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JOINT REPORT

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NAVAL AEROSPACE MEDICAL INSTITUTE

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MOTION SICKNESS PRODUCED BY HEAD MOVEMENT AS A FUNCTION OF ROTATIONAL VELOCITY*

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NAVAL AEROSPACE MEDICAL INSTITUTE
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SUMMARY PAGE

THE PROBLEM

To measure the stressor stimulus effect of rotational velocity in terms of the number of the standardized head-tilt movements required to evoke a common severity level of symptoms characterizing motion sickness.

FINDINGS

The accumulative number of standardized head tilts (approximately 90°) within the frontal and sagittal planes that were executed in reaching the specific test end-points of either moderate (M IIA) or severe (M III) malaise was recorded at each test velocity. Sixteen young healthy subjects were rotated in a laboratory chair (Stille) at various velocities within a range suitable for each subject and the limits of 1.0 to 30.0 rpm. When individual ability to make head movements without evoking symptoms was exceeded, the average relative stressor effect (E factor) of each head movement varied directly and, in log-log terms, linearly with rotational velocity. These data provide the basis for grading individual susceptibility to the Coriolis type of motion sickness with a single numerical score as well as define the high rate of change of Coriolis stressor effect as a function of rotational velocity, which may find practical application in specifying rotational rates of space stations.

INTRODUCTION

Motion sickness susceptibility can be assessed either by judging the relative manifestation of symptomatology resulting from a common physical stimulus or by measuring the magnitude of the stimulus that provokes an essentially equivalent response among subjects. The latter experimental approach became practical with the categorization and quantification of specific diagnostic symptoms that formed the basis for defining five levels of motion sickness (2). These diagnostic criteria were used in a related study (6) that introduced standardized head movements in combination with constant velocity of a rotating chair to evoke a common endpoint in the grading of individual susceptibility. Marked interindividual differences required that the test velocity be selected from a wide range of values (1.0 to 30.0 rpm). For the procedure to be effective as well as controllable, the intensity of stressor stimulation, applied incrementally in this case, had to exceed each subject's homeostatic capability, yet fall below the level that would result in the rapid and explosive development of symptomatology beyond the preselected endpoint. At the proper test velocity the number of head movements indicated the relative susceptibility of the subject. The results, however, were difficult to evaluate since the collective magnitude of the stressor stimulus was some unknown product of two parameters (number of head movements and chair velocity), which prevented a direct comparison of subjects tested at different velocities.

The purpose of the present study was to determine the provocative effect of head movement, in terms of Coriolis (motion) sickness, as a function of angular velocity, both for its basic information value as well as to establish the required basis for grading individual motion sickness susceptibility with a single numerical score. The latter task evolved into determining the average relative effect of a single head movement executed at each of several rotational velocities within limits that were found to be effective for the measurement of a wide spectrum of motion sickness susceptibilities.

PROCEDURE

SUBJECTS

Sixteen young Navy men who demonstrated normal otolith and semicircular canal function in tests of ocular counterrolling (4, 5), and caloric irrigation (3) or oculogyral illusion threshold (1), respectively, were selected as subjects and separated into two test groups: Group 1, five enlisted personnel and two officers whose ages ranged from 19 to 26 years; Group 2, nine enlisted personnel, 18 to 20 years of age. Each subject remained in his excellent state of health throughout the test period, as verified by the Subject's Preexperimentation Questionnaire (6).

METHOD

The method used in this study of quantitatively grading an individual with respect to his susceptibility to Coriolis sickness is described in another report (6). Essentially, the subject while rotating in a laboratory chair (Stille) at a constant speed is required to tilt his head, and upper body, as necessary, to effect approximately 90° positive and negative displacement of his head from its upright position within the frontal and sagittal planes according to the following sequence: front, upright, pause; right, upright, pause; back, upright, pause; left, upright, pause; front, upright, rest. Each movement 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 and the final pause, i.e., the rest between sequences, lasted 20 seconds. The predetermined endpoint defined by specific diagnostic criteria (2) was severe malaise (M III) for Group 1 and moderate malaise (M IIA) for Group 2. Although the overt symptoms characterizing these endpoints disappeared within a relatively short period of time, subsequent testing was always delayed at least 48 hours for the Group 1 and 24 hours for the Group 2 subjects. The incidence of M IIA was recorded for Group 1 subjects as an incidental part of the procedure for reaching the M III endpoint. The test schedule of rotational rates was arranged in a random order among the subjects with the direction (clockwise, counterclockwise) of rotation alternated and the rpm varied between consecutive test sessions. Each of the first group of subjects was tested once and of the second group twice at each of several velocities that was selected at random from among 1.0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0, 25.0, and 30.0 rpm, but limited to that velocity which, from an ongoing analysis of the results, was predicted to exceed individual homeostatic ability; i.e., ability to make repeated head movements without evoking symptoms. The accumulative number of head movements constituted the dependent variable with chair velocity being the independent variable.

RESULTS AND DISCUSSION

The effect of varying rotational rate in terms of the number of head movements required to evoke Malaise III (Group 1) and Malaise IIA (Groups 1 and 2) is presented in Figure 1. The considerable and essentially oblique separations of subjects' response curves reflect the large interindividual differences in the basic susceptibility of our subjects and indicate the extent to which they are representative of the broad general spectrum of susceptibility (6, 7). Marked differences among these subjects also appeared in the range of test velocities effective in evoking the preselected endpoint of moderate (M IIA) or severe (M III) malaise. The most susceptible subject, for example, could be tested only within the range of 1.0 to 10.0 rpm; three head movements at 10.0 rpm evoked M IIA and even a single head movement executed at a velocity above 10.0 rpm was found to produce severe symptoms. Most subjects, on the other hand, could be effectively tested over a wider range of velocities within 5.0 and 30.0 rpm, and two subjects provided valid data throughout this range. In spite of individual differences and a certain day-to-day (rpm-to-rpm) varability, each curve revealed a common trend; ever decreasing numbers of head movements were required to reach the endpoint as the rotational rate was increased. The curves are extended upward with dotted lines to indicate when a given subject failed to reach the preselected endpoint with an imposed limit of 300. The ability to make apparently unlimited head movements without evoking symptoms is typically displayed by an individual who is tested below his critical rpm level.

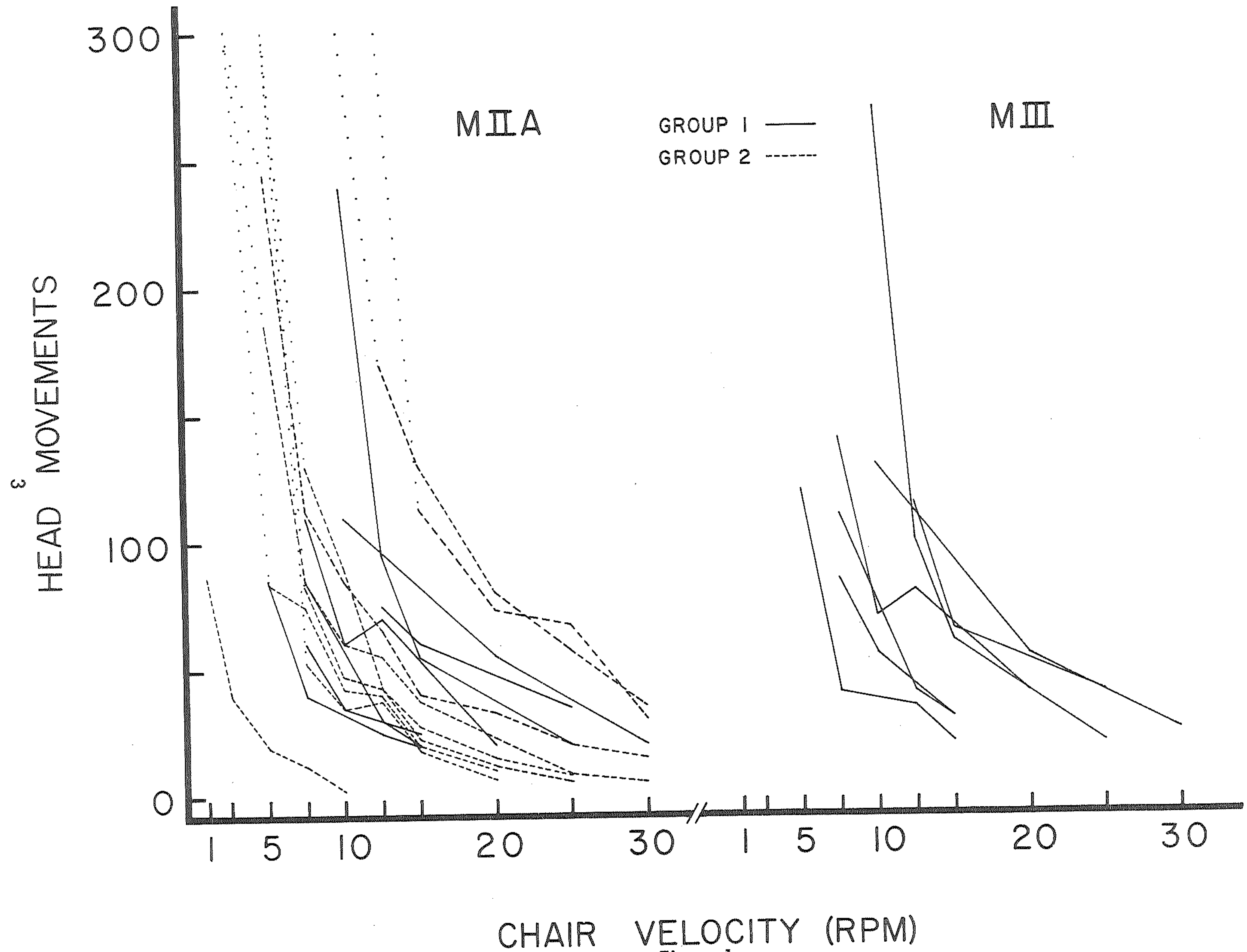


Figure 1

Head Movements Executed by Subjects of Groups 1 and 2 in Reaching a Preselected Endpoint of Moderate (M IIA) or Severe (M III) Malaise as a Function of Rotational Chair Velocity. Dotted Line Extensions of the Curves Indicate Failure to Reach These Endpoints with 300 Head Movements

Figure 2 is the M IIA data of Figure 1 plotted on log-log coordinates and fitted empirically with straight lines. This plot shows that the two parameters (number of head movements and rotational velocity), which were equated by a constant response (M IIA) factor, are linearly related and that this relationship is similar among the subjects.

The task of relating and combining the two test parameters, as the basis for grading motion sickness susceptibility with a single numerical score, centered upon expressing the findings in terms of an average stressor effect of a single head movement as a function of chair velocity. In this discussion we refer to the effect of head movement without specifying its direction. It should be recognized, however, that the four directions of movement used in the standardized procedure were not always equally stressful, and the most stressful direction, usually forward, varied in its effect among subjects; occasionally a given subject would even report a change in the maximal directional effect during the test.

Inasmuch as more data based upon the M IIA endpoint were available, they are considered exclusively in the following analysis. The log-log coordinate system for plotting the number of head movements required to evoke M IIA as a function of rotational velocity (Figure 2) depicted the individual results in a way that could be best represented by straight line curves. In this analysis the important characteristic of the resultant family of curves is their slope, which was similar among the subjects and apparently independent of their respective susceptibility levels. The average slope thus expressed the provocative effect of head movement versus velocity in a highly representative manner for our subject population.

The reciprocal of the average slope is depicted by the straight-line curve of Figure 3, which defines the relationship between the average stressor effect (E factor) of a single head movement and angular velocity. The E factor scale approximates that derived from the reciprocal of the average number of head-movements data, but reduced in magnitude in order to limit susceptibility scores derived from these E factors to 100 points.

The E factor, expressed as a function of rpm, formed the basis for grading susceptibility by a single numerical score. Susceptibility is simply determined by multiplying the number of head movements (N) executed in reaching the preselected endpoint (M IIA in this case) times the appropriate E factor, the stressor value of a single head movement executed at a particular chair velocity. The individual's resultant score, representing the collective magnitude of the stressor stimulus required to evoke the endpoint, is termed his Coriolis Sickness Susceptibility Index, or CSSI:

$$CSSI = \underline{E} \times \underline{N}$$

The maximum susceptibility score (M IIA level) within the range of 0 to 100 points, by definition, can be attained only by an individual who fails to reach M IIA or does so only after completing his 150th head movement while rotating at 30 rpm. This limit has

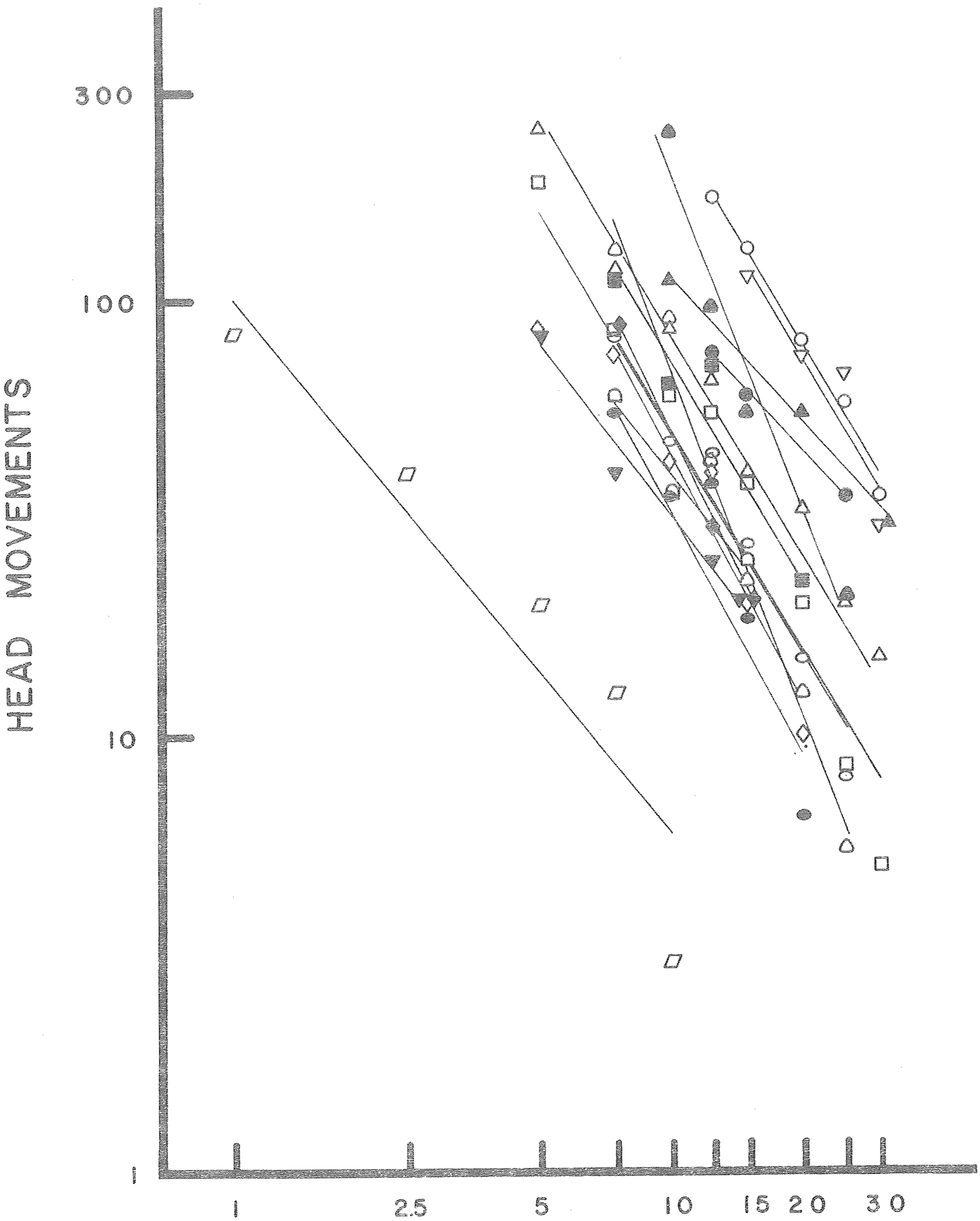
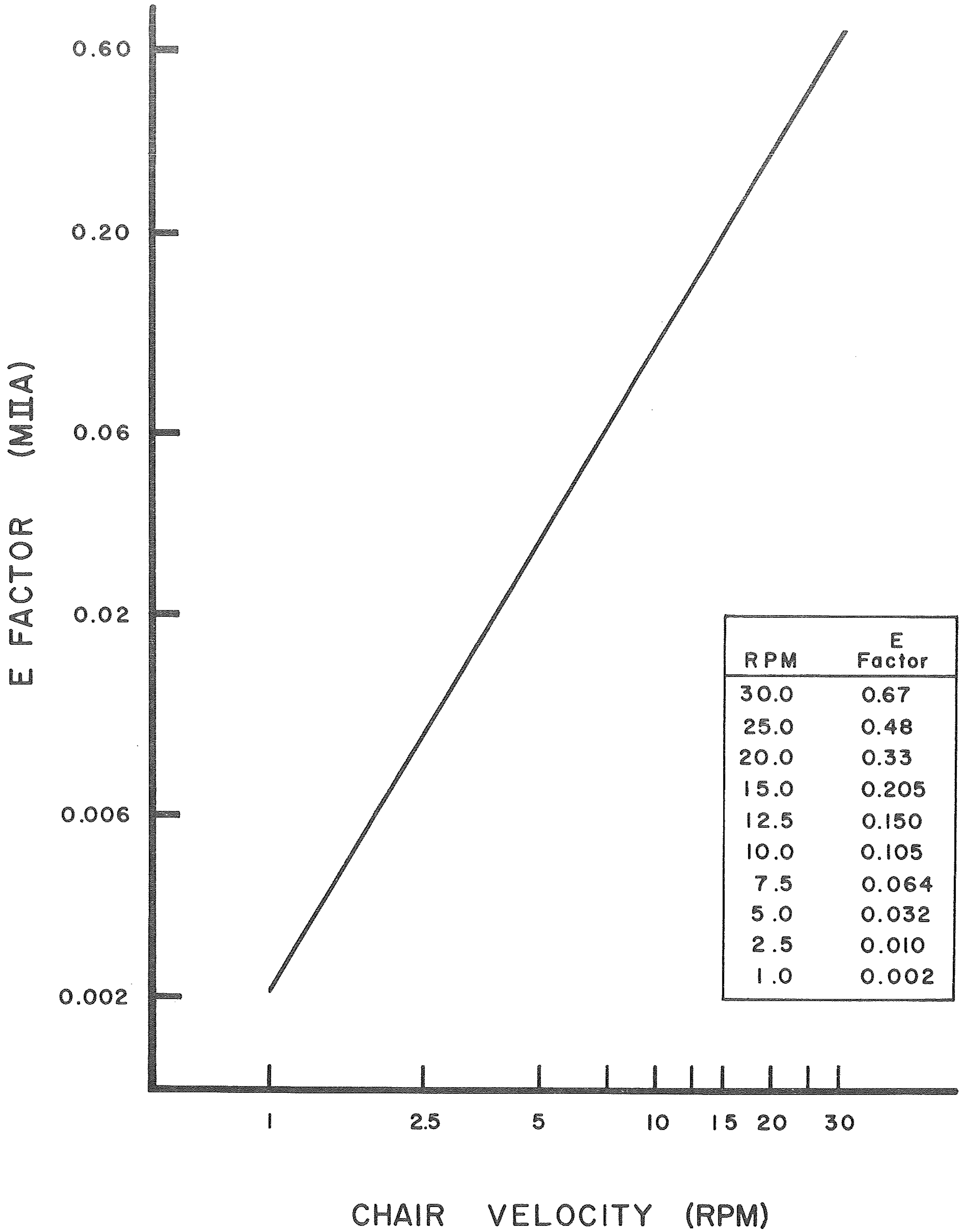


Figure 2

M IIA Data of Figure 1 Plotted on Log-Log Coordinates with Subjects Differentiated by Coded Symbols



RPM	E Factor
30.0	0.67
25.0	0.48
20.0	0.33
15.0	0.205
12.5	0.150
10.0	0.105
7.5	0.064
5.0	0.032
2.5	0.010
1.0	0.002

Figure 3

Relative Stressor Effect (E Factor) of a Single Head Movement, Moderate Malaise (M IIA) Endpoint, as a Function of Rotational Velocity proven, in practice, to be a reasonable cut-off since few (1.6 %) individuals among rather large populations have reached it. We have, therefore, assumed that a score of 100 indicates high resistance if not essential immunity to the Coriolis type of motion sickness. Furthermore, it has been demonstrated that little is probably gained by requiring more than 150 head movements, since several subjects with this level of resistance have been able to execute up to 300 head movements without manifesting any additional symptoms. Although it was found possible in this study to reach the endpoint with larger numbers of head movements when testing at lower velocities, 150 head movements have now also been set as a limit for routine tests of susceptibility at these velocities unless the buildup of symptoms indicates that the endpoint is imminent. This practice assures a relatively short test-time (usually less than 15 minutes) and avoids overtaxing the endurance or interest of the subject. If the M IIA endpoint is not reached after 150 head movements, the test is considered invalid and rerun on a subsequent day at an appropriately higher velocity (7).

The validity of the CSSI score in grading individual susceptibility in lieu of citing dual measurements of head movements and rotational velocity is shown in Figure 4 for the M IIA endpoint. It can be seen that the CSSI score is essentially independent of the rotational rate within the individual's appropriate velocity test range. When the limit of 150 head movements is greatly exceeded, the calculated CSSI score may not be a valid measure of susceptibility, as illustrated by the sharp rise in the CSSI score of one Group I subject tested at 10.0 rpm relative to his scores associated with other velocities, providing further reason for instituting this limit in routine testing. The differences in the CSSI scores as a function of test velocity that did occur were relatively small and varied at random from rpm to rpm in most cases. These fluctuations may well indicate slight day-to-day shifts in an individual's susceptibility. Covering the eyes and generally limiting the number of head movements while varying their direction as well as that of chair rotation between tests probably contributed to the stability of the susceptibility measurements since these factors act to reduce, if not eliminate, habituation training effects of the test procedure itself.

To determine and specify susceptibility with a CSSI score when M III rather than M IIA was selected as an endpoint, a set of $\underline{E}$ factors for M III was similarly derived and is presented in Figure 5 (6). Another study presents data that permit a choice of any of five motion sickness severity endpoints for grading individual susceptibility by the CSSI score method (7).

The defined logarithmic relationship between the stressor effects of head movement and rotational velocity may have value in predicting human tolerance in a rotating space station. The rapid rise in Coriolis acceleration stressor effects and the possible concomitant fall in habitability as the rotational rate is increased serve to emphasize the criticality of selecting the physical dimensions and angular velocity of the rotating portions of the space station that will be required to generate a given level of artificial gravity.

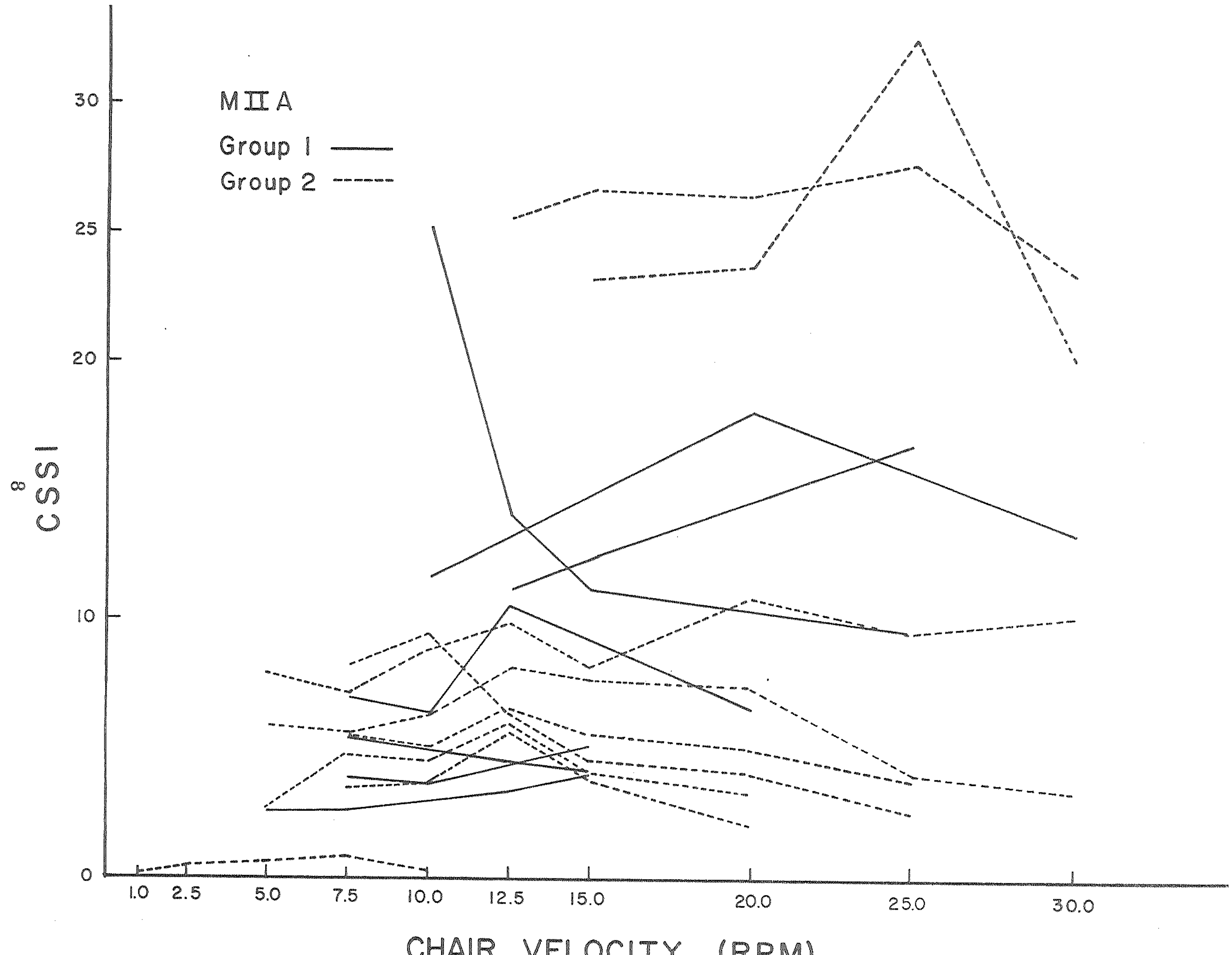
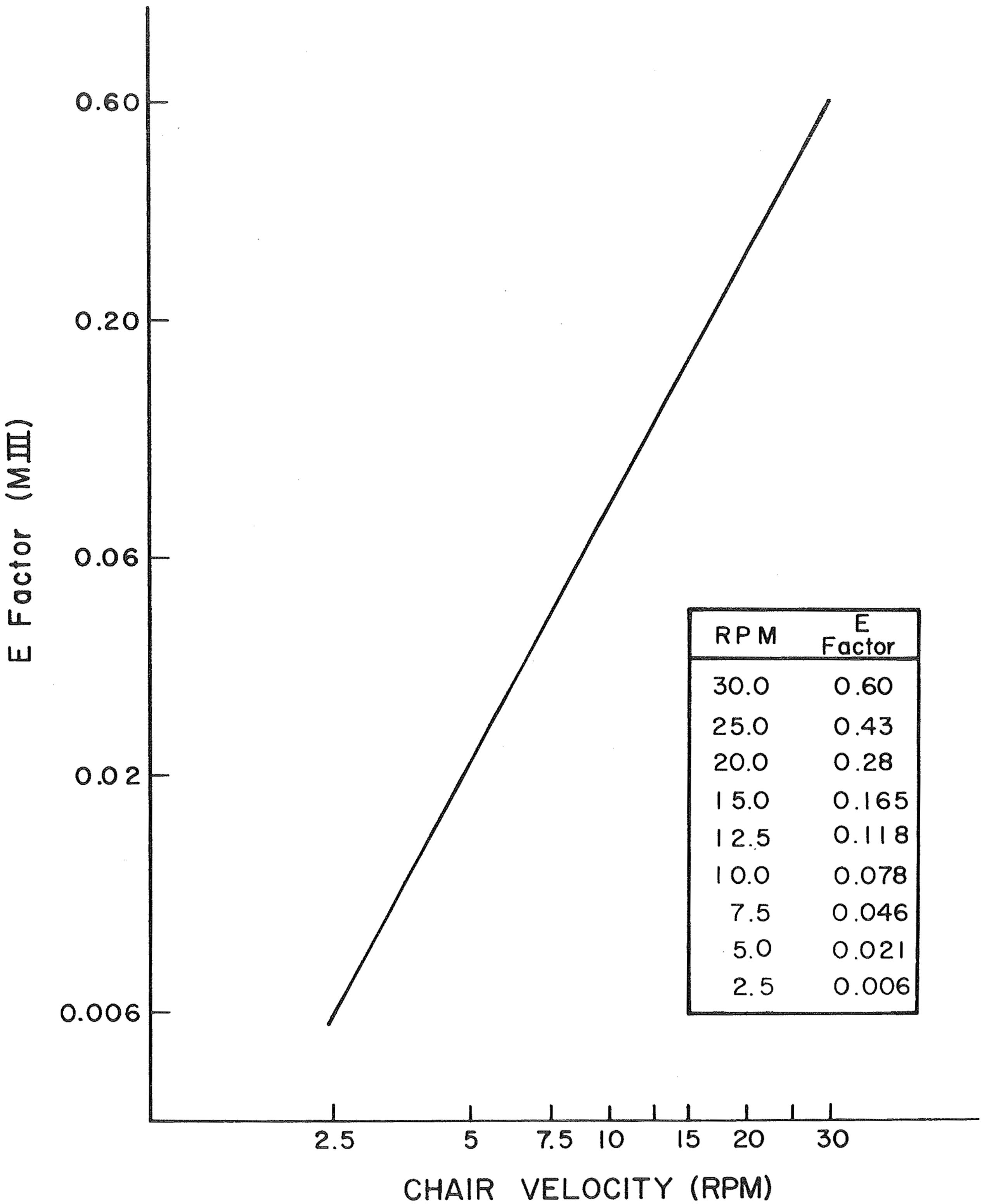


Figure 4

Susceptibility Level Graded by Coriolis Sickness Susceptibility Index
(CSSI) Scores Calculated From Results of Testing Each Subject at Several Rotational Rates



RPM	E Factor
30.0	0.60
25.0	0.43
20.0	0.28
15.0	0.165
12.5	0.118
10.0	0.078
7.5	0.046
5.0	0.021
2.5	0.006

Figure 5

Relative Stressor Effect (E Factor) of a Single Head Movement, Severe Malaise (M III) Endpoint, as a Function of Rotational Velocity

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13. ABSTRACT

To measure the stressor stimulus effect of rotational velocity in terms of the number of the standardized head tilt movements required to evoke a common severity level of symptoms characterizing motion sickness, sixteen young healthy subjects were rotated in a laboratory (Stille) rotational chair at various velocities within a range suitable for each subject and the limits of 1.0 to 30.0 rpm. Standardized 90° head movements were executed at each test velocity until the preselected and quantitatively determined motion sickness endpoint of moderate (M IIA) or severe (M III) malaise was reached. When individual ability to make head movements without evoking symptoms was exceeded, the derived average stressor effect (E factor) of each head movement varied directly and, in log-log terms, linearly with rotational velocity. These data provide the basis for grading individual susceptibility to Coriolis (motion) sickness with a single numerical score as well as define the high rate of change of Coriolis stressor effect as a function of rotational velocity, which may find practical application for specifying rotational rates of space stations.

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