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COMPARISON OF FIVE LEVELS OF MOTION SICKNESS SEVERITY AS THE BASIS FOR GRADING SUSCEPTIBILITY

Earl F. Miller II and Ashton Graybiel

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JOINT REPORT

NAVAL AEROSPACE MEDICAL INSTITUTE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY PAGE

THE PROBLEM

To identify diagnostic criteria less severe, yet equivalent statistically, to the frank motion sickness and malaise III criteria for grading motion sickness susceptibility.

FINDINGS

The motion sickness susceptibility of 275 healthy male subjects was measured quantitatively by a standardized laboratory procedure using a Stille rotational chair. The results, in terms of velocity of the chair and the number of active head movements, were combined into a single numerical score that represented the total stressor stimulus sustained in reaching, in turn, each of five specific criteria for diagnosing the severity of motion sickness; viz, frank sickness (FS), severe malaise (M III), moderate malaise (M IIA and M IIB), and mild malaise (M I). The stressor value (E factor) of a single head movement at each test rpm was adjusted to yield an equivalent susceptibility score (Coriolis Sickness Susceptibility Index, or CSSI) independent of the endpoint selected. Close agreement among the CSSI scores obtained at each endpoint was found in intercorrelations, test-retest reliability coefficients, and frequency distributions, which reflected the orderliness and stability in the appearance, ramification, and intensification of the acute symptomatology evoked in progressing from M I to FS. The endpoint M IIA appeared, however, to yield the best balance between subject acceptability and test confidence and was used without exception to calibrate the motion sickness susceptibility of 250 additional subjects.

INTRODUCTION

Vomiting or retching and nausea represent severe expressions of motion sickness well recognized by the layman and most favored as test endpoints by investigators interested in the measurement of susceptibility to this malady. Recent effort at Pensacola has been directed toward finding less severe endpoints that are based upon milder diagnostic signs and symptoms yet offer equivalent validity and reliability. Initial studies revealed that severe malaise (M III), one of a four-category test system for qualitatively defining the severity of acute motion sickness, met these requirements while avoiding in particular the act of vomiting with its systemic complications and gaining greater subject acceptability (1-4). Investigations of the appropriateness of using still milder sickness levels for this purpose became dependent upon a more precise determination of possible test endpoints than provided for in the original four-part categorization of motion sickness severity, viz, the "other symptoms" category was not identified and a rather broad category existed between M III and the first general and unspecified symptom or sign, termed slight malaise (M I), which was of no practical value as a test endpoint; finally, the lack of numerical scoring proved to be a handicap in data handling. These limitations were overcome by 1) identifying and assigning point values to all qualifying symptoms according to their type and severity, and 2) quantitatively defining, in terms of the total points accrued among the manifested symptoms, the original severity criteria levels of frank sickness (FS), M III, and M I as well as the two newly established categories of moderate malaise, M IIA and M IIB, as outlined in Table I (4, 5).

The diagnostic value of the M III criterion was demonstrated in a previous study that evaluated a standardized laboratory procedure for grading susceptibility (4). This procedure was used in the present study to determine the diagnostic validity of less severe endpoints since 1) it provided highly effective stressor conditions that typically evoked a gradual growth in the number and intensity of symptoms, and 2) the results, in terms of rotational rate and number of head movements, could be reduced to a single numerical score that represented the total stressor stimulus sustained by the subject in reaching, in turn, each of the five specific endpoints (4, 6). Thus, serial scores obtained on a subject reflected meaningful quantitative changes in response to the stressful acceleration, and differences in scores among a group not only furnished an accurate rank order of susceptibility, but also quantitative differences among them.

PROCEDURE

SUBJECTS

Group 1 included 250 men who were 193 aviators, aviation students, or flight crew personnel; 11 nonaviator officers; 41 enlisted men; and 5 civilians. These men ranged in age from 16 to 43 years; 232 of them fell within the range of 19 and 26 years. Thirty of these subjects were retested to determine test-retest reliability among the various malaise levels through M III. Twenty-five additional subjects, four aviators or aviation students and 21 enlisted men (Group 2), served in determining the relationship among the four specific malaise levels and frank motion sickness. Another sample

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 (FS)	Severe Malaise (M III)	Moderate Malaise A (M IIA)	Moderate Malaise B (M IIB)	Slight Malaise (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.

of 250 men (Group 3) of similar background to Group 1 (155 pilot type, 2 nonaviator officers, 67 enlisted men, and 26 civilians) were stressed only to the M IIA endpoint.

In addition to the standard flight-qualifying medical examination, all subjects were given specific tests for function of the otoliths [(ocular counterrolling) (7, 8)] and semicircular canals [(caloric threshold) (9) or oculogyral illusion threshold (10)]. Each subject manifested vestibular responses that were well within normal limits.

METHOD

The standardized procedure for generating set patterns of Coriolis acceleration, described fully in another report (4), was followed. Coriolis acceleration was introduced at one of several constant velocities (1.0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0, 25.0, 30.0 rpm) by having the subject bend his neck and upper body as necessary to effect approximately 90° positive and negative movements of the head from the upright position within the frontal and sagittal planes according to the following pattern: front, upright, pause; right, upright, pause; back, upright, pause; left, upright, pause; front, upright, rest (Figure 1). Each of the movements to a new position or the return to upright was executed smoothly over a 1-second period. The pauses between movements were of the same (1 second) duration with the final pause (rest) lasting for 20 seconds. The time schedule of these test procedures was achieved by having the subject follow tape-recorded instructions. The head movement sequences continued until the accumulated symptom point values totalled at least 8, the severe malaise (M III) endpoint of Group 1; 16, the frank sickness (FS) endpoint of Group 2; and 5, the moderate malaise (M IIA) endpoint of Group 3 subjects.

Table II lists the best current estimate of the chair's rotational test rate (rpm) for the M IIA endpoint that we have determined empirically from the average level of experience (X) and intensity of symptoms (S) reported by subjects in the Motion Experience Questionnaire (4). Comparable estimates for the M III endpoint have been reported previously (4).

The subject was informed of the method of executing the sequence of head movements and the expected symptoms. He was then secured in the rotary (Stille) chair and blindfolded. After the subject had demonstrated the head movement sequence while stationary, the chair was accelerated $5°/sec^2$ in the clockwise or counterclockwise direction, selected at random, until the desired constant velocity was reached; at no less than 60 seconds thereafter, the first head movement sequence was begun. Immediately upon reaching either the M III (Group 1), FS (Group 2), or M IIA (Group 3) level, the head movements were terminated, the subject returned to his upright position, and the chair was decelerated ($5°/sec^2$) to a stop.

During this procedure the test was not terminated until the selected terminal endpoint or a limit of 204 (FS), 166 (M III), or 150 (M IIA) head movements was reached. However, as the test progressed and as each of the defined levels of motion sickness severity (Table I) appeared in advance of the selected terminal point, the cumulative

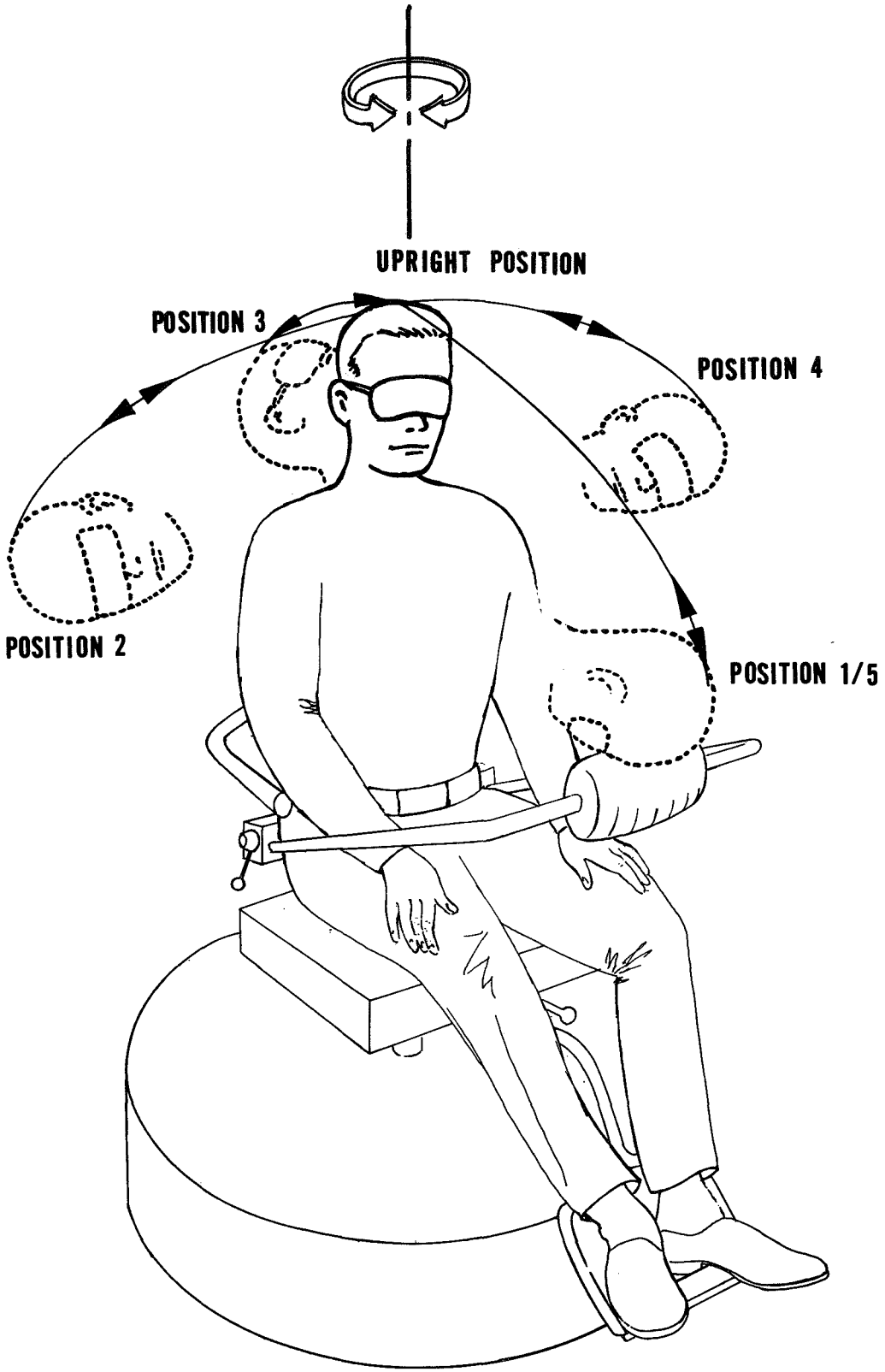

Figure 1

Diagram of Standardized Procedure for Making Each Sequence of Head Movements To and From Tilt Position 1 through 5 During Chair Rotation

Table II

Rotary Chair Test (M IIA Endpoint) Velocities Most Often Associated with Average Experience and Symptom Levels Coded from Motion Experience Questionnaires

	M IIA	SYMPTOMS S										
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
EXPERIENCE $\bar{X}$	0.5	7.5*	7.5	7.5	7.5	7.5	7.5	7.5	5.0	5.0	5.0	5.0
	1.0	10.0	10.0	10.0	7.5	7.5	7.5	7.5	5.0	5.0	5.0	5.0
	1.5	10.0	10.0	10.0	10.0	7.5	7.5	7.5	7.5	5.0	5.0	5.0
	2.0	12.5	12.5	10.0	10.0	7.5	7.5	7.5	7.5	5.0	5.0	5.0
	2.5	12.5	12.5	10.0	10.0	10.0	10.0	7.5	7.5	5.0	5.0	5.0
	3.0	15.0	15.0	12.5	12.5	10.0	10.0	7.5	7.5	7.5	5.0	5.0
	3.5	15.0	15.0	12.5	12.5	12.5	10.0	7.5	7.5	7.5	5.0	5.0
	4.0	20.0	20.0	15.0	15.0	12.5	12.5	10.0	10.0	7.5	5.0	5.0
	4.5	25.0	25.0	20.0	20.0	15.0	12.5	12.5	10.0	7.5	5.0	5.0
	5.0	30.0	30.0	25.0	20.0	20.0	15.0	12.5	10.0	7.5	5.0	5.0

*Rotary chair velocity (rpm)

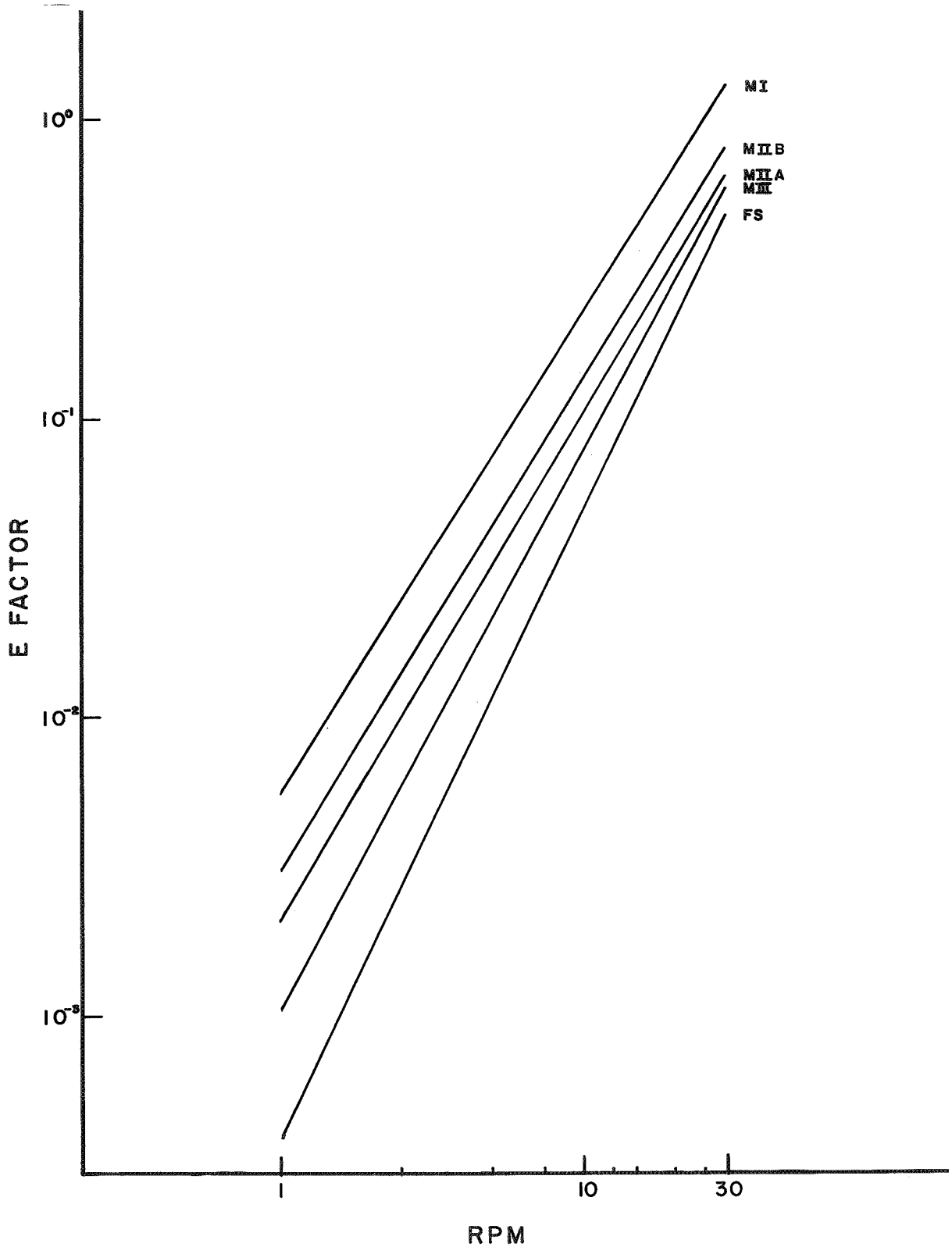

Figure 2

E Factor vs RPM for Five Levels of Motion Sickness Severity Used as Basis for Calculating Individual Coriolis Sickness Susceptibility Index (CSSI)

number of head movements executed was duly registered. This method of identifying within one test session the successive appearance of up to five potential test endpoints (five motion sickness severity levels) avoided possible intertest subject differences.

In the comparison of the several specific malaise and frank sickness levels, it was of great advantage to employ the concept of an index score of susceptibility (Coriolis Sickness Susceptibility Index, CSSI) (4). This method of grading motion sickness susceptibility removes the need for separately citing the test velocity of the rotational chair and the number of head movements executed and, instead, allows an individual's susceptibility to be graded by a single numerical score. In a previous study, the index was found to depend upon the average stressor effect, termed the E factor, of a single head movement that was found to be directly related to the rotational velocity of the chair (6). An individual's susceptibility to Coriolis sickness was, therefore, based upon this measure (CSSI) of the total stimulus sustained in reaching the selected endpoint (M IIA or M III); i.e., susceptibility equals the product of the E factor specified for either the M IIA or M III endpoint at each of several test velocities times the number of standardized head movements (CSSI = E x N). The absolute E factor was arbitrarily adjusted to yield, independent of the selected endpoint, a CSSI score of 0 to 100 points.

As the first step of this study to determine the relative value of the several malaise levels in grading susceptibility, new sets of E factors associated with each of the test velocities were determined for the moderate malaise, M IIB, and slight malaise, M I, categories as well as that of frank sickness, FS. These values were at first grossly estimated from those representing the M III and M IIA endpoints (6), then adjusted empirically to yield the best fit to lines of regression in comparisons between all endpoints. The resultant E factors versus rpm data for the five endpoints are listed in Table III and portrayed as a family of straight-line curves with slightly different slopes in Figure 2.

By using the appropriate E value, the CSSI was calculated on an individual basis for each of the four malaise (M I, M IIB, M IIA, M III) and frank motion sickness (FS) criteria, and this served as the common measurement for determining intercorrelations, test-retest reliability, and frequency distributions of these criteria.

Table III

Table of E Factors Associated with Specific Rotational Test Velocities and the Five Levels of Motion Sickness Severity

Velocity (rpm)	Levels of Motion Sickness Severity				
	M I	M IIB	M IIA	M III	FS
30.0	1.31	0.82	0.67	0.60	0.49
25.0	0.98	0.61	0.48	0.43	0.33
20.0	0.69	0.43	0.33	0.28	0.21
15.0	0.435	0.263	0.205	0.165	0.115
12.5	0.325	0.195	0.150	0.118	0.078
10.0	0.225	0.135	0.105	0.078	0.049
7.5	0.142	0.084	0.064	0.046	0.027
5.0	0.083	0.043	0.032	0.021	0.012
2.5	0.024	0.014	0.010	0.006	0.0036
1.0	0.005	0.003	0.002	0.001	0.0004

RESULTS

CORRELATIONS AMONG INDICES OF MOTION SICKNESS SUSCEPTIBILITY

The relationships among the individual CSSI scores of the Group 1 subjects derived from each of the four malaise levels are indicated by the several scattergram plots and associated correlation coefficients presented in Figure 3. Relatively high correlations were revealed among the CSSI scores calculated from data obtained at each of the malaise levels. With few individual exceptions the plotted scattergram positions of the various endpoint CSSI scores grouped about the regression lines. An almost perfect relationship, for example, was found (ρ = .98 and .97) between the M III versus M IIA, and M IIA versus M IIB endpoint scores. The group correlations decreased and the scattering of data points increased somewhat with M I comparisons. Surprisingly though, even these data based upon the mildest form of malaise (I), viz, the manifestation of a single specific sign or symptom that qualifies for the assignment of a single point value, correlated relatively well (ρ = .78 and .79) (Figure 3) with those of severe (III) and of moderate malaise (IIA).

Table IV lists similar correlations among the four malaise levels as well as frank motion sickness in the small group (Group 2). Of primary interest here is the finding that each of the malaise-criteria CSSI values correlated very highly with those representing the frank sickness level.

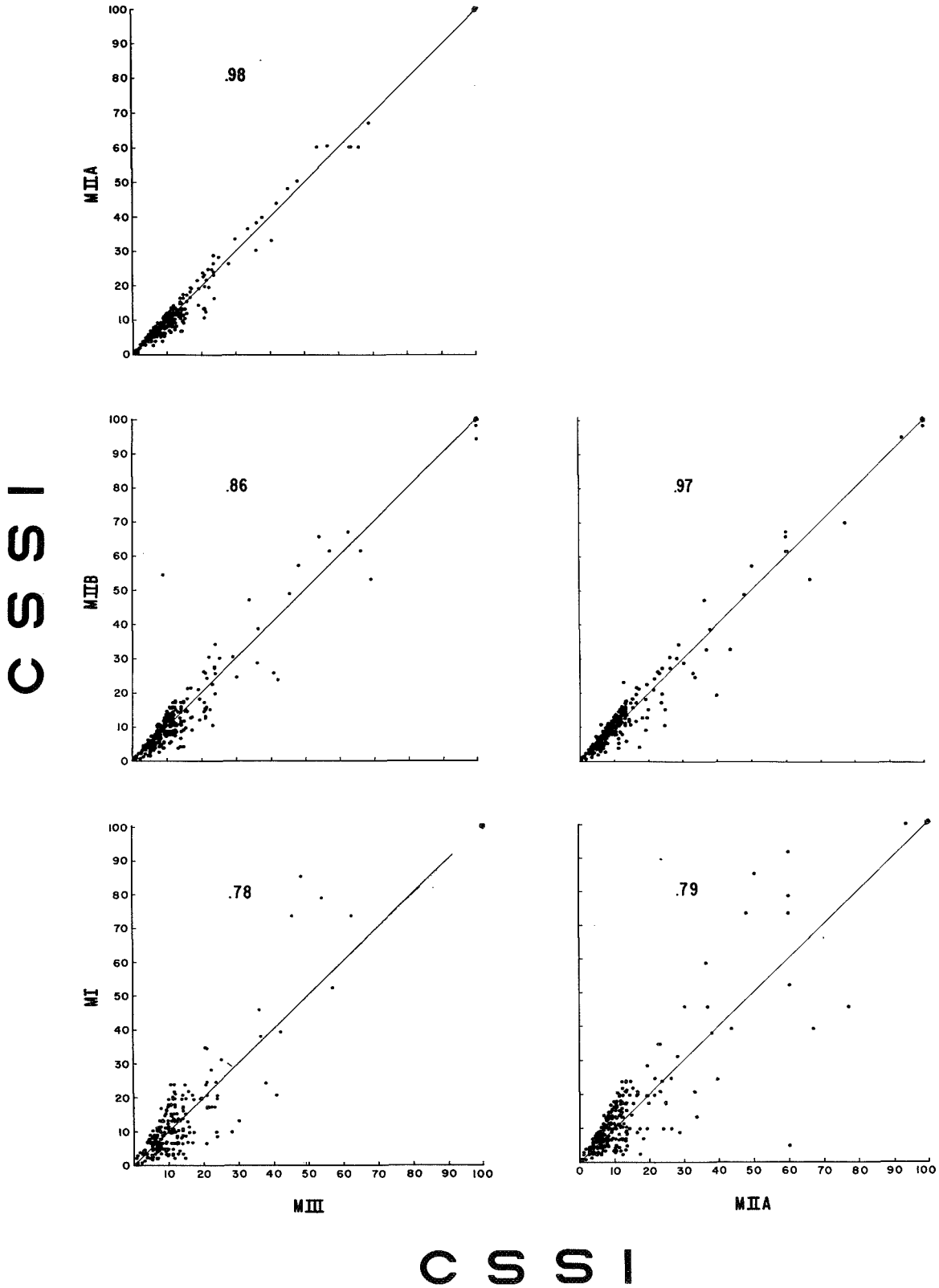

Figure 3

Scattergrams Showing Relationships Among Individual CSSI Scores (Group 1 Subjects) Derived From Each of the Four Malaise Levels

Table IV

Correlations Among CSSI Scores of 25 Subjects (Group 2) Derived From Data Acquired at Each of Four Malaise Endpoints and Frank Sickness

FS	M III	M IIA	M IIB	M I
FS	.993	.980	.936	.934
M III		.917	.870	.854
M IIA			.932	.917
M IIB				.966
M I				

RELIABILITY

Test-retest reliability results from thirty subjects are listed in Table V where it is seen that high reliability coefficients were found among each of the malaise categories.

Table V

Test-Retest Reliability of CSSI Scores of 30 Subjects of Group 1 Based Upon M I, M IIA, M IIB, and M III Endpoints

	M III	M IIA	M IIB	M I
M III	.87			
M IIA		.90		
M IIB			.86	
M I				.91

FREQUENCY DISTRIBUTIONS

The cumulative frequency distribution of the individual CSSI scores of the Group 1 subjects as determined for each of the four malaise levels approached coincidence (Figure 4).

SYMPTOMATOLOGY

The results from the Group 1 subjects expressed in terms of frequency of appearance of the various specific symptoms are summarized categorically in Figure 5 and as to specific levels within each category for Groups 1 and 2 in Table VI.

The primary symptom characterizing M I was found to be epigastric awareness or discomfort, the mildest forms of the nausea syndrome, that appeared in slightly over half of the subjects. Much less frequently seen symptoms at this lowest severity level of motion sickness were mild (I) cold sweating, moderate (II) subjective feeling of warmth, and salivation I; pallor I, dizziness I, or drowsiness I was manifested in a very small percentage of the subjects. In progressing from M I to M IIB, the number rather than the intensity of these particular symptoms experienced by each subject tended to increase. Epigastric awareness or discomfort was reported in nearly three quarters of the subjects, and the incidence of all other symptoms increased sharply, greater than threefold in four categories. Continuation of the Coriolis stressor stimulation until the M IIA level was reached resulted in further increases in the percentage of subjects experiencing particular symptoms but at a reduced rate relative to the change between M I and M IIB, with two notable exceptions. Pallor almost doubled in incidence in progressing from M IIB to M IIA, and doubled again from M IIA to M III. Dizziness II, III essentially paralleled the increases recorded for pallor but at a much lower frequency of incidence; at M III over one fourth of the subjects reported this symptom. M III was characterized more by increases in the intensity rather than variety of individual symptoms which in many cases became fixed at the M IIA level. Nausea I appeared for the first time and replaced epigastric awareness or discomfort in more than one fourth of the test population, while over nine-tenths reported one of these forms of the nausea syndrome. Among the approximately two-thirds reporting cold sweating, the moderate level (II) increased almost four-fold with a few manifesting the severest level (III). Headache II began to be reported by a small number of the subjects and drowsiness II increased six-fold. Increases in the subjective feeling of warmth and salivation were much less marked.

The results of testing Group 2 (Table VI) revealed, in terms of a much smaller number of subjects, those changes occurring in the symptomatic patterning when progressing from severe malaise (M III) to frank motion sickness (FS). The primary symptom change was increased nausea to the moderate level (II) in almost half the subjects; some form of the nausea syndrome was reported by 96 per cent of the subjects. Nausea III was not recorded. Pallor and cold sweating at some level were observed in all and four-fifths of the subjects, respectively; sixteen per cent manifested the severest level (III) of each of these symptoms. Other symptoms of FS manifested with greater intensity and

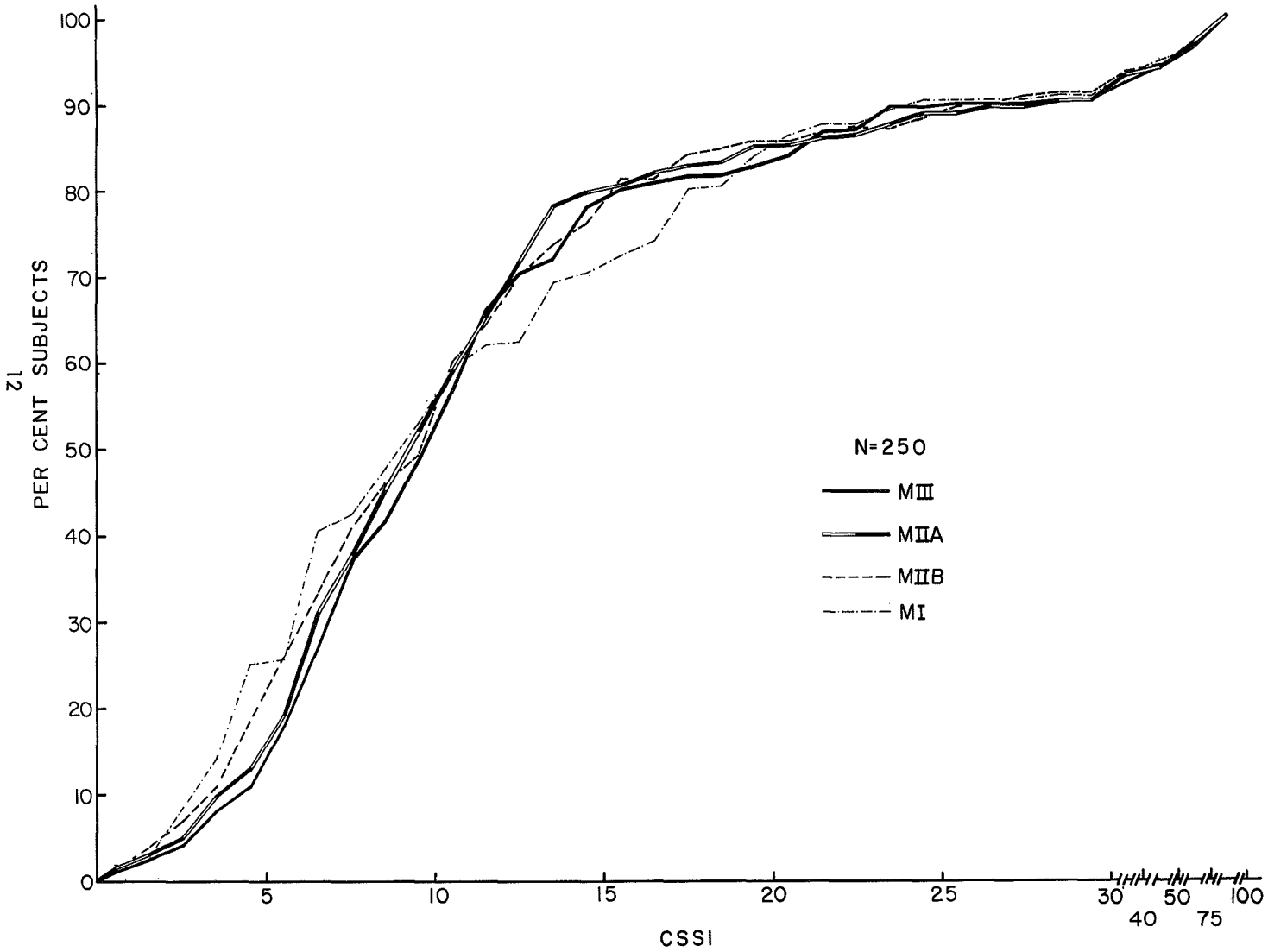

Figure 4

Cumulative Frequency Distributions of Individual CSSI Scores
(Group 1 Subjects) Determined for Each of the Four Malaise Levels

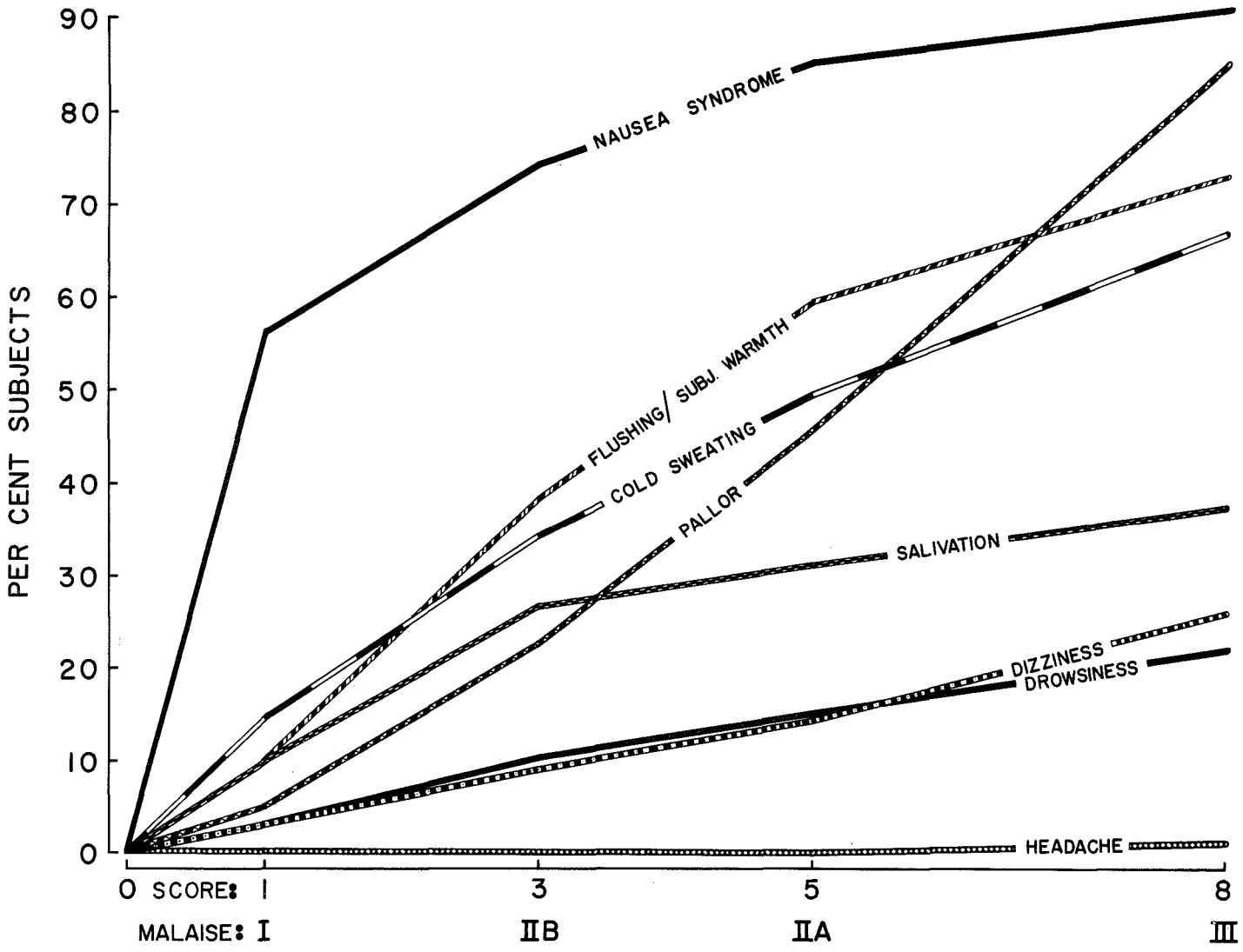

Figure 5

Results from Group 1 Subjects Expressed in Terms of Frequency of Appearance of Various Specific Symptoms

Table VI

Frequency of Appearance of Specific Symptoms Associated with the Four Malaise Criteria (Group 1 Subjects) and Frank Sickness (Group 2 Subjects)

Symptoms	M I	M IIB	M IIA	M III	FS
Flushing/subjective warmth > II	9.6*	38.0*	59.2*	72.4*	92.0**
Dizziness > II	2.8	8.8	14.0	25.6	52.0
Headache > II	-	-	-	1.2	8.0
Drowsiness I	2.8	9.6	13.6	14.4	12.0
Drowsiness II	-	0.4	1.2	7.2	12.0
Cold sweating I	14.4	32.0	43.6	43.2	28.0
Cold sweating II	-	2.0	5.6	21.6	36.0
Cold sweating III	-	-	-	1.6	16.0
Pallor I	4.8	21.6	41.2	48.4	16.0
Pallor II	-	0.8	4.0	36.0	68.0
Pallor III	-	-	-	-	16.0
Salivation I	9.6	24.8	28.4	30.4	32.0
Salivation II	-	1.6	2.4	6.8	24.0
Epigastric awareness/ discomfort	56.0	74.0	84.8	58.8	12.0
Nausea I	-	-	-	31.6	36.0
Nausea II	-	-	-	-	48.0

*Per cent subjects (Group 1, N = 250)
**Per cent subjects (Group 2, N = 25)

frequency than with M III were headache (II, III); dizziness (II, III); increased salivation (I, II); and subjective warmth (II, III). On the other hand, there was no substantial increase in the frequency of drowsiness I or II; and neither drowsiness III nor salivation III was observed.

Several subjects reached the frank sickness level, as defined by an accumulative total of symptom point values of 16 points (Table I), without the act of vomiting or retching. However, it would have been impossible to classify the condition of each of these subjects at this point in the test as other than being less than "sick," and each was actively suppressing a strong desire to vomit.

FREQUENCY DISTRIBUTIONS OF THE CSSI SCORES OF GROUP 1 AND 3 SUBJECTS BASED UPON THE M IIA ENDPOINT

The separate and combined frequency distributions of the CSSI scores of Groups 1 and 3 subjects are presented in Figure 6. The distributions of the CSSI scores of these two groups were similar, each revealing wide ranges of susceptibility and marked right skewness.

DISCUSSION

The results make evident that the specific diagnostic symptoms set forth in Table I appear, ramify, and intensify in an orderly fashion. The regularity of this process beginning with the initial (point-rated) symptom of malaise I, usually stomach awareness or discomfort, was marked by the high correlations found among the rest of the malaise levels and frank sickness. The high test-retest reliability of all endpoints indicate the temporal stability of each of these measurements in terms of the grading technique as well as the individualistic symptomatological patterning. These findings show the potential value of using criteria less severe than frank motion sickness (FS) and severe malaise (M III). The choice of endpoints short of FS was thus widened to one of ~~five~~ four malaise criteria that could provide a reliable and valid basis for grading motion sickness susceptibility and might better fit the subject or test condition. It is our present opinion that in all but exceptional circumstances, however, M IIA may be the lowest malaise level that is of practical value for assessing susceptibility since it appears to represent the best balance between test confidence and subject acceptability. Specifically, the M IIA criterion: 1) yields data that correlate extremely well with those obtained with M III and FS endpoints; 2) clearly avoids the subjective feeling of being "sick;" 3) allows a rapid recovery from mild symptoms; 4) in almost all cases is not objectionable to the subject in single or multiple measurements; and 5) makes malingering difficult since it requires the manifestation of several symptoms that must correlate.

M I, in contrast, may be described by a single subjective symptom and, therefore, may be highly dependent upon the subject's introspective ability, his honesty, or his willingness to report symptoms. Even with a good observer the M I criterion may not indicate a true measure of Coriolis sickness susceptibility since it rather poorly defines when the individual is being tested with a chair velocity that provides a stressor level

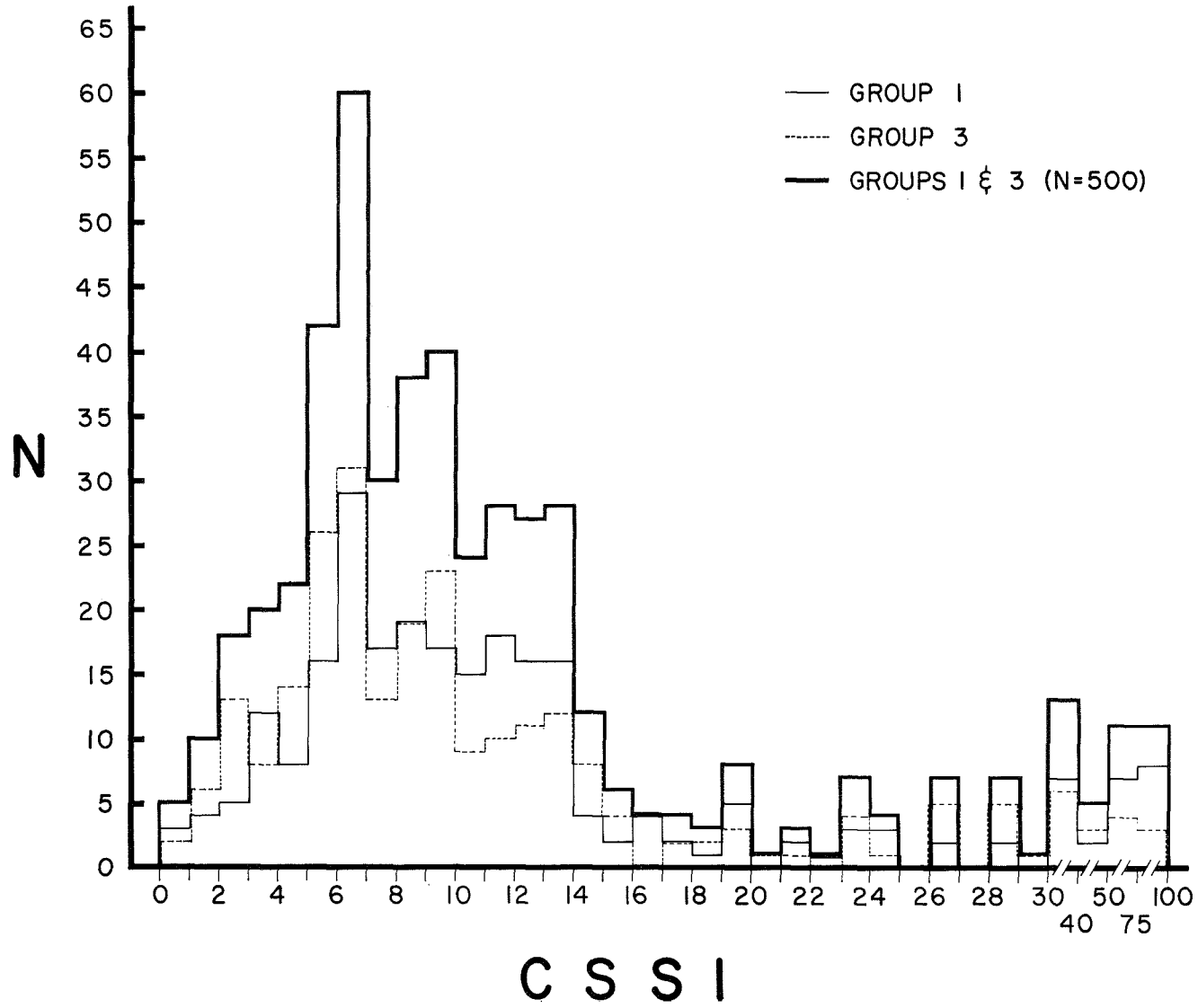

Figure 6

Separate and Combined Frequency Distributions of CSSI Scores of Groups 1 and 3 Subjects Based upon M IIA Endpoint

higher than his ability to compensate. Thus, the M I criterion may falsely indicate that the subject has low susceptibility or even is unsusceptible. On the other hand, not infrequently M I symptoms will be manifested during the initial part of the test, only to disappear as it is continued. These "misses," or false measurements of susceptibility, are not present in the data of this study since the tests were always carried beyond this malaise level, thus assuring a proper stressor level. If the final endpoint were not reached, the test was considered invalid and these particular subjects were retested on a subsequent day for inclusion in this study.

The stressor conditions of the standardized test provoke principally those symptoms denoted in Table I. Without exception, symptoms other than those recognized in this table were rarely observed or reported and when present, were not useful in the diagnosis. Although, among this limited variety of categories, there were distinct individual differences in symptom development and patterning, the order of release and intensification of symptoms was similar in the majority of subjects. These events seem dependent upon a summation process involving neural or humoral agents. The latter agent is suggested by the study of Wang and Chinn who found that insertion of plastic barriers in the fourth ventricle of several dogs removed their susceptibility to nausea and vomiting even though their emetic thresholds to apomorphine were not raised (11). Regardless of the mediating agent, its effect can be expressed for illustrative purposes in terms of units of stressor stimulus provided by each head movement in our test procedure. Each standardized head movement executed during constant velocity rotation effectively adds, in incremental fashion, a given quantity of provocative stress. The rate of release of autonomic effects, as reflected in the buildup in symptomatology, can be regulated simply and in a predictable manner through the choice of the chair's velocity which determines the unit step-size of the stressor stimulus. In grading susceptibility using a physiologically equivalent endpoint for all subjects, the strength of the stimulus must fall between that necessary to override homeostatic adjustments preventing the manifestation of symptoms of motion sickness and that which avoids provoking explosive responses. The technique for accomplishing this has been described elsewhere (4).

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13. ABSTRACT

The Coriolis (motion) sickness susceptibility index (CSSI) of 275 healthy male subjects was calculated from data obtained by a standardized laboratory procedure at each of five specific levels of motion sickness severity, viz, frank sickness (FS), severe malaise (M III), moderate malaise (M IIA and M IIB), and mild malaise (M I). The stressor value (E factor) of a single standardized head movement associated with each rotational rate of the test chair was adjusted to yield an equivalent CSSI score independent of the endpoint selected. Close agreement among the CSSI scores obtained at each endpoint was found in intercorrelations, test-retest reliability coefficients (N = 30), and frequency distributions that reflected the orderliness and stability in the appearance, ramification, and intensification of the acute symptomatology evoked in progressing from M I to FS. The endpoint M IIA appeared, however, to yield the best balance between subject acceptability and test confidence, and was used without exception to calibrate the motion sickness susceptibility of 250 additional subjects.

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