NAMI-1086

ADAPTATION TO CORIOLIS ACCELERATIONS: ITS TRANSFER TO THE OPPOSITE DIRECTION OF ROTATION AS A FUNCTION OF INTERVENING ACTIVITY AT ZERO VELOCITY

James T. Reason and Ashton Graybiel

JOINT REPORT

NAVAL AEROSPACE MEDICAL INSTITUTE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

August 1969

This document has been approved for public release and sale; its distribution is unlimited.

ADAPTATION TO CORIOLIS ACCELERATIONS: ITS TRANSFER TO THE OPPOSITE DIRECTION OF ROTATION AS A FUNCTION OF INTERVENING ACTIVITY AT ZERO VELOCITY *

James T. Reason and Ashton Graybiel

Bureau of Medicine and Surgery
MR005.01.01-0021B

NASA Order No. R-93

Released by

Captain M. D. Courtney, MC USN
Commanding Officer

5 August 1969

*This work was conducted under the sponsorship of the Office of Advanced Research and Technology, National Aeronautics and Space Administration.

NAVAL AEROSPACE MEDICAL INSTITUTE
NAVAL AEROSPACE MEDICAL CENTER
PENSACOLA, FLORIDA 32512

SUMMARY PAGE

THE PROBLEM

To determine how adaptation to Coriolis accelerations, acquired through controlled head movements in a room rotating in one direction, transfers to the opposite direction as a consequence of the stimulus mode during an intervening period at zero velocity. Under one experimental condition the subjects continued to make the same head movements during this period as those used to acquire perrotational adaptation, thus evoking postrotational responses opposite in sign but similar in quality to those experienced during the initial period of rotation. Under the other condition mechanical restraints were applied to the head and torso for an equivalent period of time.

FINDINGS

Subjects who performed head motions during the intervening static period were able to adapt more rapidly to the second (opposite) direction of rotation than to the first. In addition, the intervening activity appeared to confer some immunity to motion sickness during the second direction of rotation. Postrotational effects following the second direction of rotation were less severe and of shorter duration than those experienced following the initial period of rotation. The opposite findings were obtained for those subjects who remained immobilized during the intervening period at zero velocity.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the subjects, and the technical assistance of Mr. Roy Garlock.

INTRODUCTION

In a previous study (9) three subjects were repeatedly exposed to Coriolis accelerations produced by controlled head movements during counterclockwise (CCW) rotation in the slow rotation room (SRR). After several weeks of periodic exposure (including one period lasting for 72 hours), all three subjects manifested a high degree of adaptation, as evidenced by the absence of subjective response and motion sickness. At the completion of the CCW testing schedule, the subjects were again exposed to a quantitatively similar level of Coriolis stimulation but this time in the clockwise direction (CW) of rotation. Since adaptation to one end of what Gibson (1) has called an "oppositional" sensory dimension usually involves an increased sensitivity to the other end (7), it was expected that the CW rotation would produce a much greater sensory response than that observed during the initial exposure to the CCW direction. It was surprising, therefore, to obtain quite the opposite result; the response to CW rotation was significantly reduced with respect to the initial response to CCW rotation in all three subjects.

There appeared to be at least two explanations for this phenomenon. The first was that the sustained exposure to Coriolis accelerations experienced by these subjects during CCW rotation had resulted in some generalized suppression of vestibular activity, mediated perhaps by efferent pathways, as emphasized by Graybiel (2), which was reflected in the reduced response to CW rotation. The second explanation was based upon the fact that immediately following each period of CCW Coriolis stimulation, the subjects were required to make the same head movements in a stationary environment in order to assess the strength and persistence of the perrotatory adaptation processes. Here, it was argued that since the postrotatory responses (being opposite in sign to those obtained during CCW rotation) were qualitatively similar to those that would have been produced by Coriolis stimulation in the opposite (CW) direction, the neural record of their existence subsequently facilitated adaptation when the same type of response was actually evoked by CW rotation.

The latter type of hypothesis depended for its rationale upon the "two-stage" models of habituation advanced by Groen (5), Held (6), and Sokolov (11) as opposed to the "one-stage" models proposed by Pavlov (8) and others. Two-stage models involve a first stage in which the current sensory input is matched to a neural record of "exposure-history." The second stage depends upon the results of this matching process. A mismatch signal sets in train a number of physiological and behavioral events whose precise nature depends upon the receptors involved and the quality of the signal. In these models, the process of adaptation is due to the information contained in the neural record being progressively updated so that, eventually, it approximates to the prevailing sensory input. When this match is achieved, the second stage is not activated and the organism is considered to have adapted to that specific environment.

In the present case, it is suggested that the postrotatory responses following CCW stimulation laid down appropriate traces within the neural store; their presence, on encountering the same direction of response in the CW situation, rendered the process of updating more rapid. Thus, it is hypothesized that the postrotatory responses following

CCW rotation, although produced in the absence of a Coriolis stimulus, were of the same "neural currency" as the responses evoked during CW Coriolis stimulation and therefore hastened the process of adaptation in that condition.

Of the two types of explanations discussed, the notion of generalized suppression and that of "equivalent traces," the latter was considered to be the more amenable to experimental testing. The present experiment was designed to provide such a test by varying the type of activity carried out during a fixed period of zero velocity intervening between equal but directionally opposite exposures to controlled Coriolis accelerations. One group of subjects (the "activity" group) were occupied during the intervening stationary period with making continuous head movements of the sort used to generate the perrotational stimuli; in the other group (the "immobilization" group), each subject's head and trunk were immobilized by mechanical devices for the same period of time. The following experimental predictions were generated from the "equivalent trace" hypothesis discussed above:

1). For the activity group, the rate of adaptation to the second direction of rotation (Run II) will be faster and the responses subjectively weaker than in the initial direction (Run I). For the immobilization group, however, the direction of the difference will be reversed; the rate of adaptation for Run II will be slower and subjective responses stronger than in Run I. The latter part of this prediction is based on the assumption that the period of immobilization will preserve the postrotatory responses which, in Run II, will add on to the perrotatory responses and cause them to be felt more strongly.

2). On the same assumption, it was expected that in the activity group, the postrotatory responses following Run II (Postrun II) would be less severe and of shorter duration than those following Run I (Postrun I).

PROCEDURE

SUBJECTS

Twenty-four young men, either junior naval officers or enlisted personnel, were used as subjects. Only three had had any prior experience of experimentally induced Coriolis stimulation. All were known to be in good health at the time of the experiment.

METHOD

The experiment was carried out in a slow rotation room (SRR). A full description of this facility has been given elsewhere (4).

The perrotational procedures were designed to be identical for both the activity (N = 16) and the immobilization (N = 8) groups. In Run I, each subject executed controlled head and body movements at each of six 1-rpm increases in the angular velocity of the SRR; that is, rotation commenced at 1 rpm and proceeded via a series of 1-rpm step increments up to a terminal velocity of 6 rpm.

The 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 down 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 variable position head pads attached to the subject's chair. The movements were made in response to taped instructions and were initiated at 3-second intervals. The four down movements were ordered randomly within each sequence.

At the completion of each individual motion, the subject was required to make a forced-choice detection judgment. One of two alternative responses could be made: either "Yes," meaning that the subject had detected some sensation due to the rotating environment, or "No," meaning that he was not aware of the effects of the Coriolis acceleration. Two sensory components contributed to the affirmative response: first, those nonvestibular proprioceptive cues that told him his head and torso were being deflected from their desired path during the movement; second, those sensations of vestibular origin that could be detected both during and at the end of the motion. The latter could be perceived either as apparent visual motion within conveniently located structured visual surfaces, or as more diffuse sensations of apparent whole-body movement. The negative response was appropriate when neither of these two sensory elements was detected; that is, when the sensations accompanying the movement were indistinguishable from those in a stationary environment without prior exposure.

At each velocity step the movements were continued until each of 24 consecutive responses (three complete sequences) had elicited a negative response and the subject was judged to have no indications of motion sickness. When this arbitrary adaptation criterion was met, the angular velocity of the device was increased by 1 rpm and the procedure repeated until the terminal velocity of 6 rpm was reached; at this point, the device was brought to a stop.

For both the activity and the immobilization groups, the period of zero velocity intervening between Run I and Run II was 30 minutes. During this period, the activity group continued to make the controlled movements and Yes-No responses for a total of 50 sequences with a 5-minute rest period after the thirtieth sequence. In the immobilization group, however, an orthopedic neck brace was applied together with a device which secured the upper body to the chair's back rest before the SRR was stopped and after attaining the adaptation criterion at the terminal velocity for Run I. Those subjects remained immobilized for the entire 30-minute period at zero velocity.

At the end of this period Run II was commenced; this was identical to Run I with the exception that the direction of rotation was reversed. Within each group the directions of rotation were balanced such that approximately half the subjects went CCW during Run I and CW during Run II, while the other half went CW during Run I and CCW during Run II. At the completion of Run II the SRR was brought to a stop and subjects continued to make the controlled movements until they had achieved the adaptation criterion for their postrotatory sensations. A diagrammatic description of the stimulus profile is given in Figure 1.

The only exceptions to this procedure were made when symptoms of motion sickness were reported by the subject or detected by the onboard observer. When such symptoms were observed, a back rest was placed in the chair and the subjects were asked to remain still until they judged themselves to be sufficiently recovered to continue the movements. The experiment was stopped when the rest failed to produce recovery, or when the symptoms exceeded the Malaise III criterion (3).

RESULTS

DIRECTIONAL EFFECTS

To establish whether there was any difference due to the initial direction of rotation, a comparison was made of the total number of affirmative responses obtained in Run I between subjects who rotated CW and CCW. This comparison involved the total sample with the exception of the one subject who failed to complete Run I due to motion sickness. Means and standard deviations for the two directions of rotation are shown in Table I.

Table I

Comparison of Total Number of Affirmative Responses Produced During Run I by CW and CCW Rotation

	CW Rotation	CCW Rotation
Mean	86.54	58.10
SD	77.34	79.37
Subjects (N):	11	12

A Mann-Whitney "U" test (10) indicated that this difference was not statistically significant ($U = 44$; $n_1 = 11$, $n_2 = 12$); therefore, no differentiation was made between the two directions of rotation in the other analyses.

MOTION SICKNESS SYMPTOMATOLOGY

There was a much greater incidence and severity of motion sickness symptoms in the immobilization (I) group than in the activity (A) group. The degree of symptoms and the points at which they were observed during the experimental procedure are shown in Table II.

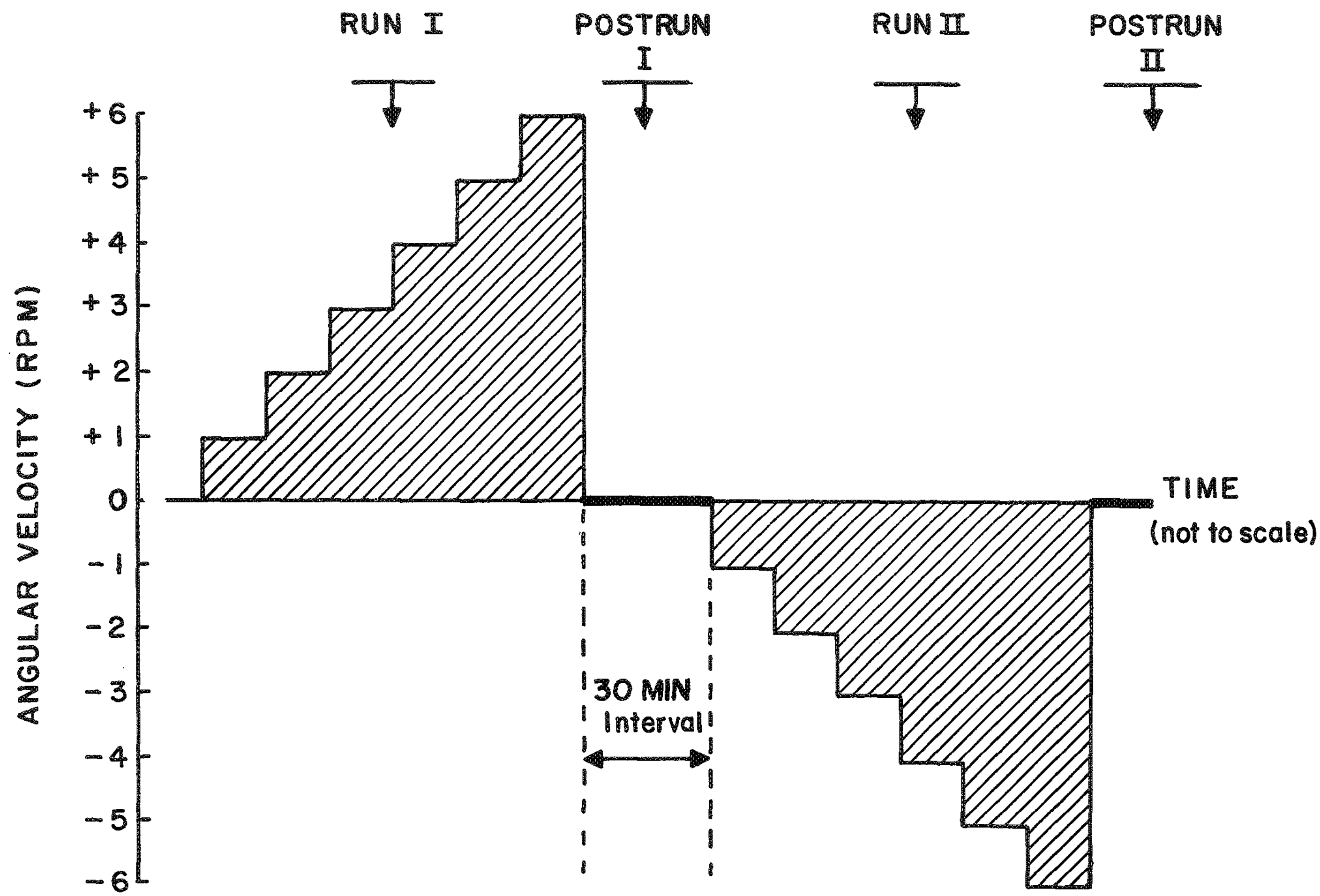

Figure 1

Diagram Showing the Stimulus Profile

Table II

Motion Sickness Symptomatology in the Two Groups

Subjects	Run I	Postrun I	Run II	Postrun II
Activity Group				
RO	NS	NS	NS	NS
PH	NS	NS	NS	NS
PL	NS	NS	NS	NS
RI	NS	NS	NS	NS
SC	NS	NS	NS	NS
SW	NS	NS	NS	NS
AC	NS	NS	NS	NS
MA	NS	NS	NS	NS
ZA	NS	NS	NS	NS
BU	NS	M II	M II (5)	M II
HA	NS	NS	NS	NS
SCH	NS	NS	NS	NS
JO	NS	M II	M III* (4)	-
JH	M II (3)	Vomit*	-	-
FR	M II (6)	M II	Vomit* (3)	-
RA	M III* (5)	-	-	-
No symptoms:	81%	73%	79%	92%
Symptoms: able to go on	13%	20%	7%	8%
Symptoms: abort run	6%	7%	14%	0%
Immobilization Group				
JL	NS	NS	M III* (1)	-
SO	NS	NS	M II (2)	M II
ST	M II	NS	M III* (1)	-
DA	NS	NS	M III* (1)	-
DU	NS	NS	NS	NS
SK	NS	NS	M III* (1)	-
SH	NS	NS	M III* (1)	-
BA	NS	NS	M III* (1)	-
No symptoms:	88%	100%	12%	-
Symptoms: able to go on	12%	0%	12%	-
Symptoms: abort run	0%	0%	75%	-

*Indicates run aborted at this point. M II = moderate malaise. M III = severe or marked malaise. NS = no symptoms. Numbers in parentheses indicate the RPM value at which symptoms first appeared in that particular condition.

It is evident from Table II that although the incidence of motion sickness for the two groups was fairly similar in Run I, it differed markedly in Run II. In the second direction of rotation, only two subjects in the A group reached an M III state or worse; whereas, in the I group, 6 of the 8 subjects reached an M III condition. It is interesting to note that all those subjects of group A who had symptoms during Run II also had had symptoms during the preceding period at zero velocity or during Run I. The impression that the symptoms had been aggravated rather than initiated by the Run II head movements was supported by statements made by these subjects.

The percentage values of the incidence of symptoms for the A group also indicate that for them the most stressful period was the intervening period at zero velocity when the postrotatory effects were most severe. This result was compatible with the notion that the return to zero velocity after adapting to 6 rpm constituted the period of greatest maladaptation for the subjects. At the cessation of rotation, there was a change from 6 to 0 rpm, whereas in the perrotational phase, the change in angular velocity never exceeded 1 rpm at any one time.

COMPARISONS WITHIN THE ACTIVITY (A) GROUP

Two related measures were used in comparing the performance of the A group in Runs I and II and their subsequent postrotatory phenomena: 1) the total number of affirmative responses during and immediately following the two periods of rotation, and 2) the total number of movement sequences executed prior to the terminal adaptation criterion. The former reflects the amount of response before a given level of adaptation is attained, while the latter indicates the amount of stimulation necessary to achieve that level.

Table III shows the total numbers of affirmative responses and sequences for each of the two perrotational and postrotational periods. Only those data for the 12 subjects who completed all four periods are shown. The means of those totals are displayed graphically in Figure 2.

It can be seen that in the perrotatory affirmative responses, nine of the twelve subjects produced a fewer number in Run II than in Run I, while three produced a greater number. For the sequences, seven executed a smaller number in Run II than in I, three executed the same number, and two a greater number. In the postrotatory periods, the predicted effects were much more clear-cut. All twelve subjects produced fewer affirmative responses in the second postrun period than in the first; nine subjects executed a fewer number of sequences in the second postrun period; and the remaining three executed the same number as in the first postrun period.

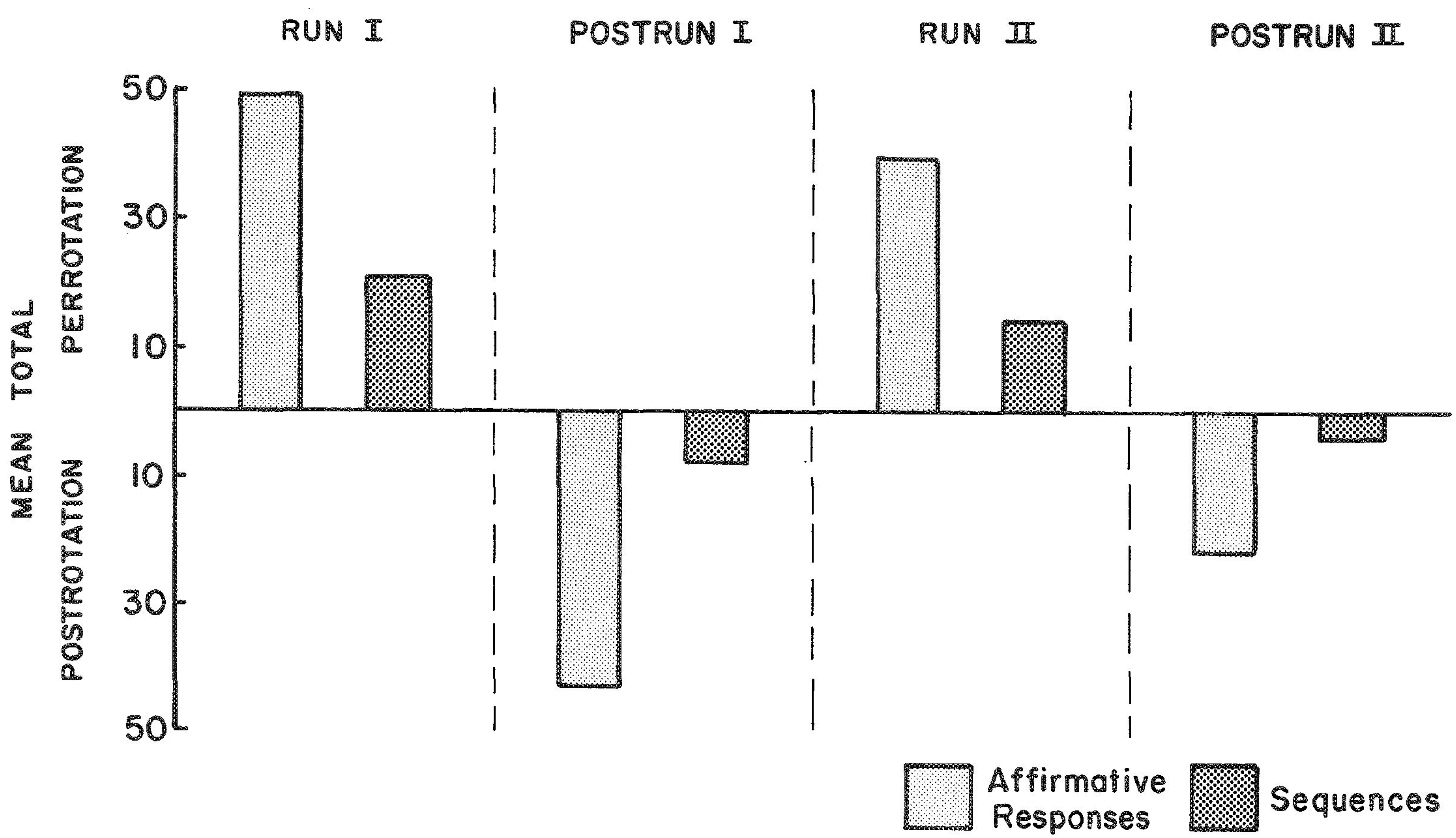

Figure 2

Summary of Results for the Activity Group

Table III

Total Number of Affirmative Responses Produced, and Movement Sequences Executed by the Activity Group In the Four Experimental Conditions

	Total Affirmatives				Total Sequences			
Subjects	Run I	Run II	Postrun I	Postrun II	Run I	Run II	Postrun I	Postrun II
RO	12	16	14	8	6	6	2	2
PH	11	8	6	3	6	5	1	1
PL	68	34	45	30	39	17	7	7
RI	32	29	28	17	9	9	4	3
SC	42	34	58	29	17	15	13	5
SW	43	63	47	31	23	30	10	9
AC	50	26	39	15	28	8	8	3
MA	32	10	25	7	11	6	4	1
ZA	56	72	56	43	27	41	13	8
BU	179	175	117	59	28	28	15	9
HA	31	4	38	18	31	3	13	5
SCH	32	3	38	3	27	3	5	1
$\bar{X}$	49.0	39.5	42.6	21.9	21.0	14.2	7.9	4.5
SD	46.2	47.9	28.1	17.1	10.9	12.4	4.8	3.1

The "t" test for correlated means was applied to each of the four conditions, and the results are as follows:

Comparison	t-value	P (one-tailed test)
Total affirmatives, Run I vs Run II	1.863	$< .05$
Total affirmatives, Postrun I vs II	4.848	$< .005$
Total sequences, Run I vs Run II	1.743	NS
Total sequences, Postrun I vs II	3.908	$< .01$

To establish whether the decrement in response observed in Run II was in any way related to angular velocity, the mean number of affirmative responses at each of the six step velocities in Runs I and II was computed; the results are shown graphically in Figure 3. For both Runs I and II there was a marked tendency for the number of affirmative responses prior to adaptation to increase as a function of the absolute angular velocity despite the fact that the step-increment in each case was held constant at 1 rpm. In general, the greatest decreases in such responses in Run II (in relation to Run I) occurred at the highest angular velocities, being greatest at 4 and 6 rpm.

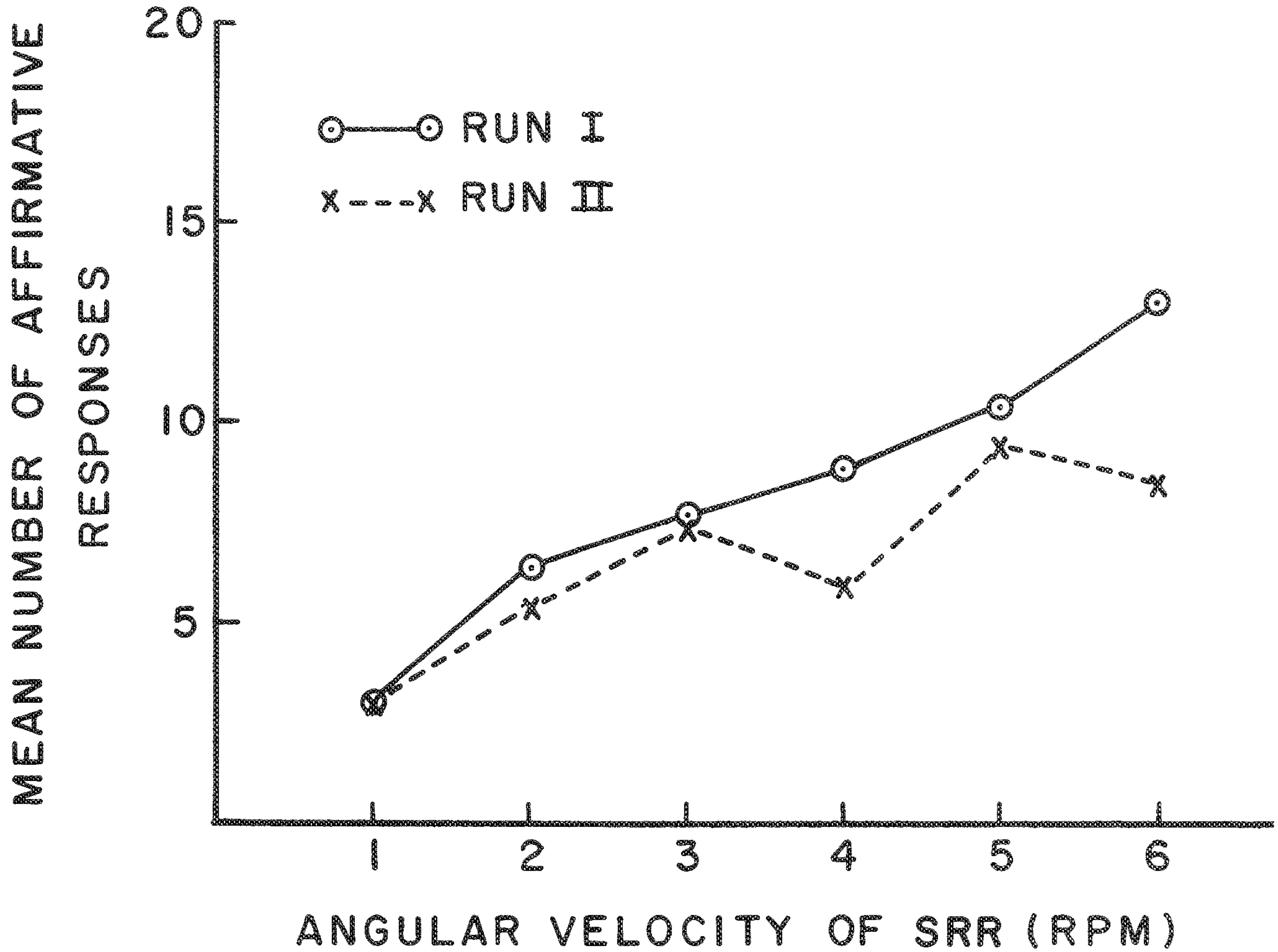

Figure 3

Comparison of the Mean Number of Affirmative Responses per Step Velocity in Runs I and II for the Activity Group

In view of the characteristic differences that are known to exist among individuals in the rates at which they adapt to Coriolis stimulation, it seemed reasonable to expect that the amount of response reduction in Run II would bear some relationship to the rate at which the individual adapted to Run I. A Spearman rank-order correlation was computed between (a) the total number of affirmative responses evoked in Run I (largest value assigned rank one), and (b) the decrement in Run II expressed as a percentage of (a) where the smallest value was assigned rank one. The resulting coefficient was $r_s = .12$ (N = 12) which was not significant.

COMPARISONS WITHIN THE IMMOBILIZATION (I) GROUP

Since most of the subjects in this group failed to complete Run II because of motion sickness, it was impossible to employ the same measures as those used for the activity group. Consequently, two other measures were used to make quantitative comparisons between Runs I and II: 1) equivalent number of affirmative responses, *i.e.*, the number of affirmative responses in Run II as compared to those obtained in the identical sequences in Run I; and 2) the average number of affirmative responses over all sequences, *i.e.*, in both Run I and II this was obtained by dividing the total number of affirmatives by the total number of sequences executed prior to criterion.

The findings for the I group are summarized in Table IV and Figure 4. The postrun II head movements were not scored since only two of the eight subjects were able to perform them.

Table IV

Total Number of Equivalent Responses and Averaged Responses From the Immobilization Group During Runs I and II

Subjects	Total Equivalent Responses Run I	Total Equivalent Responses Run II	Mean Number of Affirmatives Per Sequence Run I	Mean Number of Affirmatives Per Sequence Run II
JL	23	109	3.3	4.1
SO	13	36	1.9	3.0
ST	1	24	1.9	8.0
DA	14	28	1.6	2.9
DU	21	35	1.5	2.7
SK	20	50	3.9	5.6
SH	8	48	3.2	8.0
BA	5	8	2.5	8.0
$\bar{X}$	13.1	42.2	2.5	5.3
SD	7.9	30.1	0.89	2.4

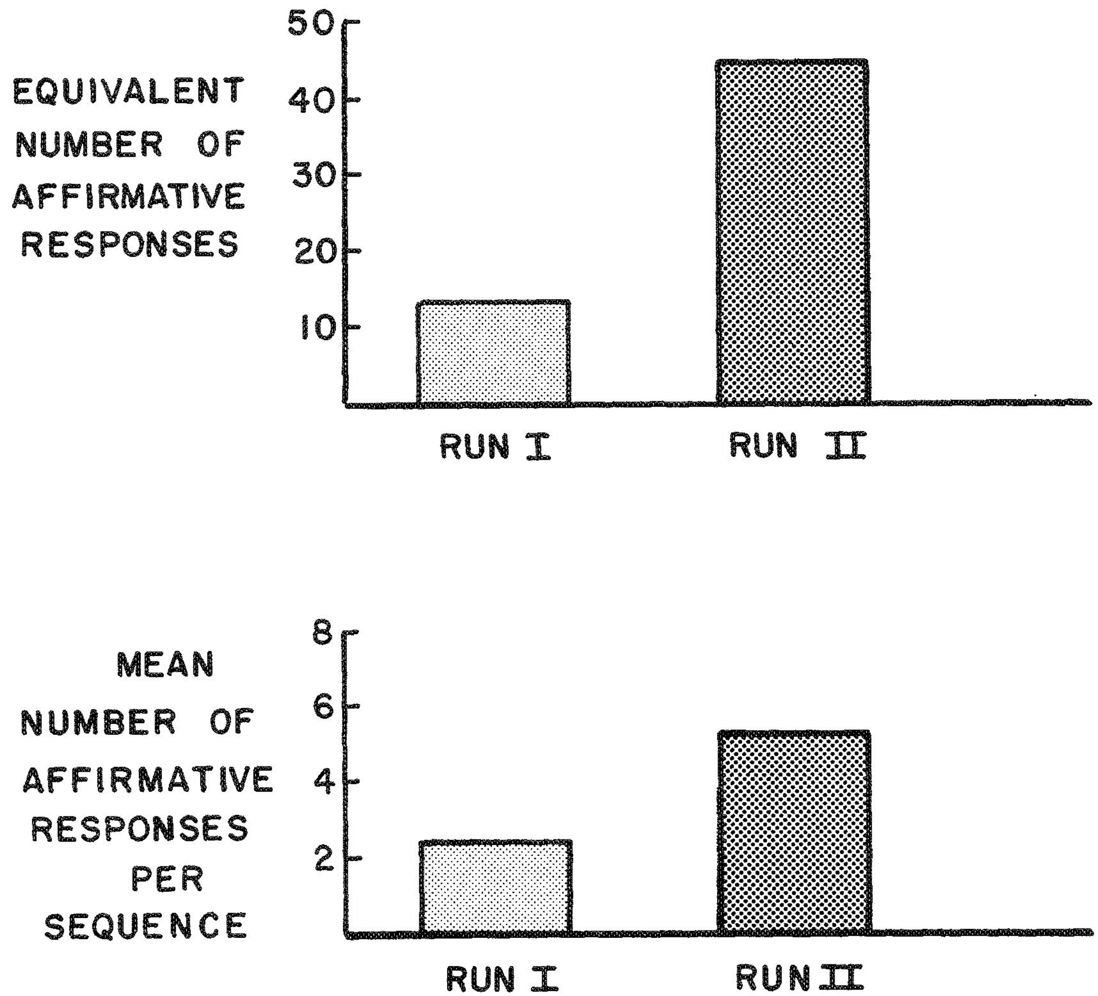

Figure 4

Summary of Results for the Immobilization Group

As before, "t" tests for correlated means were applied to both sets of data, and the results of this analysis are given below:

Comparison	t-value	P (one-tailed test)
Equivalent affirmatives, I vs II	3.49	<.01
Average number of affirmatives, I vs II	2.80	<.02

For both measures, each paired comparison was in the direction of the experimental prediction inasmuch as the responses produced in Run II were clearly more intense and more stressful than those evoked in Run I. It was not possible to obtain direct information concerning rates of adaptation owing to the incomplete data; but, from the results available, it was evident that had motion sickness not intervened, this process would have been relatively prolonged in most cases.

Examination of the individual records in the I group suggested that those subjects who reached a Malaise III state most rapidly in Run II were those who also reported a relatively high number of affirmative responses during Run I. To test this observation statistically, a Spearman rank-order correlation was computed between (a) the number of sequences executed prior to the onset of M III during Run II, and (b) the total number of affirmative responses reported during Run I. The rank of one was assigned to the largest number of affirmative responses in Run I and to the smallest number of sequences in Run II. A coefficient of $r_s = .78$ was obtained which was significant at the 5 per cent level of confidence (N = 8).

SUBJECTIVE EVALUATIONS OF THE RELATIVE STRENGTH OF SENSATION IN RUN II AS COMPARED TO RUN I

Subjects in both the A and I groups were asked to judge whether the strength of sensation evoked in Run II was generally "weaker," "the same as," or "stronger" than that evoked in Run I. The results of these subjective ratings are summarized in Table V.

Table V

Relative Strengths of Sensations Produced in Run II as Compared to Run I

	Weaker	Same As	Stronger
A group (N = 14)	71%	29%	0%
I group (N = 8)	0%	0%	100%

DISCUSSION

The findings with respect to the immobilization group were the most clear-cut and also those which are perhaps the easiest to explain. It was evident that Run II was more stressful in terms of provoking motion sickness symptoms as well as more provocative of vestibular and nonvestibular proprioceptive responses than Run I. This was clearly a case in which desensitization to one end of an "oppositional" sensory dimension (1) through the mechanism of adaptation resulted in an increased sensitivity to the other end of the same continuum. This is compatible with results obtained in most other sensory modalities (7).

It was found in a previous investigation (9) and has been amply demonstrated in the present study that immediately following a sufficient period of exposure to Coriolis stimulation, postrotatory responses which are qualitatively similar but of the opposite sign to the perrotational responses can be evoked by the same head motions as those used to administer the Coriolis stimuli. In the case of the I group, however, the head restraint devices were applied prior to cessation of rotation at the end of Run I, thus preserving, to a large extent, the degree of adaptation to 6 rpm attained in the initial direction of rotation. It seems reasonable to assume that with the possible exception of some spontaneous remission of adaptation, this state was preserved throughout the 30-minute period of immobilization in a stationary environment. Thus, when head motions were made at 1 rpm in the opposite direction of rotation, they not only evoked the normal Coriolis responses, but also "discharged" the postrotatory responses held over from the previous direction of rotation. Since both types of responses were qualitatively of the same sign, it is likely that they summated algebraically to produce the intense subjective effects and the rapid development of motion sickness observed in this condition. In effect, therefore, by this procedure, individuals who were adapted to 6 rpm in one direction of rotation and then exposed to 1 rpm in the opposite direction had little, if any, loss of the original level of adaptation as a result of the intervening 30-minute period.

The differences observed in the activity group between Runs I and II, although less pronounced, were more interesting from a theoretical point of view since they offered some insight into the mechanisms of adaptation. Here, as predicted, the differences between Runs I and II were reversed with respect to the immobilization group. In addition, the responses obtained during Postrun II were consistently fewer and weaker than those obtained during Postrun I. Both of these findings are compatible with the "two-stage" model of adaptation outlined in the introductory section.

It is argued that the process of adaptation to an atypical environment (rotation) or readaptation to a typical environment (stationary) involves the updating of a neural storage mechanism and is complete when the contents of this store are congruent with the current sensory input. Within the store, this process of updating is effected by the retention of the essential informational characteristics of the sensory response. In Sokolov's words (11), "The model postulates a chain of neural cells which preserve information about the intensity, the quality, the duration, and the order of presentation of the stimuli." The store is assumed to operate on a recency principle such that informational traces relating to recent stimuli have priority over those established by earlier sensory inputs. In more general terms, this process can be regarded as one in which the central nervous system "learns" the informational characteristics of the prevailing environment and then capitalizes upon this knowledge (with respect to its limited capacity) by not reacting to the invariant properties of this environment.

In the present experiment, the activity group were exposed to four consecutive treatments in which Run I and Postrun II, on the one hand, and Postrun I and Run II, on the other, produced responses which were directionally the same within each pair of treatments and directionally opposed across pairs; i.e., the responses in Run I and Postrun II were opposite to those in Postrun Iand Run II. On the basis of the storage concept set out above, it is suggested that during Run I and Postrun I informational traces appropriate to the sensory responses evoked in these conditions were established which accelerated the updating process when the second member of each pair of treatments was encountered. Implicit in this argument is the assumption that the informational traces laid down by the postrotatory responses are interchangeable with those established by the perrotatory responses, even though the former are evoked by different stimulus conditions than the latter.

It can be seen from Figure 2 that the difference, in the activity group, between Postrun I and Postrun II responses was greater than that between Run I and Run II; moreover, in the former case, all subjects showed a reduction in Postrun II, whereas in Run II some individuals showed an increase. There would seem to be at least two factors contributing to the greater and more consistent difference in the postrotatory responses. First, all subjects of the A group executed a greater number of sequences in Run I than in Postrun I; hence, the informational traces appropriate to Postrun II were likely to be better established than those appropriate to Run II. Second, the stimulus characteristics of the stationary environment are overlearned so that the process of updating is, in any case, likely to be more rapid during the second period of readaptation.

As far as the observation which provoked this study is concerned, it seems reasonable to assume on the basis of the present findings that the relatively muted response to CW Coriolis stimulation noted in subjects who had been continuously exposed to CCW stimulation (9) was due, at least in part, to the fact that those individuals had experienced postrotatory responses of the same "sign" as those evoked by CW rotation. This conclusion, however, does not exclude the possibility that some generalized vestibular suppression due to the prolonged CCW exposure may also have contributed to this phenomenon.

In practical terms, the results of this investigation suggest that it would be beneficial to include these postrotatory responses into any adaptation schedule designed to provide protection against motion sickness and vertigo in a rotating environment. The problem with any such schedule is that, unless it is extremely elaborate and time consuming, its prophylactic powers are likely to be directionally specific. The present findings indicate that the addition of a procedure which elicits the postrotatory responses provides some margin of protection in the opposite direction of rotation with little extra cost in time or effort.

REFERENCES

1. Gibson, J. J., Adaptation with negative after-effect. Psychol. Rev., 44: 222-244, 1937.

2. Graybiel, A., Structural elements in the concept of motion sickness. Aerospace Med., 40:351-367, 1969.

3. Graybiel, A., Wood, C. D., Miller, E. F. II, and Cramer, D. B., Diagnostic criteria for grading the severity of acute motion sickness. Aerospace Med., 39:453-455, 1968.

4. Graybiel, A., Thompson, A. B., Deane, R. F., Fregly, A. R., Colehour, J. K., and Ricks, E. L., Transfer of habituation of motion sickness on change in body position between upright and horizontal in a rotating environment. Aerospace Med., 39:950-962, 1968.

5. Groen, J. J., Problems of the semicircular canal from the mechanico-physiological point of view. Acta otolaryng., Stockh., 163:59-66, 1960.

6. Held, R., Exposure-history as a factor in maintaining stability of perception and coordination. J. Nerv. Ment. Dis., 132:26-32, 1961.

7. Helson, H., Adaptation Level Theory. New York: Harper and Row, 1964.

8. Pavlov, I. P., Conditioned Reflexes. Oxford: Claredon Press, 1927.

9. Reason, J. T., and Graybiel, A., The effectiveness of a three-day adaptation schedule designed to prevent motion sickness in a slowly rotating device. NAMI Report. NASA Order No. R-93. Pensacola, Fla.: Naval Aerospace Medical Institute, 1969.

10. Siegel, S., Nonparametric Statistics. New York: McGraw-Hill, 1956.

11. Sokolov, E. N., Neuronal models and the orienting reflex. In: Brazier, M. A. (Ed.), The Central Nervous System and Behavior. New York: J. Macy, 1960.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Aerospace Medical Institute Pensacola, Florida 32512	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE ADAPTATION TO CORIOLIS ACCELERATIONS: ITS TRANSFER TO THE OPPOSITE DIRECTION OF ROTATION AS A FUNCTION OF INTERVENING ACTIVITY AT ZERO VELOCITY.

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

James T. Reason and Ashton Graybiel

6. REPORT DATE 5 August 1969	7a. TOTAL NO. OF PAGES 17	7b. NO. OF REFS 11

8a. CONTRACT OR GRANT NO. MR005.01.01-0021B b. PROJECT NO. NASA Order No. R-93 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NAMI-1086 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* 168

10. AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The problem was to determine how adaptation to Coriolis accelerations, acquired through controlled head movements in a room rotating in one direction, transfers to the opposite direction as a consequence of the stimulus mode during an intervening period at zero velocity. Under one experimental condition the subjects continued to make the same head movements as those used to acquire perrotational adaptation, thus evoking postrotational responses opposite in sign but similar in quality to those experienced during the initial period of rotation. In the other, mechanical restraints were applied to the head and torso for an equivalent period of time.

Subjects who performed the head motion activity during the intervening static period were able to adapt more rapidly to the second (opposite) direction of rotation than to the first. In addition, the intervening activity appeared to confer some immunity to motion sickness during the second direction of rotation. Postrotational effects following the second direction of rotation were less severe and of shorter duration than those experienced following the initial period of rotation. The opposite findings were obtained for those subjects who remained immobilized during the intervening period at zero velocity.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Coriolis accelerations						
Transfer of adaptation						
Motion sickness						
Mechanism of adaptation						
Adaptation schedule						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.