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AN ATTEMPT TO MEASURE THE DEGREE OF ADAPTATION PRODUCED BY DIFFERING AMOUNTS OF CORIOLIS VESTIBULAR STIMULATION IN THE SLOW ROTATION ROOM

James T. Reason and Ashton Graybiel

JOINT REPORT

DEPARTMENT OF THE NAVY NAVAL AEROSPACE MEDICAL INSTITUTE

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SUMMARY PAGE

THE PROBLEM

To obtain a quantitative estimate of the degree of adaptation acquired as the result of different amounts of Coriolis stimulation. Subjects executed a predetermined number of controlled 90° head motions at 5 rpm in the slow rotation room. Three measures of adaptation were used: 1) the number of perrotatory head movements evoking sensations due to the Coriolis acceleration, 2) the direction and duration of the Coriolis oculogyral illusion both during and immediately after the period of rotation, and 3) the number of postrotatory motions producing some detectable after-sensation. The first measure was included to provide an indication of individual differences in adaptability; the remaining two were designed to reveal treatment effects.

FINDINGS

Six conditions of exposure, ranging from 30 to 180 sequences of eight head motions each, produced no measurable differences in the degree of adaptation acquired. A positive and significant correlation was obtained between the number of perrotatory motions evoking a Coriolis reaction (irrespective of the total number of sequences executed) and the number of postrotatory motions producing an after-sensation.

In a second experiment, the range of exposures was limited to 5, 10, 15, 20, and 25 sequences. Only the shortest exposure produced a measure of adaptation that was significantly less than that in the other conditions.

INTRODUCTION

This study was part of a larger investigation concerned with the design of an adaptation schedule intended to confer residual protection against motion sickness in rotating spacecraft with the minimum use of preflight time. A previous experiment in this series (6) had indicated that protection could be achieved most effectively if the amount of Coriolis stimulation at each velocity step in the schedule was graded to the absolute speed of the rotating environment. That experiment also demonstrated that the technique of requiring subjects to indicate the presence or absence of sensation at the completion of each head movement was valuable in estimating the degree of adaptation acquired.

The same technique was used in the present study to investigate the manner in which adaptation develops as a function of preexposure to varying amounts of Coriolis vestibular stimulation; i.e., the number of effective head movements. The variable number of head movements were made at a single angular velocity, 5 rpm. Three methods were used to assess the amount of adaptation acquired in the perrotational period: 1) the number of head movements that elicited some sensation during the postrotatory period while the device was stationary, 2) the direction and duration of the Coriolis oculogyral illusion (OGI) both during and immediately after the rotational period, and 3) the number of head movements during rotation that yielded sensations due to the force environment. Only the first two measures were expected to vary as the direct result of the amount of stimulation received; the third measure was included as an index of individual differences in adaptability.

Assuming that adaptation as a function of Coriolis stimulation develops in a way which is not markedly different from that in other sensory systems, it was reasonable to expect that there would be no measurable increase in adaptation beyond a certain amount of stimulus exposure (1,2). In other words, it was presumed that adaptation, in this situation, would grow as a negatively accelerating function of the amount of stimulation. With regard to the development of an adaptation schedule, the primary purpose of this experiment was to determine the amount of stimulation necessary to achieve this asymptotic level for a single rotational speed.

EXPERIMENT 1: PROCEDURE

SUBJECTS

Twenty-four young men served as subjects; two additional subjects were eliminated due to early onset of severe malaise. An extensive test program prior to the experiment had established that all possessed normal vestibular function although there was a wide range of variation in their susceptibility to motion sickness in a rotating environment. These subjects were either enlisted men serving at the Naval Aerospace Medical Institute, or junior officers awaiting reassignment to other duties. All were in good health at the time of the experiment.

APPARATUS

The major item was the Pensacola Slow Rotation Room (SRR), a circular windowless room 15 feet in diameter and 7 feet high. A complete description of this device can be found elsewhere (4). The onboard facilities were identical to those used in the earlier experiment (6).

METHOD

A full description of the head movements and the sensation-detection technique used in this experiment can be found in the earlier report (6). The subject was seated in a specially constructed chair facing toward the center column. The distance from the axis of rotation to the center of the subject's head in the upright position was 42 inches.

The stimulus movements were grouped into sequences of eight: four "down" movements (front, back, left, and right) and four "return" movements to the upright position. With each movement, the neck and trunk were flexed sufficiently to enable the head to pass through an arc of 90°. The extent of these movements was controlled by carefully adjusted pads. Movements were made in response to taped instructions and were initiated at 2-second intervals. The order of the four down movements was randomized within each sequence. Rotation of the SRR was in the counterclockwise direction.

At the completion of each discrete movement, the subject was required to indicate whether or not he had detected sensations due to the force environment by making either a "yes" or "no" response. Two sensory components contributed to the yes response: 1) those nonvestibular proprioceptive cues which told him that his head and torso were being deflected from their desired path during the movement (for convenience, this phenomenon was termed the "giant hand effect"); 2) those sensations of vestibular origin that could be detected both during movement and at its cessation. The latter could be perceived either as apparent visual movement within a test patch, or as more diffuse sensations of whole-body movement. The negative response was appropriate when neither of these two sensory elements was present; i.e., when the sensations accompanying the movement were indistinguishable from those in a stationary environment.

The 24 subjects were randomly allocated to one of six stimulus conditions: 30, 60, 90, 120, 150, and 180 sequences at 5 rpm. All subjects received the same instructions prior to rotation and executed the same 30 sequences of movements first at 3 rpm. This intermediate velocity step was incorporated to allow some adjustment to the rotating environment prior to the test run at 5 rpm in order to minimize the problems due to motion sickness at the higher velocity. Upon completing the 30 sequences, the subjects were given a 5-minute rest period with the head restrained. At the end of this period, they were taken to 5 rpm whereupon they made the previously assigned number of head and body movements.* During these movements, they were also required to give the

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*Five-minute rest periods with the head restrained were given after every 45 sequences.

yes-no responses. When the subject completed his specified number of sequences at 5 rpm, the SRR was brought to a halt and the same movements were performed in the stationary condition. Each subject continued these movements postrotation until he achieved the criterion of three consecutive sequences in which each of the 24 separate movements elicited a negative response. The number of affirmative responses prior to this criterion was the major dependent variable.

In addition to the procedure described above, Coriolis oculogyral illusion tests (OGI) were given at the following fixed points throughout the experimental sessions:

1) Prior to rotation (pretest)

2) At 5 rpm prior to commencing movement sequences (pertest I)

3) At 5 rpm immediately following sequences (pertest II)

4) At rest prior to commencing sequences (posttest I)

5) At rest immediately following sequences (posttest II)

For each OGI test, the subject made two 45° head movements: a tilt toward the left shoulder, and a return to the upright. The only object visible within the SRR at these times was a dimly illuminated cube. On the instructions of the experimenter, the subject made a rapid tilt movement and then maintained his head in the tilted position. When the apparent motion of the OGI cube ceased, the subject said "stopped." The subject was also asked to indicate, with reference to the clock-face, the direction of apparent motion. Both duration and direction were recorded. The procedure for the return movement was identical to that for the tilt. The direction and duration values for these tests constituted the second dependent variable.

Subjects were asked to report whenever they detected stomach awareness, constriction of the throat, headache, or any other prodromal indication of motion sickness. They were also closely watched for the onset of pallor or sweating. In the event of symptoms being detected, the subject was rested with his head in a fixed position until the symptoms had passed.

RESULTS

Number of Affirmative Responses

The results showing the number of affirmative responses during and after rotation at each level of stimulus exposure are summarized in Table I.

Looking first at the postrotatory affirmative responses, it is apparent both from the mean values and from the variability within each group that the different amounts of pre-exposure to Coriolis stimulation did not contribute to the variation in the number of postrotatory affirmative responses in any significant or systematic way.

Table I

Number of Perrotatory and Postrotatory Affirmative Responses* Following Each of Six Levels of Stimulus Exposure

	Number of Sequences at 5 rpm											
	30		60		90		120		150		180	
	4	(28)	199	(88)	9	(37)	13	(31)	5	(27)	1	(22)
	8	(20)	230	(103)	91	(72)	1	(7)	30	(54)	31	(59)
	17	(34)	345	(50)	24	(33)	15	(26)	50	(76)	122	(90)
	12	(41)	15	(52)	37	(64)	12	(40)	1	(18)	4	(24)
(Per-) $\bar{X}$	10.2		197.0		40.2		10.2		21.5		39.5	
(Post-) $\bar{X}$		(30.7)		(73.2)		(51.5)		(31.2)		(53.0)		(59.2)

*The values without parentheses represent the number of affirmative responses in the perrotational period; those with parentheses refer to the number of affirmative responses during the postrotation period. Each pair of values was generated by one subject.

Further examination of this table shows that the mean number of affirmative responses during the rotational period (no parentheses) fluctuated in close accordance with the mean number of affirmative responses during the postrotational period over the range of stimulus exposures. Since all the subjects reached the adaptation criterion of three negative sequences prior to the completion of their prescribed number of sequences, it was possible to compute a Spearman rank-order correlation coefficient between the number of per- and postrotatory affirmative responses. The value of this coefficient was .88 which was significant for 24 subjects at the 1 per cent level of confidence.

On the assumption that the number of perrotational affirmative responses reflected an individual's basic level of adaptability, these data suggest that, between 30 and 180 sequences of preexposure, the greater part of the postrotatory variation can be accounted for by the characteristic differences among the subjects in their rates of adaptation. This notion could be checked, in part, by examining the data from the parallel measure of adaptation, the Coriolis oculogyral illusion.

Coriolis OGI Data

Two measures were used to indicate the degree of adaptation following the differing amounts of stimulus preexposure: 1) the number of times within each stimulus group that the postrotatory OGI was reversed in direction with respect to the perrotational OGI, and 2) the difference in duration of OGI between pertest I and pertest II. The findings relating to the former measure are shown in Table II; those relating to the latter are shown in Table III.

Table II

Analysis of the Direction of the Postrotatory Oculogyral Illusion

Number of Perrotational Sequences	Frequency: Same Direction as Perrotational Sensation		No Sensation		Reverse Direction	
	Tilt	Return	Tilt	Return	Tilt	Return
30 (N = 4)	1	2	0	0	3	2
60 (N = 4)	0	1	0	0	4	3
90 (N - 4)	0	0	0	0	4	4
120 (N = 4)	1	1	2	1	1	2
150 (N = 4)	0	0	0	0	4	4
180 (N = 4)	0	0	2	2	2	2

If the degree of adaptation had increased as a function of stimulus exposure, one would have expected a greater number of reversals and a corresponding increase in the size of the difference (pertest I - pertest II) to be associated with the larger numbers of stimulus sequences. In neither case was there any indication of a systematic relationship. Thus, it seems reasonable to accept the conclusion derived from the affirmative response data that increasing the stimulus exposure from 30 up to 180 sequences results in no measurable increase in adaptation.

Table III

Duration of the Perrotational Oculogyral Illusion (Seconds)

Stimulus Group	Mean Duration Pertest I		Mean Duration Pertest II		Mean Difference (I - II)	
	Tilt	Return	Tilt	Return	Tilt	Return
30 seq. (N = 4)	2.2	2.2	3.1	3.5	-0.9	-1.3
60 seq. (N = 4)	3.1	2.9	2.4	2.7	+0.7	+0.2
90 seq. (N = 4)	4.2	6.4	4.5	7.9	-0.3	-1.5
120 seq. (N = 4)	4.6	3.7	3.1	4.1	+1.5	-0.4
150 seq. (N = 4)	4.0	4.5	4.7	3.0	-0.7	+1.5
180 seq. (N = 4)	5.9	4.2	1.0	1.7	+4.9	+2.5

Motion Sickness

Of the 24 subjects who completed the experiment, 7 showed obvious symptoms of motion sickness at some point throughout the session. In general, subjects presenting the most severe symptoms were those who were susceptible to the postrotatory sequences. Three subjects fell into this category; one of them actually vomited during the postrun sequences, after which he made an almost complete recovery and continued the head movements. All the perrotational episodes of motion sickness were mild and did not require more than a 10-minute rest period before the movements could be continued.

In addition, two subjects were eliminated from the sample due to the early onset of severe malaise (MIII) (5). One further subject, not included among the seven mentioned above, complained of a severe frontal headache at the cessation of rotation. This was not accompanied by stomach awareness nor by any other premonitory indication of the nausea syndrome.

The relatively low incidence of motion sickness (38 per cent) in this experiment suggested that the intermediate step involving 30 movement sequences at 3 rpm was in fact helpful in providing some preliminary adjustment to the force environment. None of the subjects reported any symptoms during the 3-rpm movements.

Individual Differences

There were some interesting differences among individuals in the qualitative nature of the sensations they reported during the movement sequences. Subjects fell into one of two groups: "visual producers" and "somatosensory producers." The former were able to detect some apparent motion within the visual test patches in addition to the "giant hand effect," while the latter were able to detect only the head and body deflection comprising the giant hand effect. The division of the total sample into these two groups was exactly equal, with 12 subjects in each group. Four of the subjects showing motion sickness symptoms were visual producers; the other three were somatosensory producers.

The most important difference between the groups was in the number of movements eliciting affirmative responses during the rotational period. The median number for the visual producers was 39.5, while that for the somatosensory producers was only 6.5. This clearly indicates that the giant hand effect adapted far more rapidly than the visual sensations of vestibular origin.

One hypothesis to account for these differences was that the visual producers were more sensitive to the OGI than the somatosensory producers. To examine this possibility, the mean durations of the OGI for the pertest I were computed for the two groups and are shown below in Table IV:

Table IV

Mean Durations of the OGI at Pertest I for Visual and Somatosensory Producers

	Tilt	Return
Visual producers	3.3 sec	3.6 sec
Somatosensory producers	4.7 sec	4.4 sec

The somatosensory producers, contrary to expectation, produced OGI durations that were slightly more persistent than those of the visual producers. It seems likely, therefore, that an explanation based solely upon differential sensitivity is inadequate.

DISCUSSION

One explanation for the apparent lack of variation in adaptation due to differing amounts of stimulus exposure was that maximum rate of change in adaptation occurs with fewer sequences than were used in this experiment. In other words, it was probable that the 30- to 180-sequence range was sampling the asymptotic region of the hypothetical adaptation curve where no differences were likely to be demonstrated. This possibility would be compatible with the finding that variation in the postrotatory affirmative responses was largely accounted for by individual differences in adaptability.

Consequently, a second experiment was performed that sampled a stimulus range of less than 30 sequences. The wide variation among subjects in Experiment 1 suggested that repeated measurements on the same individuals would be a more meaningful way of collecting the data. This second experiment is reported below.

EXPERIMENT 2: PROCEDURE

SUBJECTS

Nine of the enlisted men used in the previous experiment served as subjects. All were in good health at the time of the experiment.

METHOD

The apparatus and procedure were essentially the same as that used in Experiment 1. The only major difference was that the same nine subjects were tested over five stimulus exposures: 5, 10, 15, 20, and 25 sequences at 5 rpm. At least 12 hours elapsed between one testing session and the next. The order of presentation of the stimulus exposures was counterbalanced to avoid sequential bias.

A further variation in design was that the intermediate 3-rpm velocity step was not included. It was felt that the stimulus exposures were of such short duration that motion sickness would not present a problem.

RESULTS

Number of Postrotatory Affirmative Responses

The number of postrun affirmative responses prior to achieving the adaptation criterion of three negative sequences is shown in Table V. Since one subject produced atypically high values, the median was taken as the more appropriate measure of central tendency.

It was evident from these results that the 10, 15, 20, and 25 sequence conditions did not differ significantly from one another with respect to the number of affirmative responses produced during the postrun period. The 5-sequence condition, however, produced fewer affirmative responses than any of the other stimulus exposures. Sign tests were computed between the 5-sequence condition and each of the other four conditions and, with the exception of the 5 to 10 comparison ($p < .05$), were significant at the 1 per cent level (one-tailed test).

Table V

Number of Postrotatory Movements Yielding an Affirmative Response

	Number of Sequences at 5 rpm				
Subjects	5	10	15	20	25
1	9	27	14	27	32
2	7	18	32	15	35
3	8	9	14	17	10
4	28	40	39	34	36
5	10	17	17	18	17
6	9	14	15	11	13
7	5	13	5	5	8
8	24	36	35	50	107
9	13	10	25	18	19
Mean:	12.6	20.4	21.8	21.7	30.8
Median:	9	17	17	18	19

Coriolis OGI Data

These data were analyzed in the same way as in Experiment 1. Table VI shows the number of times reversals were found within each exposure condition.

There was little or no difference in the number of reversals of illusion direction following the various stimulus conditions. Thus, an exposure of less than 5 sequences was sufficient to achieve the maximum number of reversals. This suggests that the OGI direction was extremely sensitive to relatively small amounts of stimulus exposure and, as such, is unlikely to prove a useful index of the degree of adaptation acquired by the fairly extensive stimulation envisaged for the protection schedule.

An analysis of the OGI duration data (as in Experiment 1) similarly failed to find any differences due to the varying amounts of stimulus exposure.

Table VI

Analysis of the Direction of Postrotatory Oculogyral Illusion

Number of Perrotational Sequences	Frequency: Same Direction as Perrotational Sensation		No Sensation		Reverse Direction	
	Tilt	Return	Tilt	Return	Tilt	Return
5 (N = 9)	2	2	1	2	6	5
10 (N = 9)	3	2	1	2	5	5
15 (N = 9)	2	2	1	0	6	7
20 (N = 9)	3	2	1	2	5	5
25 (N = 9)	2	1	1	2	6	6

DISCUSSION

While the OGI measures were inconclusive, the variation in the number of affirmative responses during the postrotatory period suggested that the "leveling out" of the adaptation curve occurred somewhere between 5 and 10 sequences of prior exposure. Increasing the amount of exposure beyond 10 sequences produced no substantial increase in the degree of adaptation acquired.

CONCLUSIONS

There is strong evidence to suggest that protection against motion sickness develops as a function of adaptation in the vestibular system or its central projection areas (3). If this is the case, then the relatively small number of sequences required to achieve maximum adaptation is an encouraging sign that protection can also be achieved with a correspondingly small amount of stimulus exposure. A further point is that the present findings, based as they are upon a group of subjects showing wide variability in their susceptibility to motion sickness, are likely to overestimate the number of sequences necessary to achieve the same degree of adaptation (or protection) in individuals of less than average susceptibility.

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13. ABSTRACT

The problem was to obtain a quantitative estimate of the degree of adaptation acquired as the result of different amounts of Coriolis stimulation. Subjects executed a predetermined number of controlled 90° head motions at 5 rpm in the slow rotation room. Three measures of adaptation were used: (1) the number of perrotatory head movements evoking sensations due to the Coriolis acceleration, (2) the direction and duration of the Coriolis oculogyral illusion both during and immediately after the period of rotation, and (3) the number of postrotatory sensations producing some detectable after-sensation. The first measure was included to provide an indication of individual differences in adaptability; the remaining two were designed to reveal treatment effects.

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