, on the basis of research performed using the slow rotating room at the Naval Aerospace Medical Institute, it was determined that vestibular adaptation to the weightless environment might progress more rapidly if the crewmen executed planned head movements very early during their flights. Also, the antimotion-sickness drug was changed from Marezine to a combination of scopolamine and Dexedrine.

During the first day of the Apollo 10 flight, the LMP executed the recommended head movements in an attempt to hasten vestibular adaptation. The head movements quickly induced stomach awareness and nausea, and he was compelled to stop. He tried these head movements again on the second day and again had to stop after one minute because of the rapid onset of symptoms. After the second day of flight, he apparently had adapted and experienced no further difficulties. On the seventh day of the mission, he experimented with the head movements again and was able to perform them for five minutes before symptoms began to appear. No other Apollo 10 crewman experienced any inflight symptomatology.

Although several of the Apollo 11 and Apollo 12 astronauts had positive motion sickness histories, none of these crewmen reported any difficulties either during weightless flight or on the lunar surface. The complete absence of vestibular problems during lunar surface activity throughout the Apollo Program has proved significant. Before the Apollo 11 mission, many predictions had been made regarding possible disorientation and postural stability problems that might occur on the lunar surface.

Very early in the Apollo 13 flight, vestibular problems were experienced by two of the crewmen, including the LMP, who vomited on the second day. All available information indicated that both of these crewmen had negative motion sickness histories. The CDR, who had a definite history of motion sickness, experienced no vestibular symptomatology during this flight. Although comprehensive historical data are not available for the Apollo 14 flight crew, at least two of the crewmen had some past experience with motion sickness. This history was especially true of the CDR, who, several years before the Apollo 14 flight, underwent successful corrective surgery for Ménière's disease. No crewman encountered vestibular difficulties during the Apollo 14 mission.

Complete historical data are not available for the Apollo 15 flight crew; however, at least two of the crewmen had some minimal past experience with motion sickness. During the flight, the CDR and the Command Module Pilot (CMP) had no illusions or symptoms. The LMP reported, however, that he experienced a sensation of impending vestibular difficulties and therefore limited his motions during the first several days of the flight. This condition cleared, and he had no subsequent problems during lunar extravehicular activity and return to Earth. Following splashdown and recovery, however, he developed some unusual symptoms that probably were partly vestibular in origin. He reported a feeling of dizziness or lightheadedness that persisted for seven days following recovery. This condition was not accompanied by any type of gastrointestinal disturbance. Locomotion was not impaired, nor was any tinnitus reported. In addition, he commented on a 30° head-down, tilted sensation experienced when supine. This sensation was most apparent during periods of "twilight" sleep and persisted even when he turned onto his side. The tilted sensation was not present when he was fully awake, regardless of postural position. This condition gradually lessened; the degree of tilt appeared to decline and disappeared entirely after the fifth postrecovery day. At about the same time that his symptoms disappeared, he was subjected to several different clinical vestibular tests, which were conducted by an otolaryngologist. The tests included a standard Hallpike (measurement of the amount of nystagmus produced by alternate irrigation of the right and left ear canals with warm or cold water), positional nystagmus, postrotary nystagmus, and standard audiometry. The crewman's responses on all of the tests were normal.

All Apollo 16 and Apollo 17 crewmen had positive motion sickness histories. However, only the Apollo 17 CDR and LMP experienced inflight disturbances. In both of these cases, the symptoms were mild and disappeared after the third day of flight.

An overall summary of Apollo motion sickness findings is presented in table 2. Eleven of the 33 individuals who have flown on Apollo flights have experienced apparent vestibular difficulties. Of these eleven, nine had positive motion sickness histories. Conversely, 18 of 27 individuals with positive histories had no inflight symptomatology. Six of the eleven crewmen with inflight problems experienced minor symptoms, two experienced moderate symptoms, and three had severe symptomatology. As previously stated, it is questionable whether the vomiting experienced by one of these latter individuals was vestibular in origin or due primarily to gastroenteritis. Six (40 percent) of the 15 individuals making their first space flight developed inflight symptoms. Of the 18 veteran pilots, only five (approximately 28 percent) experienced symptoms.

Table 2

Apollo Motion Sickness General Summary

Category	Number of Crewmen
Motion Sickness (MS) History and Inflight MS	
Total Apollo crewmen	33
Positive MS history	27
Positive MS history with inflight MS	9
Positive MS history with no inflight MS	18
Negative MS history	6
Negative MS history with inflight MS	2
Negative MS history with no inflight MS	4
Total crewmen with inflight MS	11
Severity of Inflight Symptoms	
Occurrences of mild MS (stomach awareness)	6
Occurrences of moderate MS (stomach awareness, nausea)	2
Occurrences of severe MS (stomach awareness, nausea, vomiting)	3
Previous Space Flight Experience	
Inexperienced crewmen (first space flight)	15
Inexperienced crewmen with inflight MS	6
Veteran crewmen (one or more space flights)	18
Veteran crewmen with inflight MS	5

Special Laboratory Measurements

Because no postflight tests were performed on the Apollo 17 flight crew, complete laboratory data for the Apollo 16 crewmen only are described.

Test results showing the ability of each Apollo 16 crewman to balance on rails of various widths are presented in figure 1. Preflight findings for all three crewmen are within the range of performance typically exhibited by young, healthy, pilot-type subjects. Examination of figure 1 indicates that during the first (R + 3) and second (R + 7) postflight test periods, postural equilibrium with eyes open was nearly identical to preflight performance for all crewmen. The CDR actually demonstrated a slight progressive improvement on this task with time. At R + 3, however, the CDR and the CMP exhibited a marked decrease in postural stability when deprived of all visual sensory cues. When these two individuals were tested again at R + 7, there was a definite improvement in postural stability with eyes closed compared to their R + 3 performance. The CMP bettered his preflight, eyes-closed scores, whereas the performance of the CDR was approximately midway between his two previous scores.

The principal characteristics of the spontaneous nystagmus – as well as the lag, the maximum velocity, the maximum frequency, and the duration of nystagmus elicited from each Apollo 16 crewman in response to the two irrigation temperatures – are summarized in table 3. Lag is defined as the time between the onset of irrigation and the first measurable nystagmus. Maximum velocity was obtained by selecting the ten-second epoch of a given record that contained the greatest preponderance of high-velocity, slow-phase nystagmus, and by calculating the average slow-phase velocity value for that epoch. Maximum frequency was obtained similarly. The duration of nystagmus is the interval between onset and complete cessation of nystagmus.

In general, the preflight responses indicate that all crewmen possess normally functioning canals bilaterally. The nystagmus produced was always in the expected direction. Spontaneous nystagmus was present in all three Apollo 16 crewmen, but no meaningful trends were observed with this parameter. Also, all of the crewmen exhibited an asymmetry or labyrinthine preponderance which, with the exception of a slight reversal in the CMP at R + 7, remained unchanged.

To facilitate more discernible intersubject and intrasubject comparisons, the primary parameters of lag, maximum velocity, maximum frequency, and duration of nystagmus are plotted in the form of bar graphs for each Apollo 16 crewman at each irrigating temperature in figures 2 to 4. Right and left ear data are shown separately in each figure. Examination of figure 2 indicates that during the first test period (R + 3), the nystagmic responses of the LMP were very similar to his preflight responses, particularly at 308.65°K. The tendency toward shorter lag times, higher velocities and frequencies, and longer durations of nystagmus with the more stressful water temperature (307.15°K) is also quite apparent in these data, as is the consistent right-greater-than-left response asymmetry. Because no postflight changes were detected with either postural equilibrium or caloric irrigation procedures, the Apollo 16 LMP was not tested further. Changes in the CDR's responses to caloric irrigation at R + 3 are readily observable in figure 3. With two exceptions that occurred with the 307.15°K stimulus, all of the R + 3 response parameters are elevated compared to the F – 30 baseline. When tested again four days

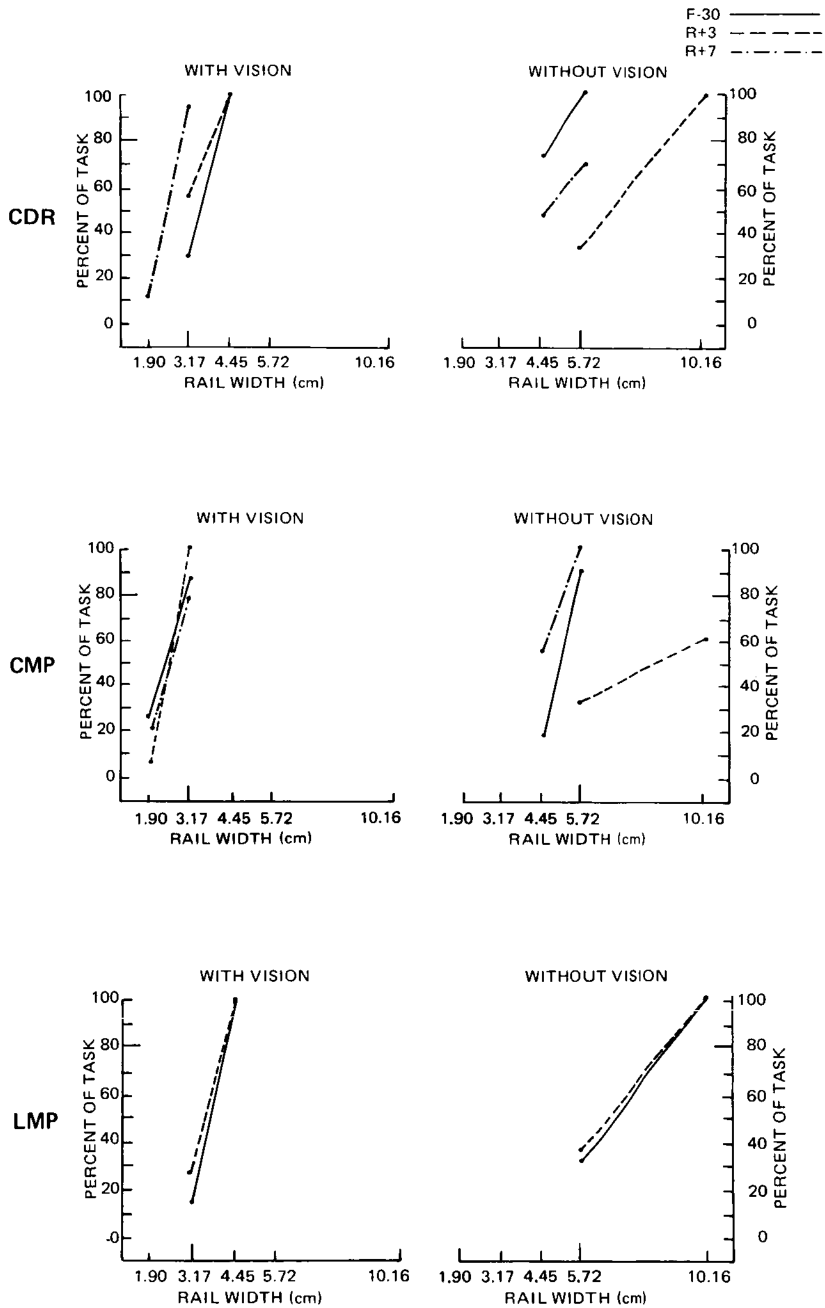

Figure 1. Pre- and postflight postural equilibrium scores for the Apollo 16 CDR, CMP, and LMP. Performance with eyes open and eyes closed, expressed as percent of task, is plotted as a function of rail width.

Table 3

Apollo 16 Pre- and Postflight Caloric Irrigation Results

Crewman	Temperature °K (°C)	Ear	Nystagmus: Direction			Lag (sec)			Avg. Velocity (°/sec)			Max. Velocity (°/sec)			Max. Frequency (beats/sec)			Duration (sec)			Total Beats (40 sec)			R/L* Asymmetry (Percent)		
			F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7	F-30	R+3	R+7
CDR	SN**	–	R	R	R	–	–	–	1.5	2.2	2.3	–	–	–	–	–	–	–	–	–	9	9	10	–	–	–
	308.65 (35.5)	R	L	L	L	27.0	48.9	42.7	–	–	–	2.6	4.1	3.4	0.4	1.0	0.6	151	178	115	–	–	–	37.0 (L>R)	33.0 (L>R)	37.2 (L>R)
	308.65 (35.5)	L	R	R	R	32.3	33.3	35.5	–	–	–	6.1	10.7	7.2	0.6	0.8	0.7	173	234	199	–	–	–	–	–	–
	307.15 (34.0)	R	L	L	L	34.6	36.3	53.0	–	–	–	4.7	9.2	4.7	0.3	0.8	0.5	179	170	164	–	–	–	–	–	–
	307.15 (34.0)	L	R	R	R	22.4	43.0	29.4	–	–	–	9.8	15.7	10.5	1.5	0.5	1.4	192	244	194	–	–	–	–	–	–
LMP	SN	–	L	L	–	–	–	–	0.3	0.8	–	–	–	–	–	–	–	–	–	–	5	17	–	–	–	–
	308.65 (35.5)	R	L	L	–	25.0	18.4	–	–	–	–	6.1	5.9	–	1.0	1.2	–	265	189	–	–	–		33.4 (R>L)	38.0 (R>L)	–
	308.65 (35.5)	L	R	R	–	41.6	35.2	–	–	–	–	2.2	2.5	–	0.6	0.8	–	148	134	–	–	–	–	–	–	–
	307.15 (34.0)	R	L	L	–	17.2	19.0	–	–	–	–	12.3	11.5	–	1.5	1.9	–	262	203	–	–	–	–	–	–	–
	307.15 (34.0)	L	R	R	–	24.8	22.2	–	–	–	–	7.0	5.3	–	1.5	0.8	–	159	188	–	–	–	–	–	–	–
CMP	SN	–	R	R	–	–	–	–	2.0	2.1	0	–	–	–	–	–	–	–	–	–	12	7	0	–	–	–
	308.65 (35.5)	R	L	L	L	43.5	78.2	72.9	–	–	–	2.1	2.8	3.5	0.4	0.7	0.3	149	130	122				33.2 (L>R)	6.0 (L>R)	6.6 (R>L)
	308.65 (35.5)	L	R	R	R	42.0	66.0	38.9	–	–	–	6.9	5.9	5.1	0.8	1.0	0.4	192	114	129	–	–	–	–	–	–
	307.15 (34.0)	R	L	L	L	30.2	40.0	67.9	–	–	–	8.6	9.0	11.0	0.6	0.8	1.3	186	215	110	–	–	–	–	–	–
	307.15 (34.0)	L	R	R	R	31.2	55.9	69.0	–	–	–	14.4	7.4	7.6	1.0	0.7	0.8	177	201	130	–	–	–	–	–	–

*R = Right; L = Left.

**Spontaneous nystagmus.

ORIGINAL PAGE IS OF POOR QUALITY

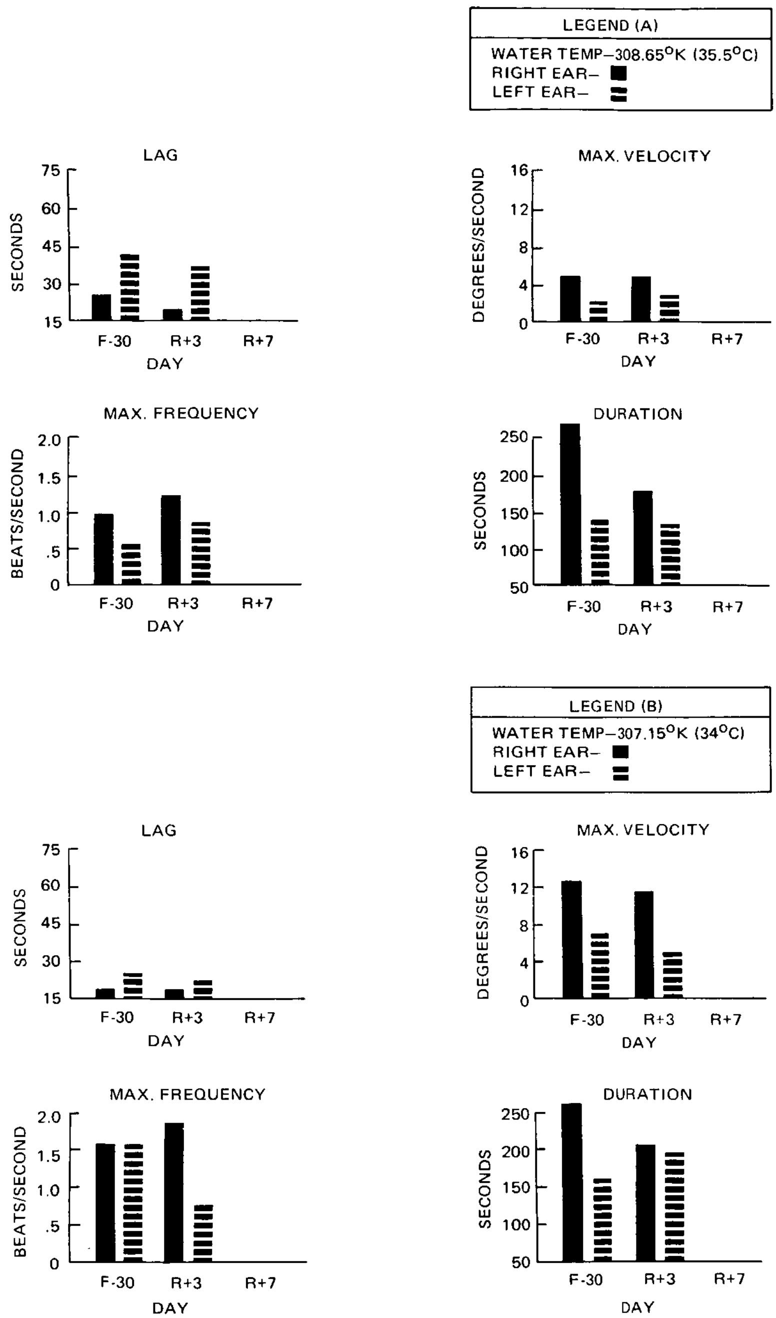

Figure 2. Pre- and postflight values for each of four nystagmus parameters obtained from the Apollo 16 LMP. Responses to irrigation with water temperatures of 308.65°K and 307.15°K are shown in (A) and (B) respectively.

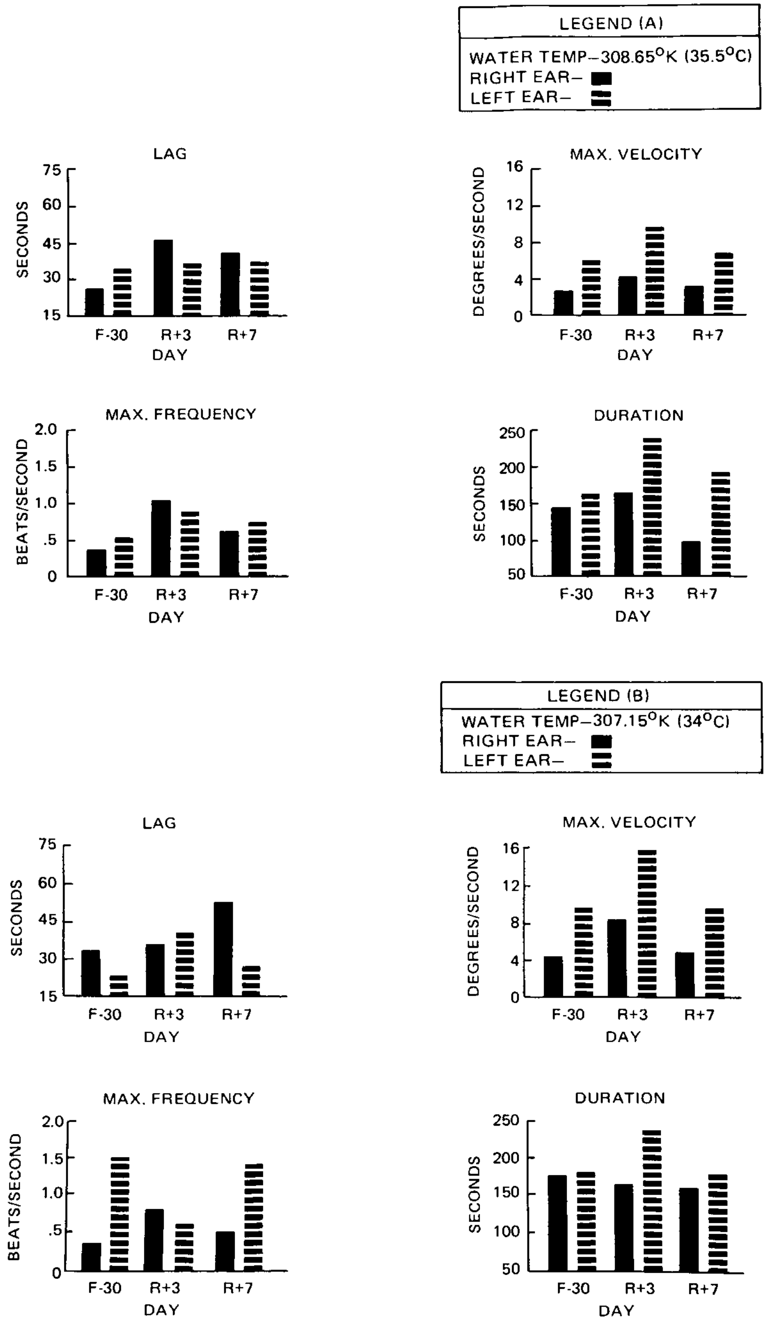

Figure 3. Pre- and postflight values for each of four nystagmus parameters obtained from the Apollo 16 CDR. Responses to irrigation with water temperatures of 308.65°K and 307.15°K are shown in (A) and (B) respectively.

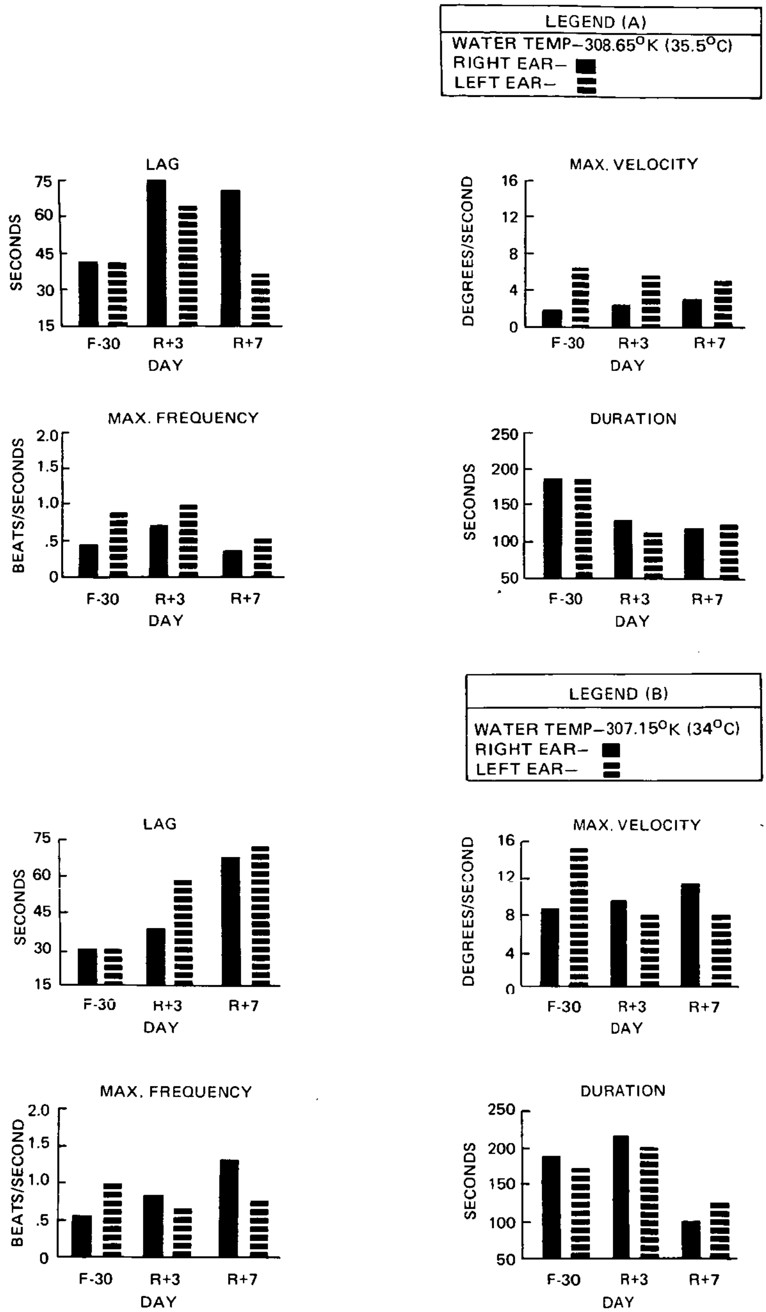

Figure 4. Pre- and postflight values for each of four nystagmus parameters obtained from the Apollo 16 CMP. Responses to irrigation with water temperatures of 308.65°K and 307.15°K are shown in (A) and (B) respectively.

later, the CDR's nystagmic responses had essentially returned to preflight values. Figure 4 indicates that, although a few parameters were elevated at R + 3 compared to F − 30 and R + 7, the data for the CMP are scattered and no overall trends are apparent. Left/right asymmetry, which is pronounced in the first two crewmen, is not well defined in this individual.

Although no provocative tests were administered, a motion experience questionnaire completed before flight by each crewman indicated that all had low susceptibility to motion sickness under one-g conditions. As stated previously, none of the Apollo 16 crewmen reported experiencing any symptoms of motion sickness during the flight.

Discussion and Implications

Apollo 16 Special Study

In evaluating the results of the Apollo 16 special study, the type of tests that were used and the manner in which they were performed should be considered. Postural equilibrium with eyes open served as a control condition for the eyes-closed portion of the test. Whereas none of the crewmen at any time showed appreciable change in postural stability with eyes open, a performance change was noted in two crewmen (CDR and CMP) when they were deprived of visual cues, and were required to balance solely on the basis of vestibular and proprioceptive sensory cues. This finding suggests that subtle alterations in these nonvisual sensory modalities were present at R + 3. The fact that the eyes-open scores did not change suggests that visual cues compensated for the relative decrease in performance observed in the eyes-closed task. This finding is not unusual. When minor changes occur in the vestibular system, they often can be overridden by vision, which normally dominates human spatial orientation (Howard & Templeton, 1966). It can reasonably be assumed that the relative improvement seen in these two individuals at R + 7 represented a return to normal of the sensory mechanisms involved.

It is also recognized that the postural stability test employed in this study is primarily a behavioral task and, as such, is subject to learning effects. Examination of the data indicates that a slight amount of learning may have occurred. The only clear evidence, however, is in the case of the CDR on the eyes-open portion of the test. Even if a learning effect was present, it could only have biased the postflight performance in a positive direction, and it is clear that a decline in eyes-closed performance occurred in two of the crewmen at R + 3. The significant improvement in eyes-closed postural stability observed in these two crewmen at R + 7 undoubtedly is more representative of a return to normal function of the sensory systems involved than of a simple learning effect.

An alert mental state is conducive to the elicitation of nystagmus (Guedry, 1965). Apparently as a result of an understandable emotional letdown following their mission, the crewmen exhibited some difficulty in maintaining an alert mental state during the caloric test at R + 3. This condition should have tended to suppress nystagmus; however, the CDR did show a very clear elevation in nystagmic activity at R + 3, indicative of a labyrinthine hypersensitivity. The somewhat erratic nystagmic activity observed in the CMP is also suggestive of unstable postflight vestibular function.

The finding of both decreased postural stability and increased nystagmic activity in the same two crewmen at R + 3 corresponds well to a study reported previously by

Fregly and Graybiel (1970). Using procedures very similar to those employed in this study, these investigators found a high positive correlation between tests of ataxia and caloric irrigation. The majority of their subjects who performed poorly on the ataxia tests, particularly with eyes closed, also yielded abnormal responses to caloric stimulation.

On the basis of the data, a tentative conclusion is that the postflight responses observed in two of the Apollo 16 crewmen reflected changes in vestibular function brought about by exposure to the conditions encountered during their mission. Because of the limitations inherent in this study, it is not possible to generalize from these data or to identify causal factors with any degree of certainty. Although lack of a gravitational stimulus was probably the most important environmental factor, other physiological stressful events such as launch, entry, and recovery activities may have contributed to the observed changes.

Overall Assessment of Apollo Series

The lack of quantitative preflight, inflight, and postflight vestibular data on individual crewmen renders a valid assessment of the Apollo findings difficult. However, certain tentative conclusions can be made:

1. Increased mobility, and thus increased head movements as afforded by the larger volume of the Apollo CM/LM, resulted in a higher incidence of vestibular disturbances in the Apollo Program than in previous programs.

2. In most cases in which symptoms did occur, they were mild to moderate and could be controlled by limiting head movements the first few days in flight.

3. Adaptation of the vestibular receptors to the weightless environment apparently occurred within the first several days of flight for most individuals. However, on the basis of these Apollo data alone, one can only speculate whether or not adaptive processes will lead to complications of a different nature during long duration missions.

4. Extravehicular activity in one-sixth g on the lunar surface resulted in no disorientation or vestibular disturbances. Apparently, one-sixth g is an adequate stimulus for the otolith organs to provide sensory information regarding gravitational upright and, hence, maintenance of posture.

5. With one important exception on the Apollo 15 mission, no crewmen experienced pronounced vestibular disturbances after returning from space flight. This finding suggests that adaptive processes that occur during weightless space flight missions of up to two weeks in duration do not render the vestibular system significantly hyposensitive or hypersensitive following sudden return to a one-g environment. Again, on the basis of these data alone, one can only speculate whether or not this condition will be true following very long exposure to zero g.

6. Whether or not an individual is likely to develop inflight vestibular problems cannot be predicted reliably from his previous history of motion sickness. However, astronauts making their first space flight appear to be slightly more susceptible to the development of inflight symptoms than are experienced astronauts.

The results of followup studies on two individuals who demonstrated the most significant inflight and postflight vestibular problems have already been discussed. However, further comment about one of these cases is warranted.

The severe motion sickness of the LMP during the Apollo 9 flight, and the subsequent negative findings during laboratory tests, underscore a very important problem in understanding vestibular function in weightlessness. Parabolic flight research has shown that it is very difficult to predict an individual's vestibular responses in zero g on the basis of his responses in one g. An individual may have normal vestibular responses on the ground and show markedly greater or lesser susceptibility to vestibular stimulation in weightlessness (Miller et al., 1969). The Apollo 9 LMP may well be one of these unique individuals who become more sensitive.

One of the most obvious implications of the Apollo flight crew vestibular evaluation is a need for more inflight as well as preflight and postflight vestibular information on the astronaut population. Only by examining with quantitative methods the men who actually fly in space can a thorough understanding of the effects of weightless space flight on vestibular function be attained. Without such information, reliably predicting possible vestibular problems for individual crewmen will be difficult. One positive step toward achieving this desired goal will be available through the Skylab human vestibular function experiment.

References

Berry, Charles A.; and Homick, Jerry L.: Findings on American Astronauts Bearing on the Issue of Artificial Gravity for Future Manned Space Vehicles. Aerospace Med., vol. 44, no. 2, Feb. 1973, pp. 163-168.

Fregly, A.R.; and Graybiel, A.: Labyrinthine Defects as Shown by Ataxia and Caloric Tests. Acta Oto-Laryngol., Stockholm, vol. 69, Mar. 1970, pp. 216-222.

Graybiel, A.; et al.: Vestibular Experiments in Gemini Flights V and VIII. Aerospace Med., vol. 38, no. 4, Apr. 1967, pp. 360-370.

Graybiel, A.; and Fregly, A.R.: A New Quantitative Ataxia Test Battery. Acta Oto-Laryngol., Stockholm, vol. 61, Apr. 1966, pp. 292-312.

Guedry, F.E., Jr.: Psychophysiological Studies of Vestibular Function. Contributions to Sensory Physiology. Vol. I. Academic Press, 1965.

Howard, I.P.; and Templeton, W.B.: Human Spatial Orientation. John Wiley and Sons, 1966.

Miller, E.G.; Graybiel, A.; Kellogg, R.S.; and O'Donnel, R.D.: Motion Sickness Susceptibility Under Weightless and Hypergravity Conditions Generated by Parabolic Flight. Aerospace Med., vol. 40, no. 8, Aug. 1969, pp. 862-868.

National Aeronautics and Space Administration: Apollo 9 Mission Report. MSC-PA-R-69-2. Prepared by Mission Evaluation Team, Manned Spacecraft Center, Houston, Texas, May 1969.