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JOINT REPORT

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SUMMARY PAGE

THE PROBLEM

Is motion sickness experienced in parabolic flight dependent upon vestibular function?

Is motion sickness susceptibility influenced by g-loading?

FINDINGS

Motion sickness as provoked by parabolic flight maneuvers and induced by active head movements during the hypergravity phases in certain subjects did not occur in any of the five subjects without functional labyrinths.

Among the 25 normal pilot-type subjects, great inter- and intra-individual differences were found in susceptibility to motion sickness under the different force environments used in this study. Acute motion sickness developed in four subjects merely as a result of the oscillations of g-load encountered in the parabolic maneuvers, while the remaining 21 were symptom free. These 21 and the most resistant subject among the other four were tested on other and separate occasions to determine the effect upon their susceptibility of standardized head movements during: 1) the hypergravic phase, 2) the weightless phase of the parabola while they were restrained in an aircraft seat, and 3) the weightless phase while they were rotated in a chair.

Four of the six subjects tested under condition 1 were completely unaffected; Malaise III developed in one, and one experienced slight stomach awareness.

Head movements during weightlessness under condition 2 provoked severe symptoms in five and moderate symptoms in one of twelve subjects tested. Five of these six susceptible subjects manifested no symptoms without head movements.

The 15 subjects rotated in weightlessness under condition 3 revealed either a marked positive or negative change in susceptibility relative to that measured by a similar method under terrestrial conditions. These subjects were divided almost equally into two groups, i.e., those with increased and those with decreased susceptibility to Coriolis stimulation in weightlessness. The measurements, made on as many as three different occasions each separated by a period as long as 11 months, were found to be highly reliable.

ACKNOWLEDGMENTS

We are indebted to all the subjects and to the assistants at Wright-Patterson Air Force Base for their cooperation in the study.

INTRODUCTION

The physical properties of the cupulo-endolymph system would indicate that mechanically it is essentially independent of gravitational loading; in terms of cupular response, for example, the effect of moving the head should be equivalent under null or terrestrial gravitational conditions. One study found no significant difference between semicircular canal sensitivity in these two environments (26), while others (1, 16, 30) presented evidence that the afferent cupular signal may not escape the influence of g-loading. If the signal is modifiable, the process must involve neural interaction with gravireceptor impulses, in particular those originating in the otolith organs which are highly sensitive to gravitational change as well as to linear acceleration (21, 23) and CNS processing. In weightlessness the interaction pattern would be bizarre; with regard to both magnitude and direction of the resultant inertial force stimulus, otolithic afferent impulses would be totally different from those normally generated by head movements. Even with the head held stationary, there is evidence that zero g may constitute a sustained "minus" stimulus to the gravireceptor organs, resulting in activation rather than physiological deafferentation of these organs (1).

Research concerning the effect of weightlessness upon vestibular function was suddenly given applied status, and the problem was defined in terms of a specific behavioral response, viz, motion sickness, when Titov suffered this malady during his orbital flight (30). Controlled measurements in a previous study (10), as well as those of the present one, using parabolic flight to generate weightlessness confirmed that this response could be obtained from certain but not all individuals exposed to weightlessness and was directly attributable to agravic vestibular activity.

Titov manifested vestibulo-vegetative disorders which were intensified by head movement. After approximately his fourth revolution of the Earth and up to the end of his flight, he felt discomfort in the form of symptoms which were similar to those of mild motion sickness or seasickness and which persisted until his reentry into the Earth's atmosphere. Other cosmonauts exposed to similar or longer periods without gravity also experienced unusual responses to head movements (5, 27, 29). Popovich noted that sharply executed forward head movements produced sensations similar to those felt when such movements were made while revolving in a rotating chair in the laboratory. Feoktistov and Yegerov reported autonomic as well as unpleasant sensory reactions following abrupt head movements. The other cosmonauts (5, 29) and all American astronauts (2) at the time of our study reported no untoward vestibular responses associated with their orbital space flights even when active head movements were made in an attempt to provoke symptoms.

Individual differences in susceptibility under these circumstances cannot be considered unusual if judged by the divergent response to motion that is typically found in a variety of laboratory and field situations. Furthermore, this response may be conditioned by experience (4, 7, 12, 15, 24, 25, 28), e.g., training associated with flying and vestibular habituation exercises. No valid conclusions can be reached regarding the individual differences in susceptibility to what is now termed "space" or "cosmic" sickness, since the available information is comprised primarily of anecdotal reports of the space pilots. We lack data on: 1) the linear and angular accelerations resulting from possible spacecraft instability (3) or unusual flight conditions, as well as on the casual head or body movements which varied in number, direction, magnitude, and velocity among the pilots, e.g., Tereshkova severely limited her head and trunk movements in flight (29); 2) functional integrity of the macular and cupular organs of each pilot and his susceptibility to various accelerative force patterns under normal-g conditions; and 3) other factors including training and conditioning.

The purpose of the present study was to determine and grade systematically by standardized procedures any inter- and intra-subject differences in motion sickness evoked during exposure to weightlessness, hypergravity, and normal gravity conditions. The only available means to counteract gravity for a reasonable length of time, short of space flight, is a Keplerian curve pattern of flight, which necessarily introduces periods of hypergravity force ($\sim$2.0 g) before and after each of the repeated transient zero-g periods. Since these events in themselves are capable of provoking motion sickness symptoms (6, 15, 25), they had to be evaluated separately in this study.

PROCEDURE

SUBJECTS

A total of 25 normal individuals and five persons with complete bilateral functional loss of the labyrinthine organs were selected as subjects. Each had passed a rigid medical examination which qualified him for participating in the parabolic maneuvers.

The normal group consisted of civilians and military officers ranging in age from 23 to 42 years. Each manifested ocular counterrolling (18-20) responses and thresholds for caloric irrigation (17) which were within normal limits. All of these subjects had flight experience; most had logged between 200 and 1000 hours of flying and seven had greater than 1000 hours. Nine of the normal subjects and the five labyrinthine-defective (L-D) subjects had considerable parabolic flight experience. In general, the motion sickness susceptibility indices of the normal subjects were well distributed among those of a group of 250 normal subjects (22) who were tested by the same standard procedure during which Coriolis acceleration is used as the stressor.

The L-D subjects who served as controls were characteristically completely free of any of the symptomatology of motion sickness when tested in a variety of conveyances and devices and in aircraft during parabolic flight (8-10; 14). Their personal data and the results of functional tests of their semicircular canals and otolith organs by the threshold caloric (17) and ocular counterrolling (18-20) methods have been summarized in another report (20).

METHOD

All flights were made in a jet aircraft (USAF KC-135) specifically modified and staffed for airborne experimentation in weightlessness. The Keplerian trajectory, the standard one routinely flown by this aircraft, yielded approximately 24 seconds of zero g, ± 0.05 g, as verified by accelerometer tracings.

The endpoint for each test condition was the appearance of severe malaise (M III), a specific endpoint quantitatively identified by the type and intensity of recognized motion sickness symptoms (Table I) (11).

I. Subject Stationary: No Head Movements

This phase of the experiment was conducted to test the effect of parabolic flight stress per se upon the evocation of motion sickness symptoms among those subjects who had never flown this maneuver or who had reported that it produced significant symptoms. Each of these eight subjects was restrained with a safety belt in an aircraft seat as he would be normally in flight. His eyes were uncovered. He was instructed to remain as stationary as possible and to brace his head against the seat during the parabolic maneuvers. Objective and subjective signs and symptoms as functions of the number of parabolas flown were graded (Table I) by a trained observer. Formal testing ended when the subject's symptoms reached M III or when no symptoms appeared after 24 parabolas.

II. Subject Stationary: Standardized Head Movements

The subject was secured in an aircraft seat as in part I but he was required either to: 1) fix his head during all phases of the parabolic maneuver except in weightlessness when he was required to make five or more standard head movements as described in part III below, or 2) fix his head except during the hypergravic periods of the maneuver in which he executed these head movements. Twelve subjects moved their heads in weightlessness and six under hypergravitational conditions. Two of these subjects (EN, RE) were tested under both conditions. The buildup of symptoms to the Malaise III level as a function of the number of head movements and the number of parabolas flown was recorded by a trained observer.

III. Subject Rotated: Standardized Head Movements

The subject was rotated on a Stille-Werner chair at a speed of either 5.0, 7.5, 10.0, 12.5, 15.0, 20.0, 25.0, or 30.0 rpm in both the ground-based (1.0 g) and in-flight tests (Table II). The chair velocity used in each case was predicated upon the subject's answers on a previously administered Pensacola Motion Sickness Questionnaire (13). Susceptibility to Coriolis sickness was measured in terms of the chair velocity and the number of standardized head movements required to provoke Malaise III. Very frequently the rpm initially selected for the ground-based (1.0 g) test was too high or too low for the experimental design. In certain cases when the proper rpm could be

Table I

Diagnostic Categorization of Different Levels of Severity of Acute Motion Sickness

Category	Pathognomonic 16 points	Major 8 points	Minor 4 points	Minimal 2 points	AQS* 1 point
Nausea syndrome	Vomiting or retching	Nausea[+] II, III	Nausea I	Epigastric discomfort	Epigastric awareness
Skin		Pallor III	Pallor II	Pallor I	Flushing/Subjective warmth ≥ II
Cold sweating		III	II	I	
Increased salivation		III	II	I	
Drowsiness		III	II	I	
Pain					Headache ≥ II
Central nervous system					Dizziness Eyes closed ≥ II Eyes open III

Levels of Severity Identified by Total Points Scored

Frank Sickness	Severe Malaise	Moderate Malaise A	Moderate Malaise B	Slight Malaise
(S)	(M III)	(M IIA)	(M IIB)	(M I)
≥ 16 points	8 - 15 points	5 - 7 points	3 - 4 points	1 - 2 points

*AQS - Additional qualifying symptoms. +III - severe or marked, II - moderate, I - slight.

predicted from the initial calibration run, the test was made in weightlessness prior to the definitive retest under terrestrial conditions. In other cases, the subject was re-tested on the ground on another day and the rpm was adjusted so that Malaise III appeared after greater than 25 but less than 75 head movements. In most cases, only one additional trial was necessary to identify the appropriate rpm of the chair for a given individual, but there were instances in which it was necessary to test Coriolis sickness susceptibility on three different days. When an individual served in a second or third series of tests the previous order of testing at 0 and 1 g was reversed whenever possible. The fact that none of the subjects on repeated trials revealed any substantial variation in motion sickness susceptibility as measured by this method provided a sound basis for comparing ground-based calibration of the subject with that obtained in zero g. It is possible that the design of this test contributed to the high test-retest reliability since adaptation was more difficult with: 1) the eyes covered, 2) a complex pattern of head movements, 3) a limit in the exposure to specific head movements, and 4) a reversal of the direction (CW, CCW) of rotation from one session to the next.

Measurement of Coriolis (motion) sickness susceptibility followed a standard procedure (22). The subject was secured with seat belts and a metal bar across his lap within the Stille-Werner chair which was modified for parabolic flight maneuvers and attached to the aircraft floor. A blindfold was worn by the subject to exclude any influence from the difference in visual environment of the laboratory and aircraft interior. The head rest was adjusted so that, when used, the subject looked straight up. When he leaned forward, the horizontal lap bar formed a stop for the straight-down position. Leftward and rightward head movements of 90° were executed without using any physical stops but were monitored by the examiner. The sequence for carrying out the basic movement of the head and upper torso as required to effect approximately 90° displacement of the vestibular organs in the roll and pitch planes was carried out according to tape-recorded instructions, as follows: forward, upright, pause; rightward, upright, pause; backward, upright, pause; leftward, upright, pause; forward, upright, rest. Each of these steps was timed at 1-second duration, with the total sequence equalling 14 seconds. A rest interval of 20 seconds was interposed between each series of five head movements. When the subject had demonstrated that he was capable of making proper head movements, the chair was accelerated $5°/sec^2$ until the selected rotational speed was reached. After at least 60 seconds at constant velocity the program of head movements was begun and continued until Malaise III developed, as judged by objective and subjective signs and symptoms; at this point the chair was decelerated slowly to a stop. In most cases, when the subject was taken from the chair, he immediately began to recover from his symptoms, and full recovery occurred usually within 30 minutes following the test.

<u>In-flight measurements</u>. - The test procedure in-flight was identical to that on the ground with the exception that the interval between each five head-movement sequence was not always the same due to flight procedural requirements, but in most cases there was an interval of between 20 and 30 seconds. Under each of the zero-g and 1-g conditions six subjects were tested once, six twice, and three three times by the same

method over a period of 11 months as shown in Table II. The order of testing on the ground and aloft after initial calibration on the ground was randomized among the subjects and between the test and retest sessions.

The chair was rotated at a constant velocity throughout the several Keplerian trajectories required to complete the test. Whenever possible the trajectories were flown consecutively in "roller-coaster" fashion. However, head movements were executed only during the essential weightless (0 ± 0.05 g) period of each trajectory.

RESULTS AND DISCUSSION

The results of testing the normal subjects under all of the various conditions of this study are summarized in Table II.

Four subjects experienced emesis without head movements during parabolic flight maneuvers. The range of susceptibility of these subjects was indicated by the parabolas in which Malaise III occurred: 4, 7, 10, and 18. The three most sensitive persons of this group were not used further; the remaining one (AU) provided the opportunity to study under the other experimental conditions an individual in whom motion sickness was evoked by the parabolic maneuvers alone. The other 21 subjects were relatively resistant to parabolic zero-g flight stress per se, as indicated by their lack of symptoms throughout repeated flights of at least 24 and often more than 48 parabolas. Among the twelve persons who made the basic pattern of head movements during zero g, while restrained in the aircraft seat, no symptoms developed in six (Table II) while five experienced Malaise III and one, Malaise IIA (Table II and Figure 1). By comparison, five of these last-mentioned six subjects were symptom free when they did not make purposeful head movements in weightlessness. Such movements by the sixth (and only subject affected by parabolic flight per se) greatly accelerated the onset of his symptoms which reached the Malaise III level in 4 parabolas compared to 18 with his head stationary. This subject (AU) reported that this latter number of parabolas was approximately that required to provoke symptoms in several other zero-g flights in which he flew as a passenger.

Among the six normal subjects who were found by calibration on the ground to have relatively high resistance to motion sickness, four were unaffected by their head movements during the hypergravic portion of the 24 Keplerian maneuvers used for this test. Malaise III developed in one after 21 parabolas, and the other experienced only slight stomach awareness after 24.

The two subjects who made head movements during the weightless period in one test session as well as during the hypergravic period of the parabolic maneuver in another session remained free of symptoms in both cases.

The effect on each of the fifteen subjects who performed head movements during rotation under weightlessness as well as under normal gravitational conditions is portrayed in Figure 2. The remarkable finding is that the subjects fell into two distinct

Table II

Experimental Design and Findings in 25 Normal Subjects

Subject	Date	Subject Stationary: Head Stationary	Subject Stationary: Active Head Movements, 0 g		Subject Stationary: Active Head Movements, 2 g		Subject Rotating			Level of Symptoms
		Parab's	H-M's	Parab's	H-M's	Parab's	rpm	g level	H-M's	
AL	12-20-66	≥24								0
	1-3-67						7.5	1.0	55	M III
	1-4-67						7.5	0	25	M III
	1-6-67		75	15						M IIA
	4-20-67						5.0	0	17	M III
	4-26-67						5.0	1.0	85	M III
AU	12-28-66		20	4						M III
	1-4-67	18								M III
	1-5-67						20.0	1.0	100	M III
	1-6-67						20.0	0	35	M III
	4-19-67						20.0	1.0	90	M III
	4-20-67						20.0	0	55	M III
	11-14-67						25.0	1.0	65	M III
	11-15-67						25.0	0	35	M III
BE	11-9-67						10.0	1.0	70	M III
	11-16-67						10.0	0	15	M III
CA	12-28-66		240	≥24						0
	12-29-66						30.0	1.0	70	M III
	1-3-67						30.0	0	100	0
	1-5-67				120	≥24				M I
	4-19-67						30.0	0	32	M III
	4-25-67						30.0	1.0	35	M III
DE	1-4-67	≥24								0
	1-5-67				120	≥24				0
DH	1-4-67	10								M III
DO	1-3-67						30.0	1.0	100	0
	1-5-67				120	≥24				0
EI	12-30-66	7								M III
EN	12-30-66		120	≥24						0
	1-5-67				120	≥24				0
FO	12-29-66						15.0	1.0	5	M IIA
	12-30-66		90	14						M III
	1-5-67	≥24								0
GI	12-28-66						20.0	0	100	0
	12-29-66						20.0	1.0	95	M III
	1-4-67				105	21				M III
	4-18-67						25.0	0	160	0
	4-24-67						25.0	1.0	50	M III
	11-8-67						30.0	0	85	0
	11-17-67						30.0	1.0	60	M III
HA	1-3-67						20.0	1.0	100	M III
	1-5-67						30.0	0	110	M IIA
	1-6-67						30.0	1.0	65	M III
	4-20-67						30.0	0	162	M III
	4-25-67						30.0	1.0	50	M III
JO	1-5-67		120	≥24						0
KE	12-20-66						12.5	1.0	45	M III
	1-3-67						12.5	0	27	M III
	4-21-67						10.0	0	60	M III
	4-25-67						10.0	1.0	80	M III
OD	11-8-67						12.5	0	75	M III
	11-16-67						12.5	1.0	130	M III
PR	1-4-67		120	≥24						0
RA	1-4-67	4								M III
RE	12-29-66						30.0	1.0	65	M III
	12-30-66		120	≥24						0
	1-3-67				120	≥24				0
	1-6-67						30.0	0	100	0
	4-20-67						30.0	0	168	M III
	4-21-67						30.0	1.0	35	M III
SC	12-27-66		80	16						M III
	12-28-66						20.0	1.0	50	M III
	12-29-66						20.0	0	25	M III
	12-30-66	≥24								0
SE	1-4-67		120	≥24						0
SI	11-16-67						15.0	1.0	90	M III
	11-17-67						15.0	0	100	0
SM	12-30-66	≥24								0
	1-3-67						20.0	1.0	25	M III
	1-5-67						20.0	0	100	0
	1-6-67		70	14						M III
	4-18-67						20.0	0	46	M III
	4-25-67						20.0	1.0	15	M III
TA	12-28-66						20.0	0	75	M III
	1-5-67						20.0	1.0	20	M III
	4-20-67						20.0	0	62	M III
	4-24-67						20.0	1.0	15	M III
	11-9-67						20.0	0	55	M III
	11-16-67						20.0	1.0	15	M III
TI	10-26-67						10.0	1.0	70	M III
	11-5-67						10.0	0	30	M III
WA	11-8-67		75	15						M III
	11-9-67						10.0	1.0	75	M III
	11-13-67						10.0	0	35	M III
	11-16-67	≥24								0

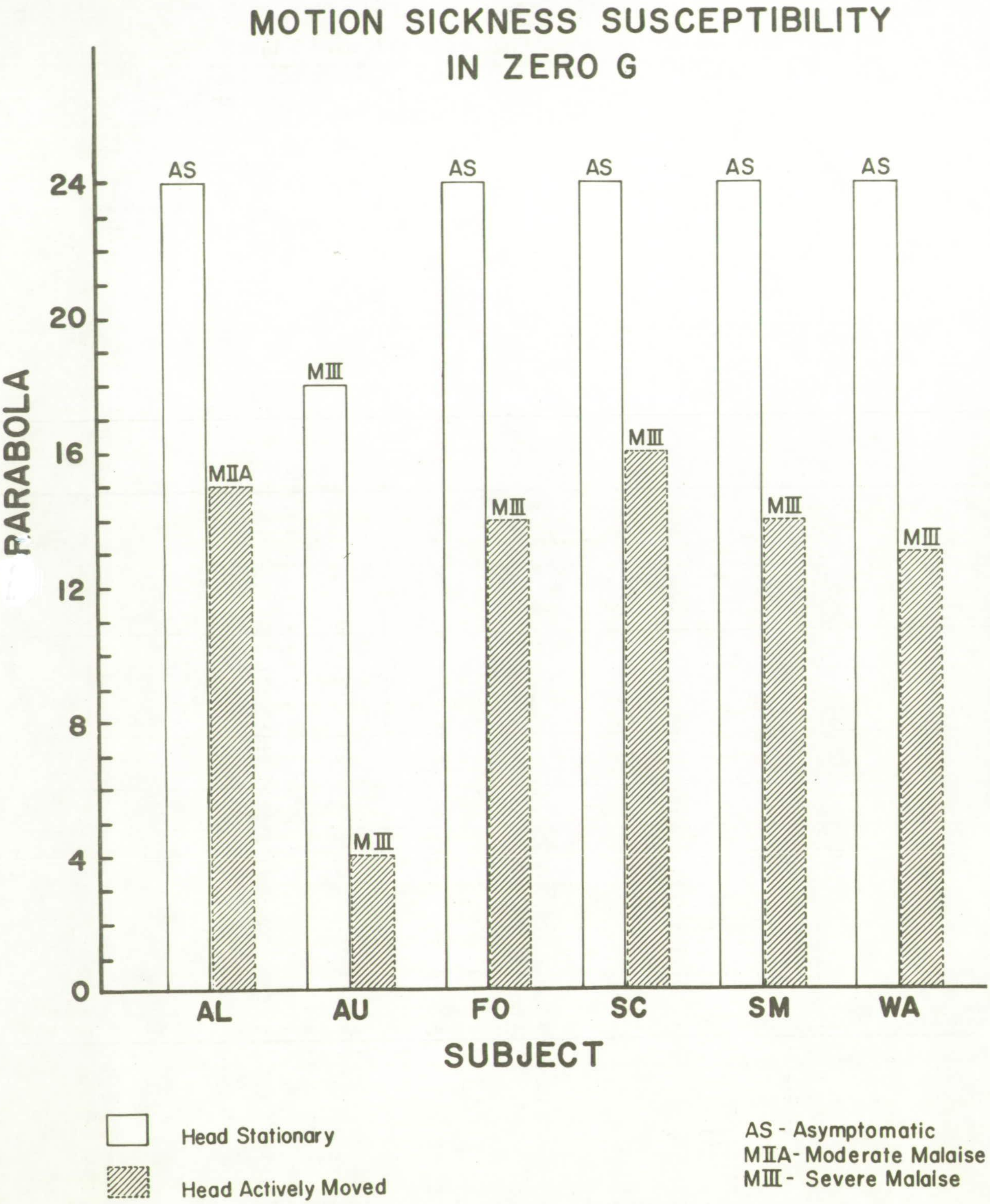

Figure 1

Effect Among Six Susceptible Subjects of Active Head Movements Relative to the Restrained Condition Upon Motion Sickness Susceptibility Measured in Terms of the Number of Parabolas Required to Provoke Malaise III

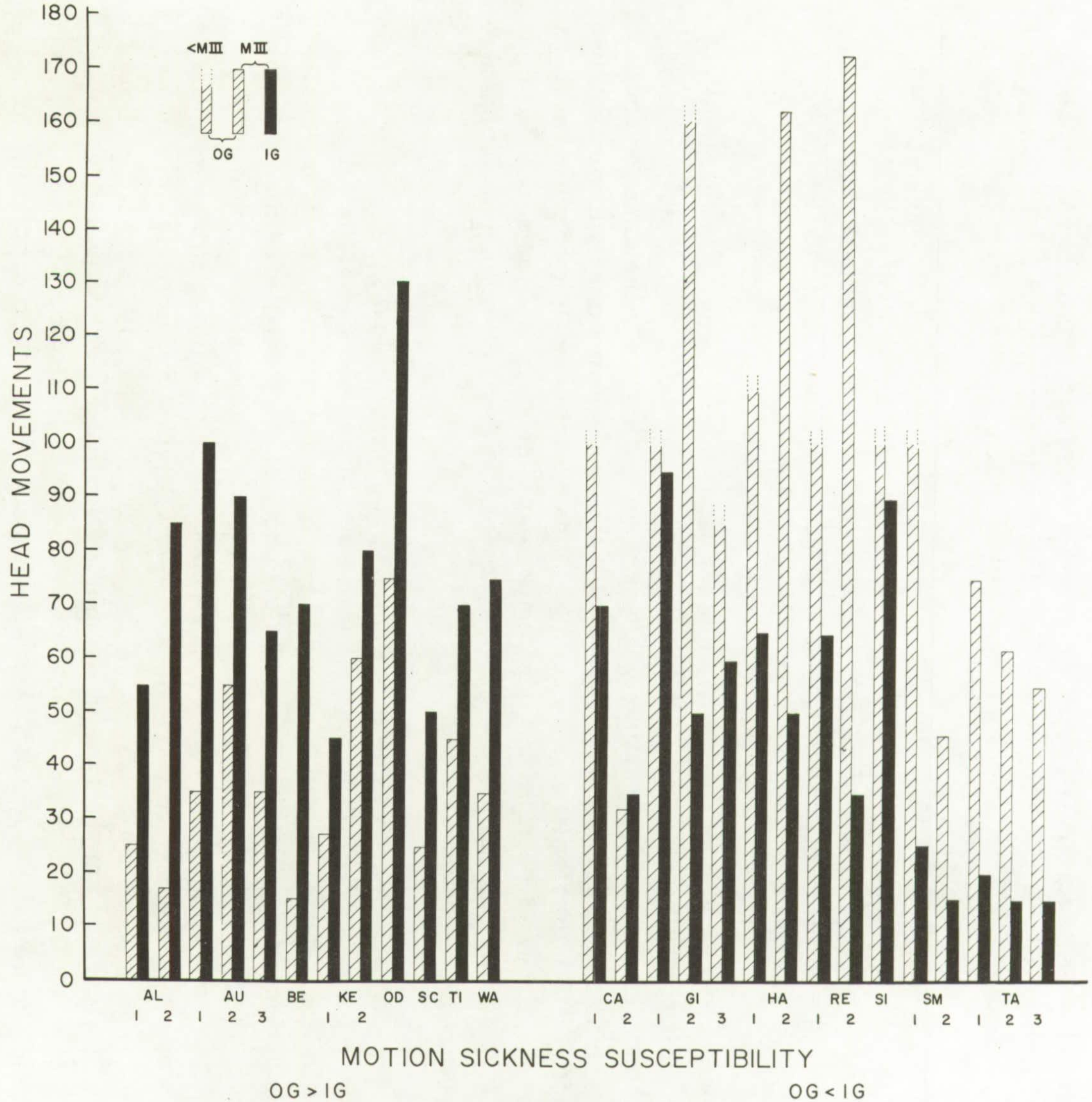

Figure 2

Comparison of Coriolis (Motion) Sickness Susceptibility of 15 Subjects
Measured in Weightlessness and Under Terrestrial Conditions

groups: those with increased and those with decreased susceptibility to Coriolis sickness in weightlessness. This change in susceptibility appears to be unpredictable from ground-based measurements. In this connection, it is interesting to note that pre- and post-flight, Titov was found to have "high stability" to vestibular stimulation (30). Only one subject (CA), on one of two occasions, demonstrated susceptibility to Coriolis acceleration which was similar under zero-g and 1-g conditions. It should be remarked that this subject's data of the second test session (April 1967) which differed markedly from those of his first session (Dec. 1966) were collected when he probably was not in his usual state of fitness. For several days and during this particular test period he had without medical supervision severely restricted his dietary intake.

Confidence in the over-all data is given by the similarity in the results of those subjects who were tested as many as three times, separated by as long as 11 months, and in random order with regard to the two force environments. These results also demonstrate the stability of the measurement of motion sickness susceptibility made under each of the two test conditions.

Introspective reports revealed that, subjectively, the two gravitational conditions were very different from each other in their effect upon evoking motion sickness symptoms although when experienced, the symptoms were qualitatively the same for each individual. Those manifesting greater susceptibility to Coriolis sickness in weightlessness reported much greater stress with each head movement under this condition. On the other hand, those who remained symptomless explained that the stress load felt upon moving the head while rotating with gravity present had greatly lessened or disappeared entirely.

On one occasion there was an opportunity to compare within a short-time span the subjective response to Coriolis acceleration in the null and normal gravity states. Subject CA (session one), who had remained symptomless throughout the rotary-chair-test procedure conducted during the weightless phase of the parabolic maneuvers, was asked to continue the test while the plane was returning to the base. With even the first head movement, CA reported the sudden appearance of a strong stress effect; the second head movement evoked slight stomach awareness and this exercise was terminated.

As expected, none of the five labyrinthine-defective subjects experienced any symptoms as a result of the parabolic maneuvers per se or tilting their heads during the hypergravic phase of the maneuver. During this study there was no opportunity to rotate the L-D subjects as was done for the normal subjects.

A curious sensation was experienced by the normal subjects and the onboard experimenter with constant rotation (head fixed) during the greater-than-normal-g phases of each parabola. As the g-load increased, the subject's spinal axis appeared to become more and more displaced from the axis of rotation; his point of contact with the seat usually formed the vertex. With rotation the upper body generated a cone shape, the size of which seemed to be in proportion to the g-loading. The sensation could be intensified by a slight off-axis displacement of the center of the head. One subject described the feeling as though he were following a funnel-shaped path or one of a "spinning toy top that gradually loses speed and begins to topple." Another subject sensed that his feet and legs moved in parallel with his head and trunk, the apparent motion describing a double cone. Characteristically as the g force was reduced, the open part of the cone decreased in size and upon entering weightlessness disappeared, with the subject sensing that he was stationary and that the discrete aircraft sounds were moving in a circle about him.

SUMMARY AND CONCLUSIONS

The results confirm the well-accepted conclusion that motion sickness cannot occur in individuals without functional labyrinths. Possession of functional vestibular organs, on the other hand, does not always result in susceptibility to this sickness. Those who are susceptible even among a highly select population (e.g., pilot-type subjects) with similar vestibular response characteristics may experience quite different intensities of this malady. Furthermore, marked inter- as well as intra-subject differences in susceptibility may be consistently manifested in response to various types of motions. In this as well as in other studies there were persons in whom severe symptoms developed during the periodic oscillations of g-load encountered in the parabolic maneuvers, while others remained symptom free. Among those individuals who were unsusceptible to the conditions of parabolic flight, certain ones reacted with severe malaise when active head movements were made during the weightless phase of the parabola, whereas others were apparently immune to stress from these conditions. Four of the test subjects remained symptomless when they moved their heads during hypergravic periods of the parabola, but two reacted with symptoms. Coriolis sickness susceptibility measured on the ground revealed great intersubject differences. When measured in zero g, these differences generally persisted but they were overshadowed by intrasubject changes in susceptibility relative to that measured in a gravitational field. These changes created a dichotomy in an otherwise heterogeneous field of subjects, viz, those manifesting substantially greater and those lesser susceptibility to Coriolis sickness in weightlessness.

When gravity is altered or counteracted, there may be a dramatic increase or decrease in a normal individual's resistance to acute motion sickness. The nature of these differences in this behavioral response to various force environments is highly individualistic and apparently not directly related to such response under terrestrial conditions. The specific processes involved in "space" sickness and, equally important, those protecting certain normal individuals from this malady are yet unknown, but they must involve vestibular activity which is strongly influenced by the bizarre functional status of the otolith organs deprived of normal weight.

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13. ABSTRACT

Motion sickness susceptibility of five labyrinthine-defective (L-D) and 25 normal subjects was tested under the force environments encountered in parabolic flight (0g and hyper-g). The L-D subjects were uniformly symptomless, while the normal subjects revealed great inter- and intra-individual differences in susceptibility to motion sickness provoked by standardized head movements during: 1) the hypergravic and 2) the weightless phases of the parabolic maneuver while restrained; and 3) the weightless phase while being rotated in a chair. Four of six subjects tested under condition 1 were completely unaffected by the condition while two reacted with symptoms. Condition 2 provoked severe symptoms in five of the twelve subjects tested and moderate symptoms in one. Fifteen subjects tested under condition 3 revealed either a marked increase or decrease in susceptibility to Coriolis acceleration in weightlessness compared to terrestrial baseline measurements.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Weightlessness						
Hypergravity						
Labyrinthine defects						
Vestibular organs						
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