

## **Individual differences in susceptibility to motion sickness among six Skylab astronauts†**

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**Abstract**—One of the Skylab experiments dealt with motion sickness, comparing susceptibility in the workshop aloft with susceptibility preflight and postflight. Tests were conducted on and after mission-day 8 (MD 8) by which time the astronauts were adapted to working conditions. Stressful accelerations were generated by requiring the astronauts, with eyes covered, to execute standardized head movements (front, back, left, and right) while in a chair that could be rotated at angular velocities up to 30 rpm. The selected endpoint was either 150 discrete head movements or a very mild level of motion sickness. In all rotation experiments aloft, the five astronauts tested (astronaut 1 did not participate) were virtually symptom free, thus demonstrating lower susceptibility aloft than in preflight and postflight tests on the ground when symptoms were always elicited. Inasmuch as the eyes were covered and the canalicular stimuli were the same aloft as on the ground, it would appear that lifting the stimulus to the otolith organs due to gravity was an important factor in reducing susceptibility to motion sickness even though the transient stimuli generated under the test conditions were substantial and abnormal in pattern.

Some of the astronauts experienced motion sickness under operational conditions aloft or after splashdown, but attention is centered chiefly on symptoms manifested in zero gravity. None of the Skylab—II crew (astronauts 1 to 3) was motion sick aloft. Astronaut 6 of the Skylab—III crew (astronauts 4 to 6) experienced motion sickness within an hour after transition into orbit; this constitutes the earliest such diagnosis on record under orbital flight conditions. The eliciting stimuli were associated with head and body movements, and astronaut 6 obtained relief by avoiding such movements and by one dose of the drug combination l-scopolamine 0.35 mg + d-amphetamine 5.0 mg. All three astronauts of Skylab—III experienced motion sickness in the workshop where astronaut 6 was most susceptible and astronaut 4, least susceptible. The higher susceptibility of SL-III crewmen in the workshop, as compared with SL-II crewmen, may be attributable to the fact that they were based in the command

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module less than one-third as long as SL-II crewmen. The unnatural movements, often resembling acrobatics, permitted in the open spaces of the workshop revealed the great potentialities in weightlessness for generating complex interactions of abnormal or unusual vestibular and visual stimuli. Symptoms were controlled by body restraint and by drugs, but high susceptibility to motion sickness persisted for 3 days and probably much longer; restoration was complete on MD 7.

From the foregoing statements it is clear that on and after MD 8 the susceptibility of SL-II and SL-III crewmen to motion sickness under experimental conditions was indistinguishable. The role played by the acquisition of adaptation effects prior to MD 8 is less clear and is a subject to be discussed.

## 1. Introduction

IN THE first two manned Skylab missions motion sickness posed an operational problem. This report deals with that problem and presents the findings of an experiment designed to compare an astronaut's susceptibility to motion sickness in the workshop aloft with his preflight and postflight susceptibility.

Prior to Skylab missions, motion sickness after splashdown was experienced by American astronauts throughout the entire manned space programs, but motion sickness aloft was not manifested until the Apollo missions. Nine among 25 Apollo astronauts [1] reported motion sickness in weightlessness, an incidence of 36%, although all recovered prior to splashdown. The severity of their symptoms varied from "stomach awareness" to nausea and vomiting.

Soviet investigators have described in detail vestibular side effects experienced by cosmonauts [2-9], and it is notable that motion sickness was reported far less frequently than were reflex illusory phenomena. Among 24 cosmonauts, four experienced motion sickness aloft, an incidence of about 17%. Postural illusions were noted immediately after the cosmonauts' transition into orbit; while these were usually short lived, some cosmonauts continued to experience the inversion illusion until a G-load was reestablished during reentry. Illusory sensations of turning and dizziness evoked by rotary movements of the head or head and body were sometimes felt for the duration of flight, a period measured in hours.

In this report a distinction is made between two categories of vestibular side effects [10]. One category comprises a great variety of "immediate reflex responses," such as postural illusions, sensations of rotation, nystagmus, and what often is termed dizziness or vertigo. The other category, motion sickness, is a delayed epiphenomenon (superimposed on any responses in the reflex category), involving vestibular influences that cross a temporary or "facultative linkage," presumably in the brain stem reticular formation, to reach nonvestibular sites where first-order responses that lead to motion sickness symptoms have their immediate origin. First-order responses may, in turn, elicit second and higher order responses or complications until the organism is generally involved. Symptoms of motion sickness are elicited when too rapid a transition is made from one motion environment to another [11]. The primary or essential etiological factor is of vestibular origin, inasmuch as under such a transition persons with loss of vestibular function do not become motion sick [12, 13]. Secondary etiological factors are always operative, however. In healthy, normal persons visual inputs and psychological factors are usually the most important ones; in some motion environments just opening the eyes may precipitate motion sickness. In

most motion environments visual inputs are not essential for the elicitation of motion sickness; blind persons who have never perceived light may readily become sick[14].

## 2. Procedure

### *Astronauts*

Six astronauts participated in the first two Skylab missions; information about their prior flight experience is summarized in Table 1. Astronaut 1 had participated in the Gemini V mission and, along with astronaut 4, in the Apollo XII mission, which had included landing on the Moon; neither had reported any symptoms of motion sickness during those missions. All six astronauts were experienced pilots, and only astronauts 2 and 4 had ever had even mild symptoms of motion sickness in aircraft. In parabolic flight while carrying out operational tasks, astronauts 2, 3, and 6 had experienced nausea and vomiting on at least one occasion; systematic studies of their susceptibility to motion sickness in parabolic flight, however, had not been conducted. Only astronaut 3 had not been sea sick; the intensity of the sea sickness symptoms was "moderate" in astronaut 5 and "slight" in the other four.

Functional tests of the astronauts' vestibular organs revealed no definite abnormalities. These tests included a postural equilibrium test-battery for which the scores, although not shown in Table 1, were within the normal range. Of particular interest in view of the physiological deafferentation of the otoliths in weightlessness, however, are the low values for ocular counterrolling, which is a test of otolithic function. The counterrolling index (one-half the maximum roll when tilted right and left) was only 158 minutes of arc in astronauts 1 and 5; whereas, among 550 normal subjects the average was 344 minutes of arc[15]. A test[16] for grading susceptibility to motion sickness and yielding a single numerical score (Coriolis Sickness Susceptibility Index (CSSI)) was conducted. The scores were within the range of "average" susceptibility.

### *Stimulus conditions*

Under *operational conditions* the astronauts made major transitions from land to orbital flight, to sea, and back to land. While aloft, transitions were made between the command module and the workshop and, during extravehicular activity, between the spacecraft and the outer environment. During reentry there were variations in G-loading that terminated at splashdown, followed by transitions from the command module to the recovery aircraft carrier, and finally from the carrier to land.

In considering the transition from one motion environment to another it is necessary to take into account not only the "new" environment, but also the current status of adaptation effects acquired in antecedent environments. Skylab conditions in the workshop were far more stressful than those in the command module, and thus highly complicated vestibular and visual inputs were encountered in the workshop. Accelerative stimuli there were associated with passive as well as active movements, and visual stimuli were, potentially at least, disorient-

Table 1. History of motion sickness and vestibulometric findings of the six astronauts of the SL-II and SL-III missions.

Astronaut	Age	History of motion sickness						Canal function			Otolith function			
		Aircraft		Parabolic flight (OG)		Space flight		Sea		Canal thresholds of response	Modified Fitzgerald-hallpike	Preponderance	Ocular counter-rolling	Coriolis sickness susceptibility index
		Experi-ence	Symp-toms	Experi-ence	Symp-toms	Experi-ence	Symp-toms	mod. to heavy	Symp-toms					
1	42	>2000 hr	—	~8 times	—	—	Apollo XII	1-5 times	slight	within normal limits	insignificant	158 low normal	10.2	
2	40	>1000 hr	—†	>10 times	‡Nausea and Vomiting	none	none	1-5 times	slight	within normal limits	insignificant	300 normal	8.2	
3	40	>2000 hr	—	>10 times	‡Nausea and Vomiting	none	none	>100 times	—	normal limits	significant (retest)	374 normal	19.8	
4	40	>1000 hr	—†	>20 times	—	Apollo XII	10-50 times	slight	within normal limits	significant (retest indicated)	365 normal	23.1		
5	41	>1000 hr	—	~3 times	‡Nausea and Vomiting	none	none	>100 times	mod.	within normal limits	insignificant	158 low normal	26.4	
6	36	>2000 hr	—	>10 times	Vomiting	none	none	5-10 times	slight	within normal limits	insignificant	332 normal	19.2	

†Mild symptoms on rare occasions.

‡Reported by flight crew.

§Not applicable.

ing. Thus, the opportunity was present to reveal individual differences in susceptibility to motion sickness, based on vestibular inputs as well as on complexly interacting vestibular and visual stimuli.

At sea the astronauts were passively exposed to motion environments that stimulated the vestibular organs. The active execution of head (and body) movements contributed angular and linear accelerations that, combined with the passive sea motions, were capable of generating Coriolis accelerations<sup>†</sup>, stimulating the semicircular canals and the otolithic receptors [17-20].

Under *experimental conditions* (on and after MD 8 aloft and on the ground) a stressful motion environment was generated by requiring the astronauts, with eyes covered, to execute head movements while in a rotating litter chair (RLC) (Fig. 1). The RLC could be revolved at constant velocities up to 30 rpm [21]. The

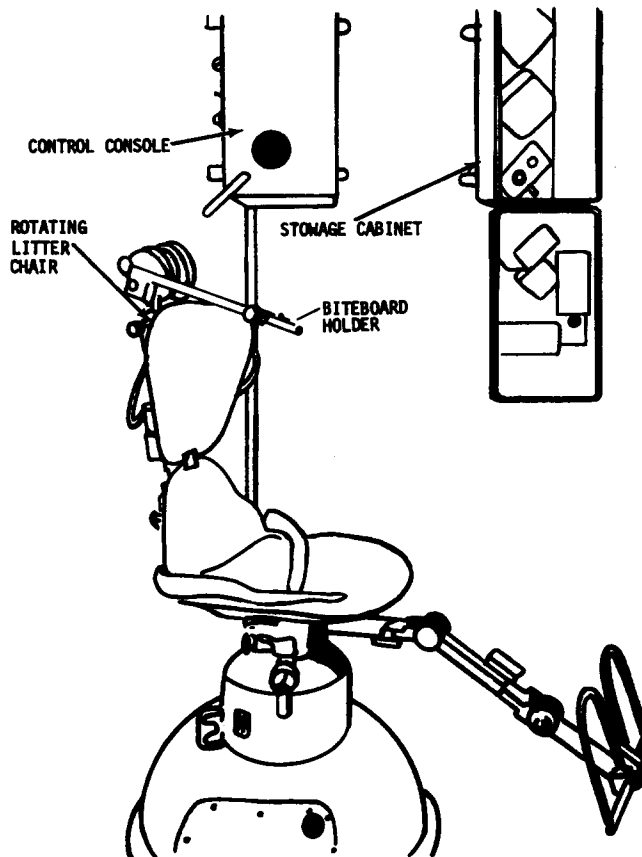


Fig. 1. The Rotating Litter Chair (RLC), motion-sickness-test mode. (From Ref. 21.)

<sup>†</sup>Coriolis acceleration is defined as the "added acceleration" generated either by simultaneous exposure to angular velocities about two axes or to one linear and one angular velocity; it is left to the reader to determine from the context which one is applicable or if both are applicable.

experimental procedures involved alternate clockwise and counterclockwise rotation, but rotation was more often clockwise than counterclockwise. Each discrete head and body movement ("over" and "back") through an arc of 90° in each of the four cardinal directions (front, back, left, right) required one second, and was followed by a "hold" for one second in the upright position. Movements were made in sets of five (the forward movement was executed twice), and after each set the astronaut kept his head in the upright position for 20 sec. The maximum number of head movements required in a test was 150 (one endpoint) unless mild motion sickness (the other endpoint) was reached earlier.

The RLC was used in the stationary as well as the rotating mode. In the stationary mode when head movements were executed aloft, the canals were stimulated in the same way as on the ground, but the otolith organs were stimulated in an abnormal manner because the impulse linear accelerations generated were not combined with a gravity vector as they would have been on the ground. These impulse linear accelerations were transient but well above threshold for stimulation of the otolith receptors. When the RLC was rotating, the intensity of the stimuli generated by head movement was a function of the rotational velocity, and although the angular and cross-coupled angular accelerations stimulating the semicircular canals aloft were the same as on the ground, the impulse and Coriolis accelerative forces generated aloft were not combined with a gravitational vector. These forces, nevertheless, were substantial at all levels of angular velocity used, and at 30 rpm the centripetal force was, respectively, 0.3 G and 0.6 G at radii of 1 and 2 feet.

#### *The diagnosis of motion sickness*

The diagnostic criteria for motion sickness in the Skylab experiments are summarized in Table 2 and are described in detail elsewhere[22]. In brief, the severity of motion sickness symptoms was given a numerical score; sixteen points and above comprised the range of "frank motion sickness," and less than sixteen points, the range of "mild motion sickness."

Under *experimental conditions* the diagnosis of acute motion sickness was aided by the close temporal relation between exposure to stressful stimuli and elicitation of responses. In all Skylab experiments the motion sickness endpoint, moderate malaise (M II A) (a point score of 5 to 7), was of very mild intensity; the avoidance of more severe symptoms was an operational requirement.

An observer in collaboration with the subject estimated the severity of each predesignated symptom and recorded any "other" symptom not mentioned in Table 2. There was always adequate time after execution of each set of head movements to make the estimates and record them by depressing the appropriate push-buttons in the response matrix of the RLC Control Console. One-hundred and fifty head movements or a score  $\geq 5$  points automatically triggered a signal that the test had been completed.

Under *operational conditions* the astronauts' ability to diagnose different levels of severity of motion sickness was enhanced by their training in connection with the preflight experimental evaluation of motion sickness susceptibility. Nonetheless, under operational conditions diagnosis was more difficult than under

Table 2. Diagnostic categorization of different levels of severity of acute motion sickness. (From ref. 22.)

Category	Pathognomonic 16 points	Major 8 points	Minor 4 points	Minimal 2 points	ACS† 1 point
Nausea syndrome	Nausea III‡ retching or vomiting	Nausea II Pallor III	Nausea I Pallor II	Epigastric discomfort Pallor I	Epigastric awareness Flushing/Subjective warmth ≥ II
Skin		III	II	I	
Cold sweating		III	II	I	
Increased salivation		III	II	I	
Drowsiness		III	II	I	
Pain					Persistent Headache ≥ II
Central nervous system					Persistent Dizziness Eyes closed ≥ II Eyes open III
Frank Sickness (FS)	Severe Malaise (M III)	Moderate Malaise A (M II A)	Moderate Malaise B (M II B)	Levels of Severity Identified by Total Points Scored	
≥ 16 points	8-15 points	5-7 points	3-4 points	Slight Malaise (M I)	1-2 points

†AQS—Additional qualifying symptoms.

‡III—severe or marked, II—moderate, I—slight.

experimental conditions because the identification of the stressful stimuli was not always easy, and the symptomatology of "chronic" or prolonged motion sickness (experienced aloft) differed in some respects from that of acute motion sickness.

### *Drugs*

The astronauts carried with them antimotion sickness (AMS) capsules containing 1-scopolamine 0.35 mg + d-amphetamine 5.0 mg which had proven to be effective under experimental [23] and operational conditions [24]. This drug combination acts by raising the stimulus thresholds for eliciting motion sickness responses and is effective in any motion environment. Indeed, preflight bioassay tests were carried out on all six astronauts, and endpoints were not reached even at maximal angular velocities.

### **3. Results**

Motion sickness was experienced under operational conditions by five of the six astronauts in SL-II and SL-III. Table 3 summarizes these reports with regard to: (1) exposures in the different motion environments, (2) the estimated levels of susceptibility, and (3) the administration of drugs that affected the intensity of the symptoms. In describing the findings particular attention will be given to symptoms during the orbital phases of the two missions.

#### *Operational Conditions*

*Skylab II.* The astronauts in SL-II realized that they faced a difficult task in having to deploy a canopy over the workshop in order to control its overheating. In addition, astronauts 2 and 3 were somewhat apprehensive that they might experience motion sickness.

Astronaut 2, in a debriefing, stated, "I took the one 'scop/dex' (antimotion sickness drugs) right after insertion (into orbit) that I had preprogrammed myself to take, whether I needed it or not." He further stated, "I felt that, although we had no overt symptoms of motion sickness or any other specific syndrome related to transitioning to weightlessness, my appetite was a little bit less, neglecting day 1 when it was completely normal, and that it was a little less for somewhere like the first week. I don't know why this is. As I said, I had no particular symptoms. I felt fine during those first 7 days, but I thought I felt even better after that." Moreover, he did not reject the possibility that the anorexia and "less-than fine" feeling might have represented symptoms of motion sickness.

Astronauts 1 and 3 did not take the AMS drug and neither of them had any symptoms of motion sickness while carrying out a variety of tasks aloft. In answer to the question whether his susceptibility to motion sickness in weightlessness changed during the first week aloft, astronaut 2 replied, "There (was) no discernible difference to me in how I felt subjectively throughout the flight." It is also noteworthy that both astronauts 1 and 2 reported that, while engaged in spinning rapidly about their long axes or "running" around the inside of the workshop, they experienced immediate reflex vestibular side effects, mainly "false sensations" of rotation. Based on past experience, both astronauts ex-



Table 3. Time course of the incidence of motion sickness and the administration of drugs among the six astronauts under different operational conditions of SL-II and SL-III missions.

Astronaut	SL	Mission Day							Carrier	Land			
		1	2	3	4	5	6	7					
		Command Module		Workshop							R + 0	R + 1	R + 2
		Predock <sup>1</sup>	Postdock <sup>2</sup>										
1	II	—	—	—	—	—	—	—	—	—	—	—	—
2	II	C† L+15 Min	—	—	—	—	—	—	—	—	—	—	—
3	II	L+60 Min A	—	—	—	—	—	—	—	—	—	—	—
4	III	—	—	—	—	—	—	—	—	—	—	—	—
5	III	—	—	—	—	—	—	—	—	—	—	—	—
6	III	—	—	—	—	—	—	—	—	—	—	—	—

Command Module		Workshop							R + 0	R + 1	R + 2		
1	II	—	—	—	—	—	—	—	—	—	—	—	—
2	II	C† L+15 Min	—	—	—	—	—	—	—	—	—	—	—
3	II	L+60 Min A	—	—	—	—	—	—	—	—	—	—	—
4	III	—	—	—	—	—	—	—	—	—	—	—	—
5	III	—	—	—	—	—	—	—	—	—	—	—	—
6	III	—	—	—	—	—	—	—	—	—	—	—	—

Command Module		Workshop							R + 0	R + 1	R + 2		
		Predock <sup>1</sup>	Postdock <sup>2</sup>										
		Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked
		N	V	N	V	N	V	N	V	N	V	N	V
		L + 70 Min	L + 21 Hr	L + 60 Min	L + 21 Hr	L + 60 Min	L + 21 Hr	L + 60 Min	L + 21 Hr	L + 60 Min	L + 21 Hr	L + 60 Min	L + 21 Hr
		C	B	A	B	A	B	A	B	A	B	A	B
		1720 CDT	1720 CDT	1300 CDT	1700 CDT	1300 CDT	1700 CDT	1300 CDT	1700 CDT	1300 CDT	1700 CDT	1300 CDT	1700 CDT
		before	before	before	before	before	before	before	before	before	before	before	before
		Meals	Meals	Meals	Meals	Meals	Meals	Meals	Meals	Meals	Meals	Meals	Meals
		30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min	30 Min
		3C	3C	3C	3C	3C	3C	3C	3C	3C	3C	3C	3C
		Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.
		SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
		90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min	90 Min
		?	?	?	?	?	?	?	?	?	?	?	?
		C	C	C	C	C	C	C	C	C	C	C	C
		prior	prior	prior	prior	prior	prior	prior	prior	prior	prior	prior	prior
		H-F	H-F	H-F	H-F	H-F	H-F	H-F	H-F	H-F	H-F	H-F	H-F
		40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min	40 Min
		BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC
		?	?	?	?	?	?	?	?	?	?	?	?
		Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.
		Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked
		N	N	N	N	N	N	N	N	N	N	N	N
		Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked
		N	N	N	N	N	N	N	N	N	N	N	N
		Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked	Marked
		N & V	N & V	N & V	N & V	N & V	N & V	N & V	N & V	N & V	N & V	N & V	N & V
		1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT	1700 CDT
		2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT	2100 CDT
		C	C	C	C	C	C	C	C	C	C	C	C
		0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT	0900 CDT
		—	—	—	—	—	—	—	—	—	—	—	—

† Demonstrated by symptoms or need for preventive measure. ?, slight, moderate, or marked increase in susceptibility.  
 ‡ Drug taken:  
 A Aspirin (320 mg) D Nasal emollient  
 B Seconal (100 mg) E Mylanta  
 C Scop/Dex (0.35/5.0 mg) F Chloral Hydrate  
 § Launch

pected that motion sickness would follow the reflex effects and were surprised by their immunity.

During reentry the astronauts did not perceive the oculogravic illusion. Astronaut 2 stated afterward, "I never picked it up at all. I think it just had to do with the fact that you have so many visual cues and you're so well lighted and also your attention is so rivited on the instruments that you have no such illusion . . . . The first time we were conscious of any vestibular inputs was after we were on the water and unstrapped and moved from the couch. There was nothing at all during the entry." Astronaut 1 stated, "My first head movement was when I was unstrapped and on the water, when I rolled up on my right and moved around . . . . It was exactly what I would expect had I been riding the centrifuge and done the same thing." Astronaut 3 stated, "And I did move. I got up from the couch and looked out the window for the ship while we were still on the chutes, and that didn't bother me."

At splashdown the sea state was 5, and the command module landed and remained upright. The astronauts were quite confident that they would not experience motion sickness on return and accordingly did not take antimotion sickness drugs prior to reentry. Sea sickness was not experienced by astronaut 1, but severe symptoms were manifested by astronaut 2 and mild symptoms by astronaut 3.

*Skylab III.* The SL-III astronauts were quite confident before their mission that they would not become motion sick in weightlessness. Nevertheless, *astronaut 6* reported symptoms within an hour after insertion into orbit. Helmet and space suit were worn during launch. On transition into zero gravity, no illusory phenomena were reported. Shortly after transition into orbit his helmet was removed and soon thereafter his space suit. It was in close relation to taking off his suit that the first symptoms of motion sickness were experienced. He took an AMS capsule that relieved his symptoms for a few hours. Later these returned and he restricted his activities; he deliberately avoided taking another AMS capsule.

During the activation of the workshop, about 11 hours into the flight, astronauts 4 and 5 also reported the onset of symptoms. Shortly thereafter astronaut 6 vomited. For 3 days all three astronauts' symptoms of motion sickness were intensified by movements and were lessened after taking the drug or restricting movements. They lightened their work schedule, which indicated a decrement in their performance.

On MD 2 astronaut 5 executed standardized head movements for 30 min with the object of increasing his rate of acquiring adaptation. With eyes closed he had "no difficulty," but with eyes open he experienced "developing malaise." After executing the head movements for 15 min he had slight "nausea and malaise" when he stopped and opened his eyes.

On MD 4 regular working hours were resumed, although some degree of susceptibility to motion sickness remained in all three astronauts for one or two more days. Recovery was complete by the seventh mission day.

Prior to splashdown the antimotion sickness drugs were taken, and symptoms were prevented even though the sea state was twice as severe as that to which the

SL-II crew had been exposed. On both days at sea aboard the carrier astronaut 6 took an AMS capsule.

*Experimental conditions*

*Skylab II.* The findings in Fig. 2 demonstrate that astronauts 2 and 3 (astronaut 1 did not participate) were less susceptible to motion sickness when they executed

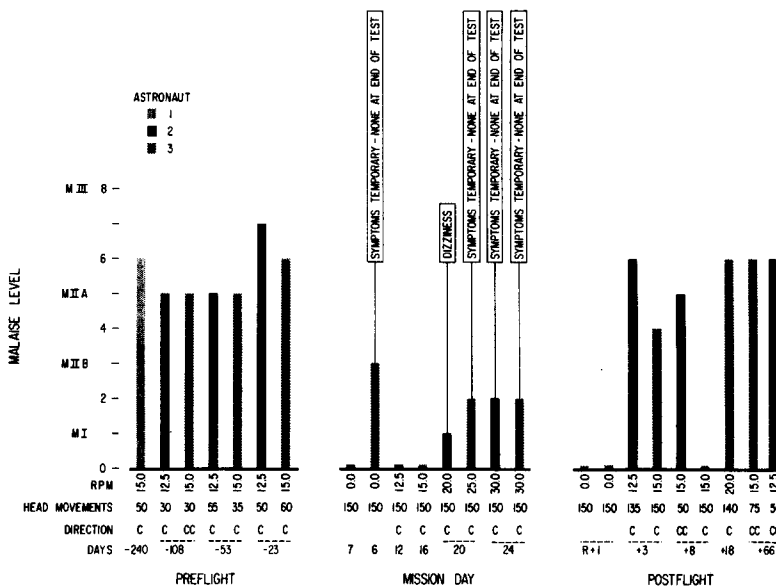


Fig. 2. Motion sickness symptomatology, scored in points, of astronauts 1, 2, and 3, quantitatively expressed in terms of malaise level, as evoked by the test parameters (rotational velocity, number of head movements, and direction of rotation) used before, during, and after the SL-II mission.

head movements during rotation aloft than when they did so on the ground. Preflight, on three widely separated occasions, the M II A endpoint was consistently elicited after 30 to 60 head movements while those astronauts were being rotated at 12.5 rpm (astronaut 2) or 15 rpm (astronaut 3). When rotation tests were carried out aloft in the workshop, both of these astronauts were virtually symptom free. Then their minimal responses, which were transient, did not even qualify for a score of 1 point. This was true even when the angular velocities were increased in two steps to 30 rpm. The ephemeral manifestation reported by astronaut 2 on MD 20 was a slight increase in subjective body warmth, and on MD 24, a mild cold sweating. The temporary manifestations reported by astronaut 3 on MD 6 when the rotating litter chair was stationary were epigastric awareness and increased salivation; on MD 20, epigastric awareness and increased body warmth; and, on MD 24, slight dizziness and cold sweating.

Postflight there was no significant change in the susceptibility of astronaut 2 to motion sickness compared with preflight; and, in astronaut 3, no significant change

on recovery day +3 (*R* +3). The decrease in susceptibility manifested by astronaut 3 on *R* +8 does not, in all likelihood, reflect more than a temporary change in his susceptibility.

*Skylab III.* The findings in astronauts 4, 5, and 6 are summarized in Fig. 3. It can be seen that they were virtually immune to experimental motion sickness aloft and that their susceptibility was lower, at least temporarily, after the mission than before.

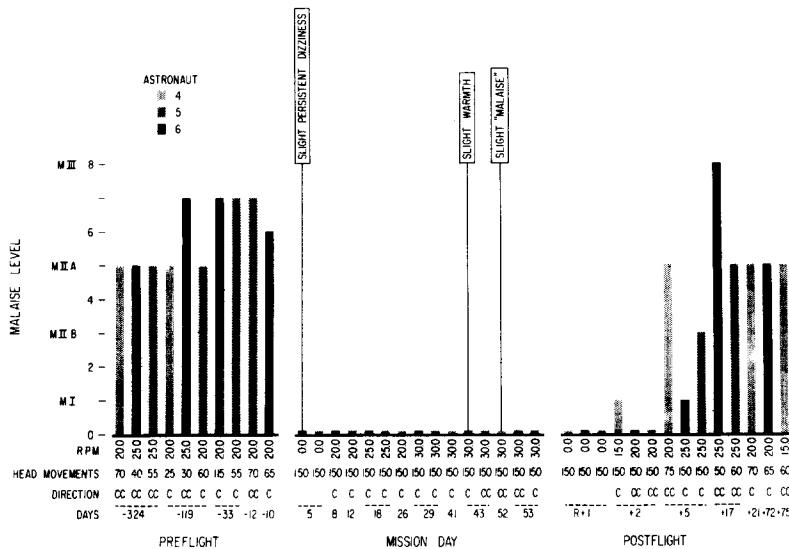


Fig. 3. Motion sickness symptomatology, scored in points, of astronauts 4, 5, and 6, quantitatively expressed in terms of malaise level, as evoked by the test parameters (rotational velocity, number of head movements, and direction of rotation) used before, during, and after the SL-III mission.

Astronaut 4 was tested on the RLC on two widely separated occasions preflight and demonstrated similar susceptibility levels each time. On MD 26 and MD 41 he was symptom free when rotated clockwise, respectively, at 20 and 30 rpm. On MD 52 he was rotated counterclockwise at 30 rpm and experienced what he described as a slight vague “malaise” that persisted for approximately 30 min following the test. The question arises whether secondary etiological factors accounted for both the appearance and nature of this symptom, which is not typical of acute motion sickness, or whether the astronaut was not quite adapted to counterclockwise rotation. Postflight, astronaut 4 was symptom free on *R* +1 when he executed head movements with the RLC stationary and on *R* +2 when it was rotating clockwise at 15 rpm. On *R* +5 an endpoint was reached that approximated his preflight susceptibility level.

Astronaut 5 was tested on four widely separated occasions preflight, and an M II A endpoint was always reached with approximately the same stressor stimulus. Aloft astronaut 5 was tested on six occasions, the first on MD 5 with the RLC

stationary. Thereafter, the angular velocities of the chair, beginning at 20 rpm, were increased to 25 rpm, then to 30 rpm for the last three tests; symptoms of motion sickness were never elicited. Postflight astronaut 5 was symptom free on  $R + 1$  when the RLC was stationary and again on  $R + 2$  when the RLC was rotating counterclockwise at 20 rpm. On  $R + 5$  astronaut 5 experienced very mild symptoms (dizziness II, drowsiness I), but an endpoint was not reached when the RLC was rotating clockwise at 25 rpm. The M II A endpoint was reached on  $R + 17$  with the RLC rotating counterclockwise.

Astronaut 6 was tested on four widely separated occasions preflight and demonstrated similar test scores on all four occasions (Fig. 3). Aloft astronaut 6 was tested on six occasions. On MD 5 he experienced slight but persistent "dizziness" when the RLC was stationary. (It will be recalled that on MD 5, astronaut 6 was just getting over his susceptibility to motion sickness in the workshop and that he had taken an antimotion sickness drug on MD 3.) Thereafter, he was symptom free when rotated clockwise at 20, 25, and 30 rpm on MD 8, MD 18, and MD 29, respectively. On MD 43 he experienced "some body warmth" that did not rate a 1-point score (moderate intensity required) while rotating clockwise at 30 rpm, but he was symptom free 10 days later while rotating counterclockwise at 30 rpm.

#### 4. Discussion

Although the astronauts provided an elite group of "subjects" who served as their own controls, six, nonetheless, is a small number when dealing with the complex nature of motion sickness. In consequence, only self-evident findings will be used as points of departure in the following discussion. It is convenient to distinguish not only between operational and experimental stimulus conditions, but also among four stages in orbital flight; during the first three stages the six astronauts were based in the command module and thereafter they were in the workshop.

##### *Command module*

*Sixty minutes into orbit.* Shortly after transition into orbit astronaut 6 experienced mild symptoms characteristic of motion sickness. The close temporal relation between the astronaut's activities and symptoms and the relief following administration of the AMS capsule confirmed the diagnosis, the earliest among space crewmen on record. The question arises whether the events associated with transition into orbit rendered astronaut 6 liable to motion sickness even though his activities furnished the immediate eliciting stimuli. On entry into weightlessness few of the internal adjustments that were initiated during the transition are complete. Alternations such as in hemodynamic adjustments, redistribution of body fluids, and changes in electrolyte balance that might affect susceptibility to motion sickness, either via the vestibular system or more indirectly, are at various stages along their time course [25-29]. Even though the stimulus to the macular receptors due to gravity is lost, the question has arisen whether the physiological deafferentation process has stabilized. Loss of the G-load would affect the

“modulating influence” of the otolithic system. If the otolithic influence is inhibitory, the responses elicited by stimulation of the canals are said to be “exaggerated” [30]. The observations bearing on this point in parabolic flight, however, indicate reduced responses to canalicular stimulation [31–33] during the weightless phase.

Fortunately, in the case of astronaut 6, it was possible to follow his course which demonstrated that there was little or no support for the notion that predisposing factors in addition to the immediate eliciting factors were involved.

It is noteworthy that astronaut 2, prior to insertion into orbit, took one AMS capsule. The drug, after absorption, almost certainly reduced susceptibility to motion sickness for a few hours, hence, afforded a degree of protection during a period of changing conditions whether this protection was needed or not. None of the other four astronauts experienced motion sickness during this period, implying only that they were far less susceptible than astronaut 6. In the absence of symptoms there is no further clue to the way in which their susceptibility to motion sickness was affected by transition into orbit.

*Continuation of the predock period.* The duration of these periods in SL-II and SL-III was, respectively, 10 hr 36 min, and 7 hr 40 min. Astronaut 6 continued to be susceptible to motion sickness. He purposely refrained from taking another AMS capsule, and symptoms of motion sickness were partly controlled by self-imposed limitation of activities. It is important to point out that, by limiting activities, he was also limiting his rate of acquisition of adaptation effects. None of the other five astronauts experienced motion sickness. Astronaut 2 remained under protection of the single AMS capsule during much of the first half but not for the latter half of this period. The inference may be drawn that, under the stimulus conditions, astronauts 1, 3, 4, and 5 would not have experienced motion sickness however much longer they remained under such conditions. This is supported by the evidence that in pre-Skylab space missions, the onset of symptoms in space crewmen experiencing motion sickness was within the time frame of the predock periods of the Skylab missions.

*The postdock period.* This period was 18 hr in the SL-II mission and 65 min in the SL-III mission.

Not only was the duration of the postdock period far longer for the SL-II crewmen as compared with the SL-III crewmen, but also their activities were more varied. These tasks included extravehicular activity and intense preparations for entering the workshop. In the foregoing section on Results it was pointed out that when the SL-II crew went aloft, they were charged with difficult tasks. If these tasks had any influence on their susceptibility to motion sickness, the influence would be favorable.

In the SL-III mission astronaut 6 not only remained susceptible, but the presence of symptoms caused him to restrict his activities. Astronauts 4 and 5 did not experience motion sickness, although activities during this period increased.

*Workshop: Under operational conditions* astronauts 4 and 5 experienced motion sickness for the first time, inferring that stimulus conditions were more stressful than at any time in the command module and implying that the adaptation acquired in the command module offered inadequate protection in the

workshop. In contrast, none of the SL-II crewmen experienced acute motion sickness during this period; this indicates that either there was never any need to adapt, or, far more likely in the case of astronauts 2 and 3 at least, that the adaptation acquired prior to entry was adequate.

The spaciousness of the workshop provided the greatest opportunity up to the present time to reveal the great potentialities in weightlessness for limiting natural movements and encouraging highly unnatural movements that often resembled acrobatic feats. Movies of the astronauts carrying out their tasks in the workshop, often involving transitions from one place to another, best display the relatively large component of passive movement associated with active movements, with the opportunities for generating unusual patterns of vestibular stimulation and unusual or abnormal visual inputs.

Astronauts 4 and 5 began to have symptoms shortly after entering the workshop, and soon thereafter astronaut 6 vomited. The question has been raised whether the motion sickness experienced by astronaut 6 influenced unfavorably the elicitation of symptoms in the other two crew members. This seems unlikely for two reasons; namely, astronaut 6 had been motion sick (or highly susceptible to motion sickness) since the first hour in flight, and symptoms appeared in astronauts 4 and 5 before astronaut 6 vomited. Among those three astronauts under workshop conditions, astronaut 6 was not only most susceptible but also susceptible for the longest period while astronaut 4 was least susceptible with the shortest time course.

It was on MD 2 that astronaut 5 executed standardized head movements for a short period and did not have any symptoms with eyes closed, but, continuing the head movements with eyes open, he did experience symptoms. Whether symptoms would have been elicited if the head movements had been continued with eyes closed is not known, but the visual inputs contributed to the interacting sensory stimuli and probably were of etiological significance. This brief "experiment" represented an attempt at programming the acquisition of adaptation effects and underscores the possible advantage of "eyes closed" in the early stage, something that has been demonstrated under laboratory conditions [34].

On MD 1 to MD 3 astronauts 4, 5, and 6 were either experiencing symptoms or using preventive measures to avoid symptoms. After the third day it is difficult to sort out the countervailing influences of eliciting and restoring mechanisms, upon which were superimposed the nonspecific general effects of a period of ill health. Recovery was complete on MD 7.

There is much resemblance between the time course of the symptomatology of motion sickness elicited in the workshop and in a slow rotation room. This resemblance is due in large part to the etiological relation between "activities" and eliciting stimuli. The two environments have, in common, the generation of stressful stimuli when a person is engaged in various activities and abolition of the stressful stimuli when the head and body are fixed. In both environments there are: (1) a delay in appearance of symptoms after the onset of the stressful stimuli, (2) a gradual or rapid increase in severity of symptoms, (3) modulation by secondary influences, (4) perseveration for a time after sudden cessation of stimuli, and (5) a response decline, indicating that restoration is taking place

spontaneously through homeostatic events and processes. If the intensity of the stimuli is high, the latencies associated with the appearance and disappearance of symptoms will be brief. With the acquisition of adaptation effects and concomitant reduction in the intensity of the stimuli, the latencies are increased, and, characteristically, restoration may not only be prolonged but also complicated by the appearance of symptoms not typical of acute motion sickness. Thus, in a slow rotation room it has been demonstrated that drowsiness may be elicited in the virtual absence of other symptoms[35] and that after the nausea syndrome has disappeared, drowsiness, lethargy, and fatigue remained[36].

An analysis of the foregoing and similar manifestations has led to the definition of a unique syndrome. For clarity, it is termed the Sopite syndrome (from the Latin Sopor, meaning drooping or drowsy) (Graybiel, A. and Knepton, J. C., "The Sopite syndrome: A component or even sole expression of motion sickness symptomatology," in preparation). This syndrome may be part of the clinical symptomatology or, if the eliciting stimuli are at a critical low level of intensity, it may be the sole manifestation. In addition to drowsiness and lethargy, there is a reduced interest in ongoing events and a performance decrement, especially when attempting to carry out tasks involving high-level mental activity. Lastly, just as in recovering from any illness, there is a period termed "convalescence." It is possible that astronaut 2 experienced something in the nature of the Sopite syndrome in the workshop.

*Workshop: Under experimental conditions* in the workshop the virtual failure to elicit symptoms of motion sickness in any of the five astronauts who were exposed to a stressful type of accelerative stimuli in a rotating chair (on or after MD 8 in the workshop) implies that, under the stimulus conditions, susceptibility was lower aloft than on the ground, where symptoms were elicited preflight and postflight. The amount of this decrease in susceptibility could not be measured because the "ceiling" on the test (30 rpm) was so quickly reached.

The difference in susceptibility between workshop and terrestrial conditions is readily traced to the otolith system for the reason that stimulation of the canals was the same aloft as on the ground, and visual inputs were always excluded. If it is assumed that the otolith system is responsible, then the absence of stimulation to the otolithic receptors due to gravity must have a greater influence (tending to reduce the vestibular disturbance) than the disturbing influences of the transient centrifugal linear and Coriolis accelerations generated when head and trunk movements were executed in the RLC. These transient accelerative forces, as pointed out in the section on Procedure, are substantial, and their repetitive pattern is a characteristic that tends to elicit motion sickness through summation or cumulation. It is reasonable to conclude that the effects of the "transients" generated aloft would be at least as unusual in pattern as on the ground; thus, the difference in susceptibility must be traced to the difference in G-load. The absence of gravity, causing what has been termed "physiological deafferentation" of the otolith receptor system, would be expected to reduce not only the indirect modulating influence of the otolithic system on the canalicular system but also its opportunity to interact directly with this system.

The important question arises whether the prior adaptation to weightlessness



“transferred” to the rotating environment or whether it played a secondary role; namely, simply ensuring the absence of overt as well as any covert symptoms of motion sickness. In this connection, the findings in parabolic flight are pertinent, inasmuch as the periods of exposure to near-weightlessness are brief. The alternating periods of supragravity and subgravity states in parabolic flight create a bias in favor of increased susceptibility to motion sickness in the RLC. Motion sickness susceptibility has been compared in 74 healthy subjects who executed standardized head movements while they rotated at constant velocity during sequential weightless phases of parabolic flights and during periods of exposures under laboratory conditions [37]. Most subjects demonstrated either a substantial increase or decrease in susceptibility, while a few experienced little change in susceptibility.

## 5. Conclusions and recommendations

1. Skylab findings indicate three ways or means that permit weightlessness, a static state, to qualify as a unique motion environment: first, its quasidynamic potentialities for inducing changes in nonrigid parts of the body; second, its unique potentialities at once limiting a person's natural movements and encouraging unnatural movements that may result in unusual vestibular and visual sensory inputs; third, the demonstration under specific experimental conditions, designed to elicit motion sickness by stimulation of the vestibular organs, that susceptibility is lower aloft than on the ground. An attempt has been made to implicate mechanisms that might be involved, but a full understanding awaits systematic investigations.

2. The lower susceptibility to vestibular stimulation aloft, compared with that on the ground under experimental conditions, was “traced” to the reduction in G-load but had to meet a precondition; namely, either there was no need to adapt, or, as exemplified by astronaut 6, adaptation to weightlessness had been achieved. The inference is that from the standpoint of the vestibular organs, the “basic” susceptibility to motion sickness is lower in weightlessness than under terrestrial conditions; how much lower remains to be measured.

3. In the case of astronaut 6 one must account for: (a) a rapid increase in susceptibility to motion sickness on transition into orbit, (b) an aggravation of symptoms on entry into the workshop, (c) long persistence of increased susceptibility until adaptation was achieved, and (d) reduced susceptibility under experimental conditions (compared with ground-based tests) on and after MD 8. The prolonged period of susceptibility would seem to rule out short-lived factors associated with entry into orbit, and the acquisition of adaptation appeared to be in response to activities generating vestibular stimuli, with visual inputs also playing an important role. If it is assumed that astronaut 6 was simply more susceptible aloft than astronauts 4 and 5, the differences among them would be quantitative and ascribed if not explained on the basis that weightlessness qualifies as a true, if unique, motion environment.

4. In the workshop astronauts 4 and 5 experienced motion sickness for the

first time aloft, thus inferring at once the more stressful stimulus conditions in the workshop compared with those in the command module and the inadequate level of adaptation previously acquired. The SL-II crewmen did not have motion sickness in the workshop, implying either there was no need to adapt (a possibility in the case of astronaut 1) or that prior adaptation in a less stressful environment was adequate. These findings should be exploited from the scientific and operational standpoints. For example, the period during which the "adequate" adaptation in the command module was acquired by the SL-II crewmen was much shorter than the period during which SL-III crewmen were motion sick; let alone the additional period while recovering from motion sickness. Both of these implications are arguments for programming the acquisition of adaptive effects.

5. Vestibular side effects tend to fall into two categories; namely, immediate reflex phenomena (illusions, sensations of turning, etc.) and delayed epiphenomena that include the constellation of symptoms and syndromes comprising motion sickness. Under both operational and experimental conditions in SL-II and SL-III missions the reflex phenomena were often striking, yet did not herald the onset of motion sickness. The relationship between the two categories deserves further study.

6. The symptomatology of motion sickness in the workshop resembled in some respects the symptoms manifested in a slow rotation room when the subjects were immediately exposed to a predetermined terminal velocity. Under both stimulus conditions the stressful effects depended on "movements" that are under voluntary control. Not only is there a continual alteration between "eliciting stimuli" and "recovery events" (which are spontaneous), but, also, a delay precedes the appearance of symptoms and a delay precedes their disappearance.

7. The drug combination l-scopolamine and d-amphetamine was effective in prevention and treatment of motion sickness; nonetheless, it is not the "ideal" AMS drug. Used as a therapeutic test it was helpful in diagnosing motion sickness in astronaut 6. The effectiveness of the drug in the workshop provides evidence that antimotion sickness drugs are useful in a motion environment where visual cues play a large etiological role.

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