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Research Report

THE EFFECTS OF VISUAL DEPRIVATION ON ADAPTATION TO A ROTATING ENVIRONMENT*

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SUMMARY PAGE

THE PROBLEM

Investigators differ regarding the influence of visual factors in adaptation to rotation.

FINDINGS

Visual factors play a significant role in adapting to a rotating environment. The lack of visual information appears to minimize the symptomatology of vestibular sickness. In addition, performance during rotation, on tests of postural equilibrium, is at least as good and improvement is probably more rapid in an individual when visually deprived.

Reduction in the magnitude of the Coriolis illusion as a function of time-under-rotation occurs whether vision is permitted or denied, but is more variable in the latter condition. In addition, the post-adaptation Coriolis illusion was absent following the no-vision rotation condition. It was evident, however, when visual information was available during rotation, and this might indicate the adaptation which occurred with vision was "deeper."

Contiguous (four days or less) duration exposures on the Slow Rotation Room show evidence that adaptation is more easily attained on the second exposure, thus indicating a transfer of training. Little, if any, transfer appears when exposures are 30 days apart.

INTRODUCTION

Recent experiments at this facility have shown that exposure of normal humans to certain angular velocities aboard the Pensacola Slow Rotation Room (SRR) results in symptoms of motion sickness (6,12,17,30) as well as visual (13) and postural illusions (17). The motion sickness observed under these conditions may be the result of the conflicting vestibular-ocular-proprioceptive inputs which occur when a person moves his head and body out of plane of the room's rotation. Because of the bizarre stimulus (13) to the semicircular canals in the SRR and because people whose labyrinths have been removed or destroyed do not exhibit motion sickness (15,29), this malady has been termed canal sickness (12). Of the visual illusions routinely observed aboard the SRR, the one chosen for the present investigation was the Coriolis illusion (17). The Coriolis illusion is a special type of the oculogyral illusion (11) and occurs when an unadapted man, who is bodily rotated in one plane, makes a head movement in another. With the repeated elicitation of this illusion during constant rotation, the magnitude of the illusion may be reduced (13,17).

The postural illusions aboard the SRR are a direct result of the room's rotation, and perhaps are made more disturbing because the subject receives no visual cues to the spinning of the room. In order for a subject to walk in a straight line relative to the room, he must actually move in a curved path relative to the earth. A naive subject's ability to perform this task is an indication of the adaptation process (17,22).

If canal sickness is a result of the sensory conflicts listed above (14), it would seem that visual deprivation would minimize the conflict and thus the incidence of motion sickness. However, information in the literature regarding the efficacy of visual information in vestibular adaptation is not conclusive. In some cases visual deprivation minimizes (33) and in some maximizes (43-45) nystagmic output. Subjects who were exposed to rotation for eight hours performed head movements in one quadrant only and had more symptoms of canal sickness and less reduction in nystagmus when visual information was minimal (21). Guedry (21) interprets this result as being due to the lessened mental occupation of the no-vision group. Ballet dancers fixate during their pirouettes and maintain after-nystagmus (51). The onset of motion sickness symptomatology in dogs who were hoisted in a crane has been delayed by suturing their eyelids (48). However, humans in a swing exhibited motion sickness more quickly when blindfolded, or when vision was excluded (52). Near heterophoria or ocular imbalance has been greater in a swing sickness group (3), and less in an airsick group (26). Other authors have commented further on the influence of visual information in connection with vestibular adaptation (5,7,18,35,36,38).

The present studies were begun in an effort to discover whether lack of visual information would affect either adaptation to visual and postural illusions or the symptomatology of motion sickness encountered in a rotating environment.

APPARATUS AND PROCEDURE

The major piece of equipment used in these studies was the SRR. This nearly circular, windowless room is constructed on the center platform of a human centrifuge and is described in detail elsewhere (6,12). It is capable of smooth accelerations and, because of the heavy superstructure, is virtually vibration free at constant velocities.

MAJOR TESTS

The Bolt Test

This stress test was devised to produce and partially control the bizarre sensory influx to the semicircular canal system. It required the subject to move his head and body through several large arcs and utilized a chair around which four receptacles had been placed: 1) in front of him and to the left, 2) behind and to the right, 3) in front-right, 4) behind-left. Three of the cups contained standard metal washers and the fourth contained bolts. A piece of perforated aluminum was suspended above the subject's head within easy reach. The subject's task was to string the three washers on the bolt and place it in the hole above. Three washers on a bolt, placed in a hole, constituted one trial and required five movements. The subject was required to complete 30 such trials in Experiment II (and 20 in Experiment III) unless interdicted by motion sickness symptomatology. This constituted one session. This test is quantitative and is similar to the Dial Test (31,32), but is probably less stressful since it is subject-paced. It has the advantage that it can be performed "with" or "without" vision.

Coriolis Illusion (CI)

This test utilized a chair on which a bracket was mounted. On the bracket was a swivel which contained a bite board. The bite board was directly in front of the subject's mouth and when he was positioned properly, the subject could actively tilt his head 45° towards either shoulder. About 10 feet from his head was a 6-inch square box with perforations along each visible edge. The box was dimly lighted from within. When viewed in an otherwise darkened room it gave the appearance of a three-dimensional figure, and pilot studies indicated that when the box was dimly lighted, the magnitude of the illusion was greatest. The subject viewed the Coriolis illusion by tilting his head to one or the other shoulder while the room was rotating. He then returned it to the upright. The amount of apparent movement in feet and inches was recorded. Each determination required but a few seconds and the room lights remained on between pairs of determinations (i.e., right, return--, left, return). This was done to minimize dark-adaptation and the possible effects of autokinesis.

SUBJECTS

All the men who served as subjects in the Pilot Study and the three experiments to be reported herein were Navy enlisted men who volunteered for temporary duty as research subjects. All passed a rigorous physical examination and were between the ages of 17-24. No subject was used in more than one experiment although Experiments II and III required 2 and 4 runs per man, respectively. The subjects used in a given experiment were always obtained from a pool of 8-10 men. In Experiment II they were selected on the basis of their perception of the Coriolis illusion and in Experiment III for their motion sickness susceptibility.

PILOT STUDY

Prior to the series of three experiments a pilot study was performed wherein three men were exposed to rotation at 5.4 RPM for forty-eight hours. The three subjects were blindfolded at the onset of rotation with standard eye patches, and the blindfolds were removed at 4, 17, and 47 hours for Subjects 1, 2, 3, respectively. Although the number of subjects was small and individual differences were uncontrolled, there appeared to be fewer symptoms during the no-vision condition. Subject 1 vomited when his blindfolds were removed; Subject 2 became extremely dizzy when his were removed, and Subject 3 was blindfolded for almost the entire duration of rotation and reported only minimal symptoms. Tests of postural equilibrium were performed (blindfolded or eyes closed), and there appeared to be no significant difference among subjects. The subject denied vision for the longest period during the run (i.e., Subject 3 - 47 hours) also experienced the least difficulty in adjusting to a nonrotating condition when the room stopped. The results of this probe suggested that additional studies be performed using more subjects in order to better understand the role of vision in adapting to rotatory conditions.

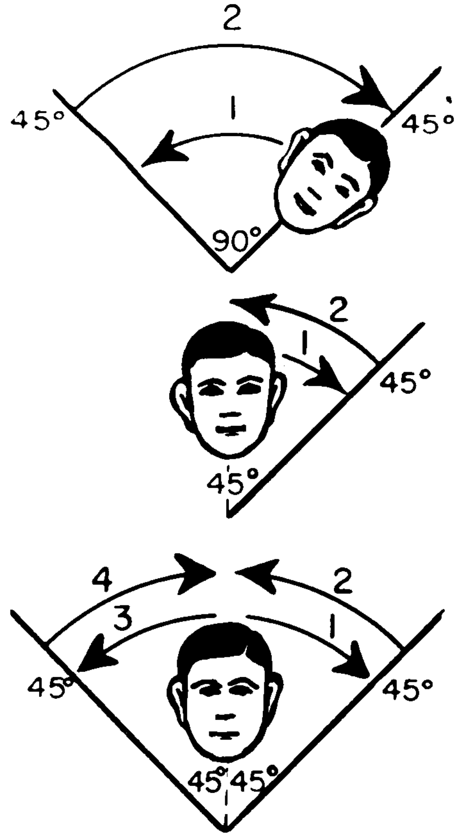
EXPERIMENT I

In this experiment of six and one-half hours rotation at 5.4 RPM the Bolt Test was not used, and the Coriolis illusion involved two discrete movements, as shown in Figure 1. The first movement was from the 45° tilt left to 45° tilt right. The second head movement required a return to the original position. Two movements constituted a trial. There were 10 trials per session, and unless precluded by canal sickness, there was one session every hour.

Four subjects were blindfolded and three were not. Those "with" vision made estimates of the illusion every half hour. Those "without" vision performed an identical number of head movements, but after viewing the illusion initially, they only made estimates of the Coriolis illusion just prior to the termination of rotation (i.e., at 6 1/2 hours).

RESULTS AND CONCLUSIONS: EXPERIMENT I

The averaged data for these subjects appear in Figures 2a and b. The first viewing of the Coriolis illusion was considered the baseline and converted to 100 per cent. Subsequent estimations of the illusion are plotted in percentage of the baseline. Conversion to percentage minimized individual differences; nonetheless, variability in responses was great. Of the individuals permitted vision, one initially perceived an illusion of sizeable magnitude and, with the exception of his estimation at five hours,



Experiment I - 2 movements: 1) head right
2) head left

Experiment II - 2 movements: 1) body left
2) return to upright

Experiment III - 4 movements: 1) head left, 2) return,
and a Pilot Study 3) head right, 4) return.

Figure 1. HEAD AND BODY MOVEMENTS REQUIRED FOR ELICITATION OF THE CORIOLIS ILLUSION IN THREE EXPERIMENTS AND A PILOT STUDY

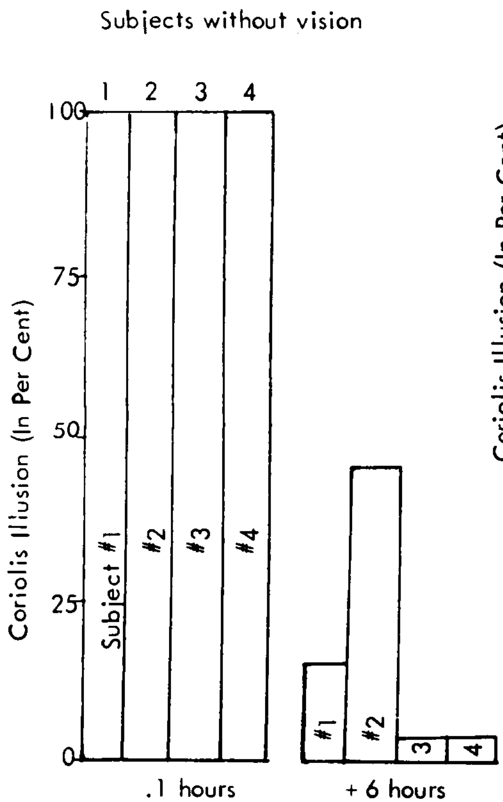


Fig. 2a

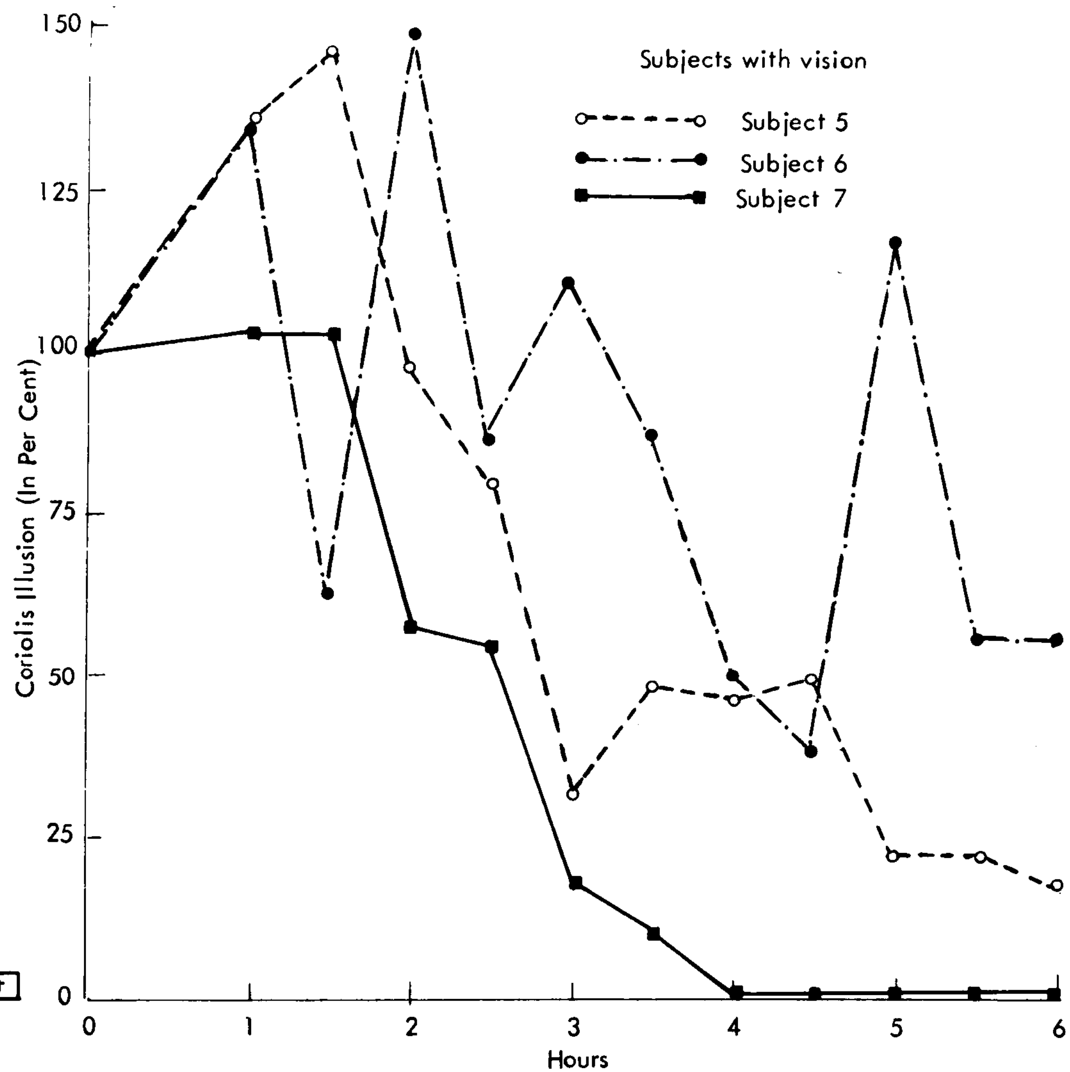


Fig. 2b

Figure 2. MEAN CORIOLIS ILLUSION, IN PER CENT, FOR 4 SUBJECTS WITHOUT VISION (a) AND 3 SUBJECTS WITH VISION (b) WHEN ROTATED AT 5.4 RPM FOR 6 HOURS.

there appeared to be an over-all reduction. Two other "with" vision subjects perceived a small illusion on the first trial and adapted to extinction by their last trial. Of the four subjects denied vision two reported a sizeable, and two a small, illusion when first viewed at the onset of rotation. Three of these indicated an illusion of negligible magnitude when they removed their blindfolds just prior to the cessation of rotation and the fourth (Subject 2) experienced a large reduction.

Symptomatology of motion sickness was not measured as such. However, of the three subjects who were permitted vision one subject vomited (Subject 5), another had to be encouraged to continue (Subject 6), and the third remained symptom free (Subject 7). Of the four men who were blindfolded only one reported nausea and the other three exhibited few, if any, symptoms. Comparisons of the two groups ("with" and "without") should be made with caution since the relative, basic susceptibilities of the subjects in the two groups were unknown prior to their exposure to the stress. However, if susceptibilities in the two groups were equivalent, then it would appear that lack of vision afforded some protection from motion sickness.

It should be noted that the CI involves the subjective perception of apparent movement and is a difficult estimation to report, even for a very sophisticated subject. Although greater familiarity with the Coriolis illusion may have produced more reliable estimations, an additional problem is encountered when the illusion is elicited frequently. It is well known that it is possible to "habituate-to-an-illusion-as-an-illusion" as has been demonstrated with the Muller-Lyer (41,42,47) and the Ames Rotating Trapezoid (37). It seems likely that this phenomenon can occur with the Coriolis illusion. This does not mean that the CI may not be an indicator of vestibular adaptation, but rather that care must be taken in its use.

The results of Experiment I, though inconclusive, suggested some reduction in the magnitude of the Coriolis illusion occurred in both modes with time under rotation and further that canal sickness symptomatology may be less when vision is deprived. However, individual differences were uncontrolled and the duration of the experiment was short. In the next study (Experiment II) it was decided to extend the rotation period and to use each subject twice (with and without vision) in order for him to serve as his own control. Further the increased exposure time permitted additional tests to be included.

EXPERIMENT II

This study was designed to assess the effects of prolonged rotation at 5.4 RPM upon: 1) the Coriolis illusion, 2) the susceptibility to canal sickness, 3) an object recognition test, 4) a body sway and balance test (Romberg test), and 5) a heel-to-toe walking test. Measures of test performance, with the exception of the CI, were made periodically during two forty-eight hour periods of continuous rotation. For the first two-day period the subjects would be blindfolded, while for the second two-day period they lived aboard the SRR, not blindfolded. The two experimental runs were spaced in time by > thirty days in an effort to minimize transfer of adaptation from the first to the second exposure.

These individuals who were unsophisticated with respect to the Slow Rotation Room device were selected from a similarly naive group by subjecting them to a brief exposure at 5.4 RPM wherein they viewed the Coriolis illusion. Each subject received three trials at body tilted left and return (cf. Figure 1). The data were averaged, and the three subjects who reported the greatest magnitude of the illusion were selected.*

The three selected subjects were then given practice sessions under static conditions, and while blindfolded. Each subject appeared to be sufficiently motivated that he practiced the tasks until he was skillful and the time-to-completion had apparently reached an asymptote. Each of the tests could be accomplished blindfolded and are described below.

Object Recognition Test

This test provided a timed, experimenter-paced task which caused simultaneous rotation about two axes of the subject's head or body. The results proved nondiscriminating, and a full description of the procedure appears in Appendix A.

Body Sway and Balance Test (Romberg)

Each subject was instructed to stand upright, with both feet together at the heels, for one minute. His performance was timed and he was given a rating on a five-point scale. This particular portion of the test eventually proved nondiscriminatory. The remainder of the test, standing first on one foot and then the other, for thirty seconds, was a more difficult task and was retained for data analysis. The basic measures were the time in seconds each was able to stand on one foot, eyes blindfolded (closed in the second rotational situation), and an efficiency of performance rating on a five-point scale. The scale values (6) were assigned as follows:

a) Rating 1: slight body sway, no foot movement.
b) Rating 2: definite sway of small amount, no foot movement.
c) Rating 3: substantial sway but no foot movement.
d) Rating 4: substantial sway and foot is moved.
e) Rating 5: substantial sway and other foot was put down to prevent fall.

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* An unfortunate circumstance of the above selection procedure was that one individual reported a very large target displacement on his first trial and none on his second or third. The mean apparent target excursion was large enough to include him as one of the subjects. He reported CI but once in any subsequent tiltings.

Walking Test (Heel-to-Toe)

Periodically, each individual was asked to walk heel-to-toe from the center to the periphery of the SRR. An auditory tone served as a target in lieu of the visual. A magnetic tape recording was made consisting of short bursts (one second) of a 1500 cps tone recorded at one-second time intervals. At each tonal burst the subject was to place his alternate foot in front of the other, as if walking a straight line, the tones pacing his gait. The experimenter turned him around whenever he reached the SRR wall and stopped him clear of the center post upon return. The total number of steps out and back were 16-20.

The Coriolis Illusion Test

The Coriolis illusion was viewed at the onset and just prior to the cessation of the first run (cf. Figure 1), and in this run and the next a 6-inch diameter circle was used in place of the box. During the second run ("with" vision) each subject was tested for the Coriolis illusion, 2, 5, 7, 24, 26, 29, 31, and 47 hours after rotation started. During both runs the subjects were tilted bodily through 45° twenty times on eight occasions. This was done to provide practice in the sort of bizarre stimuli experienced in viewing the CI, and in an effort to aid in adaptation.

RESULTS AND CONCLUSIONS OF EXPERIMENT II

The Coriolis Illusion Test

As in Experiment I the subject's first estimation of the Coriolis illusion was converted to 100 per cent, and subsequent viewings plotted in percentage of this baseline. These data are shown as Figure 3 and appear to indicate the presence of adaptation. In every case, however, there was a reduction in the illusion with time-under rotation, whether the experimental condition was "with" or "without" vision. Insofar as the CI is an indicator of vestibular adaptation, it would appear that there is a similar function whether subjects are visually deprived or not.

Body Sway and Balance Test

The data for the one foot Romberg test are graphically represented in Figure 4. The two functions are the mean number of seconds standing for three subjects in conditions of "with" and "without" vision. It may be seen that "with" vision performance is superior to "without." This may be attributable to the fact that the "without" vision run preceded the "with" vision run, and there was some residual adaptation or learning. The reduction in performance at the onset of rotation is routinely observed in rotation experiments (17, 22). Similarly, when adaptation has occurred and the SRR is stopped, there is usually a period of readjustment to zero rotation. This postadaptation effect did occur after the visual experiment but did not occur when the subjects were visually deprived. The fact that postrotation performance was disrupted less in the absence-of-

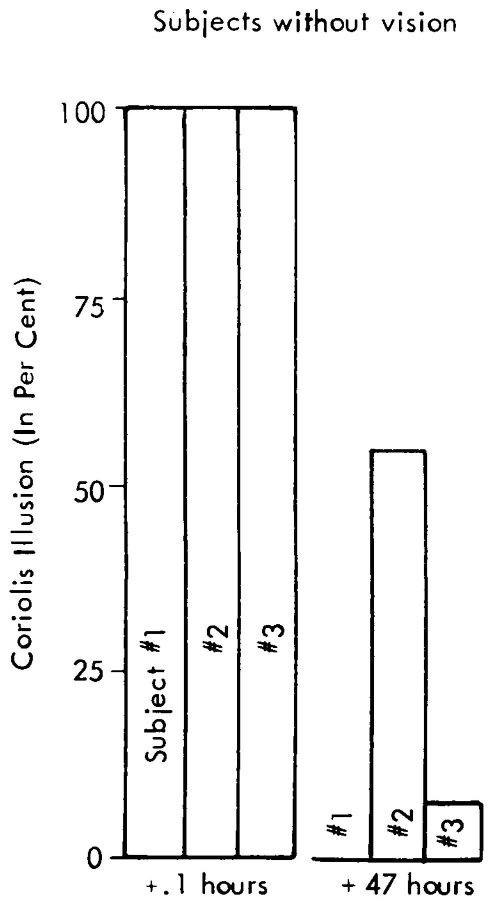

Fig. 3a

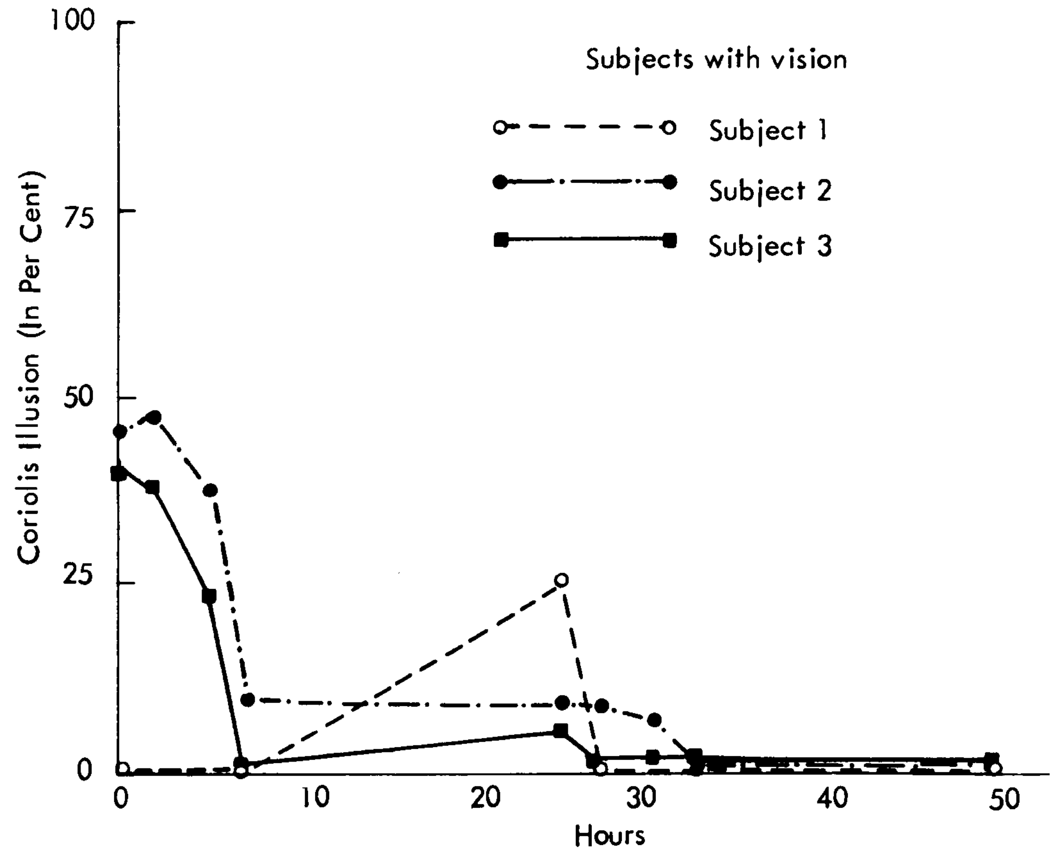

Fig. 3b

Figure 3. MEAN CORIOLIS ILLUSION, IN PER CENT OF FIRST ELICITATION, FOR 3 SUBJECTS EXPOSED TO 5.4 RPM FOR 50 HOURS ON TWO OCCASIONS (WITHOUT, THEN WITH VISION).

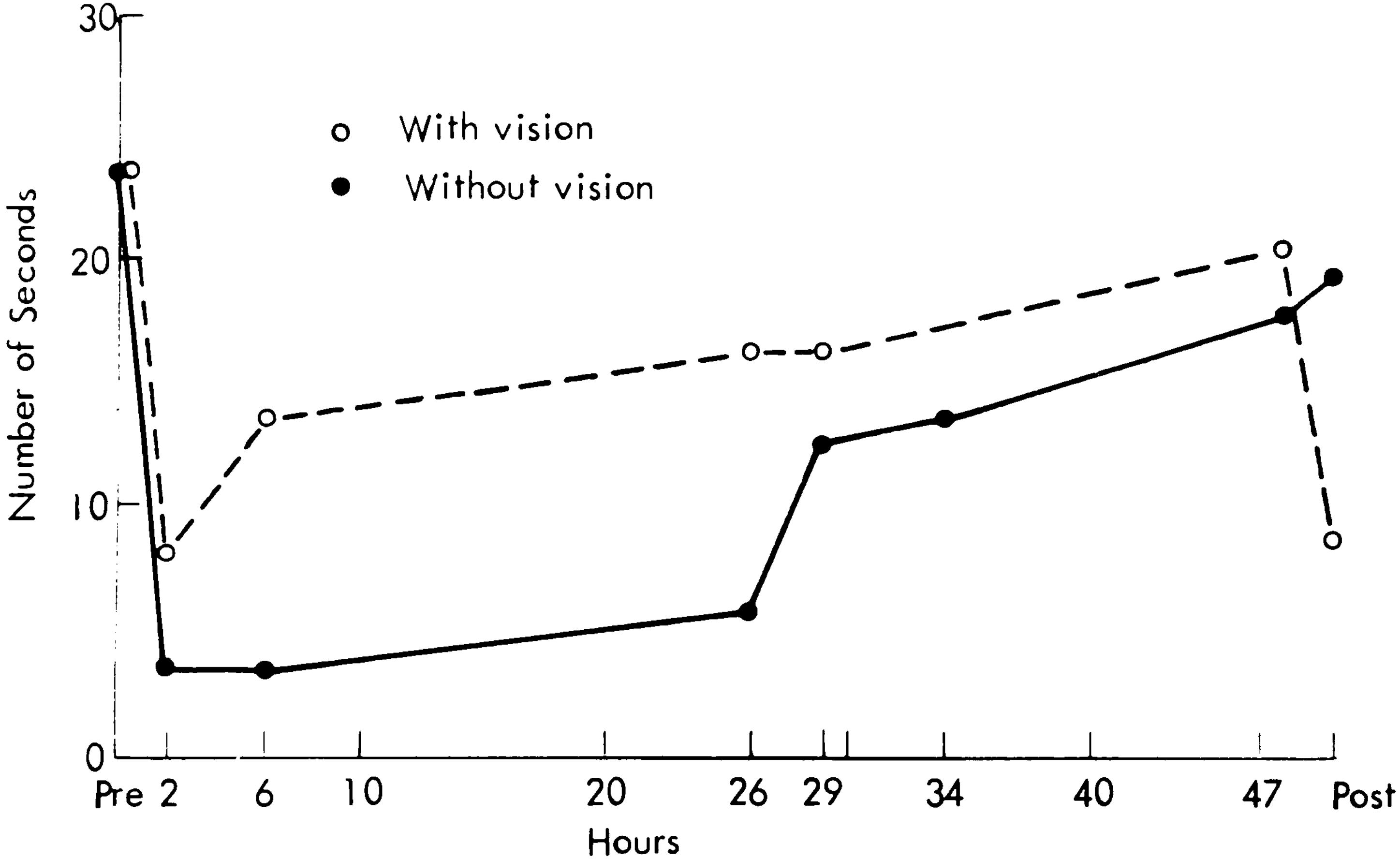

Figure 4. MEAN STANDING (ONE FOOT) ROMBERG FOR 3 MEN WITH AND WITHOUT VISION: DURING 50 HOURS ROTATION AT 5.4 RPM

vision group perhaps indicates that the adaptation which did occur in this group involved sensory suppression without the compensation reactions previously demonstrated in groups habituated with vision present (20).

The Bolt Test

The subject-paced Bolt Test served as a controlled vestibular stressor and was scored without the subject's knowledge in time-to-completion. As motion sickness symptoms diminished, the Bolt Test was performed more rapidly. The nonvisual condition showed less variability and possibly reflected the lesser symptomatology observed in this situation.

The symptoms of canal sickness which were reported during the vision condition were more numerous, more severe, and of longer duration than when vision was deprived. This occurred despite the fact that the "without" vision condition was performed first, in time, and that transfer of adaptation if present would be in favor of the second ("with" vision) condition.

Walking Test (Heel-to-Toe)

The group mean data for the heel-to-toe walking test appear as Figure 5. The two functions are similar with the exception that "without" vision shows a greater disruption at the onset of rotation but by the second day surpasses performance of the visual condition. The initial higher scores "with" vision may be attributable to a sort of memory factor for target and floor topography as each individual could survey the route before closing his eyes for the test proper. The ultimate level "without" vision is particularly significant since this condition occurred first in time. It should be also noted that since all the tests were performed blindfolded, it may be that the blindfolded subjects received more practice under conditions similar to those of the testing than the visual subjects who were visually deprived only for their testing. On the other hand, since the no-vision run appeared first, one would expect some transfer of small amount to the second run. Therefore, in a comparison of the efficacy of the two conditions, if anything the data would be biased in favor of the second run. It would seem that the fewer symptoms of canal sickness that were exhibited, and the heel-to-toe walking ability, probably represent a real advantage of "without" vision, whereas the small difference in the standing Romberg may be the result of an order effect. Considering the reservations listed in the CI section, it would appear that adaptation to this illusion occurred in the visual condition for two subjects (Subjects 2 and 3). The third subject (no. 1) never saw an illusion of any magnitude subsequent to being selected. For the no-vision condition, reduction in the illusion was certain in one (Subject 2) and less clear cut in the other (Subject 3).

Although the results of the two runs in Experiment II appeared to indicate that, in the absence of vision, there was lessened symptomatology, some adaptation to the Coriolis illusion, and no real disadvantages in the postural equilibrium tests, it was felt that counterbalancing of experimental conditions would produce information relative to

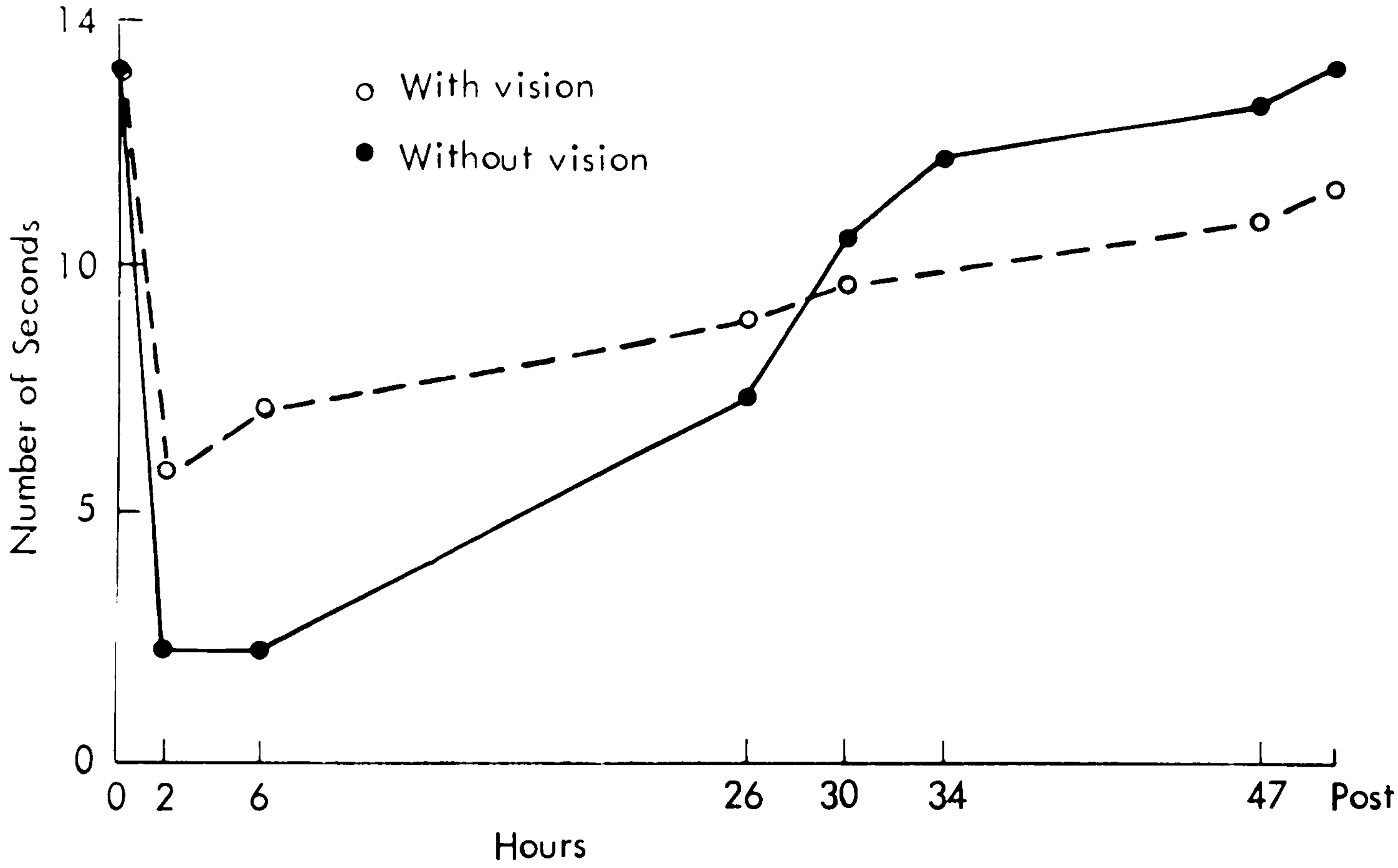

Figure 5. MEAN HEEL-TO-TOE WALKING FOR THREE SUBJECTS UNDER CONDITIONS OF WITH AND WITHOUT VISION.

sequential effects. Further, a newly developed system for the objective scoring of canal sickness (16) would increase the validity of these measures. Additionally, the disparate postural equilibrium results which were obtained "with" versus "without" vision suggested that these phenomena be restudied and that the postadaptation visual illusion, as well as the postural illusion, also be measured after rotation in order to assess the compensatory reactions as measured by these two tests.

EXPERIMENT III

Four "runs" were performed at 7.5 RPM. Each run lasted fifty hours and began at the same time of day. The procedures on all four runs were identical except that on two runs each subject was visually deprived. Five subjects participated in the first run, four in the second, and three in the third and fourth (cf. Table I). Runs 1 and 2 and runs 3 and 4 were four days apart. Runs 2 and 3 were > thirty days apart. Transfer of training might be expected from run 1 to 2 and 3 to 4; but in view of the results in Experiment II, little was expected from 2 to 3.

The subjects were five healthy males and none had a history of disease referable to the sensory organs of the inner ear. The subjects were preselected on the basis of a motion sickness questionnaire (MSQ) (1,2,4) and four days prior to the actual experiment at 7.5 RPM the subjects were tested for susceptibility to canal sickness, and they viewed the Coriolis illusion. The test for canal sickness susceptibility required that they perform the Bolt Test for as many trials as possible to a maximum of 20 (total 100) movements. Three subjects (2,3, and 4) were not able to complete the test, and on the basis of this test and their motion sickness questionnaire they were considered to be of greater than average susceptibility. Two other subjects (1 and 5) completed the test, and they were believed to be of less than average susceptibility. The subjects' motion sickness susceptibilities and the order of their visual conditions appear in Table I.

Table I

Motion Sickness Susceptibilities and Visual Conditions for Five Subjects Exposed to Rotation at 7.5 RPM: Experiment III

Subject	MSQ	Pre-Test on SRR	1	2	3	4
4	>> Av	> Av	$\bar{c}$	*	*	*
2	>> Av	> Av	$\bar{c}$[1]	$\bar{s}$[2]	*	*
3	> Av	> Av	$\bar{s}$	$\bar{c}$	$\bar{c}$	$\bar{s}$
1	< Av	<< Av	$\bar{s}$	$\bar{c}$	$\bar{c}$	$\bar{s}$
5	< Av	< Av	$\bar{c}$	$\bar{s}$	$\bar{s}$	$\bar{c}$

* Refused exposure. [1] Terminated exposure - 20 min. [2] Terminated exposure - 7 hrs.

> Greater than average susceptibility. >> Far greater than average susceptibility.

$\bar{c}$ With vision. $\bar{s}$ Without vision.

The Coriolis illusion was viewed in an otherwise darkened room, and the subjects performed four 45° head movements (to right and left shoulder and return) and made estimations of the amount of apparent movement (cf. Figure 1). All perceived the illusion.

During each fifty-hour run the subjects performed 15 Test Series as well as one Test Series before and after rotation. There were 17 Test Series in all; a routine schedule appears in Table II. Each Test Series entailed the performance of three tasks: 1) the Bolt Test, 2) the Coriolis Test, and 3) the Postural Equilibrium Test.

Table II

Time of Performance of Test Series: Experiment III

	Time	Test Series
Pre-Test	1100	Pre
Day I	1200	1
	1500	2
Day II	0800	3
	1000	4
	1115	5
	1400	6
	1500	7
	1600	8
	2100	9
	2200	10
Day III	0800	11
	0900	12
	0930	13
	1030	14
	1200	15
Post-Test	1300	Post

The Bolt Test, which has already been described, was usually performed for 20 trials. (During the four "runs," the first Test Series had 5 trials and the second, 15. All others had 20 trials per Test Series.) The Coriolis test was performed the same way as the test for the Coriolis illusion; however, the subject did not estimate the illusion at this time, and there was no target. Rather, he merely performed ten repetitions of the four head movements used for testing the illusion. Subjects who were blindfolded for the run remained so for this test. The subjects "with" vision moved their heads with the room lighted and eyes open.

The Coriolis illusion was viewed only: 1) at the onset of rotation, 2) 49 hours perrotation, 3) 50 hours perrotation, and 4) postrotation. This precaution was taken to minimize adaptation of nonvestibular origin.

The test for postural equilibrium was in two parts: The first was a test of dynamic equilibrium and required the subject to walk heel-to-toe, with his eyes closed and arms folded in front of him. His path was from the periphery of the room to the center column. If the criterion of five steps was not attained on either of two trials, he was given a third trial, and his score was the best two of three with a maximum score of 10. The test for static equilibrium required the subject to stand heel-to-toe with eyes closed and arms folded for sixty seconds. If the criterion of sixty seconds was not met on either of two trials, he was given a third, and his score was the best two of three with a maximum score of 120.

During the first run there were five subjects on board the SRR. One each of the susceptibles and nonsusceptibles was blindfolded with standard ocular plasters. During the second run which began four days later, their visual condition was reversed. One of the susceptible subjects (permitted vision in the first run) refused a second exposure. Both runs began at 1130 and ended fifty hours later. There were short stops in the morning and afternoon for supplies, during which time the subjects did not move their heads. In this manner, it is felt, they were prevented from losing any adaptation that may have obtained (13,17).

The experiment was designed so that comparisons could be made between two of the possible effects: 1) adaptation with/without vision, and 2) the effects of transfer of training from the two sets of contiguous (i.e., four days) runs.

RESULTS AND CONCLUSIONS OF EXPERIMENT III

Results

Figure 6 contains the mean scores on dynamic equilibrium for the three men who participated in all four runs.* This figure is in two parts: "6a" compares with and without vision and "6b" compares performance on runs 1 and 3 with runs 2 and 4. Insofar as dynamic postural equilibrium reflects adaptation to rotation, it may be seen in Figure 6a that there appears to be no difference between "with" and "without" vision in the time course of performance nor in ultimate level obtained. The transfer effect from runs 1 and 3 to runs 2 and 4 is depicted in Figure 6b. Runs 2 and 4 benefitted from 1 and 3 by showing: 1) less disruption at the onset, 2) more rapid adjustment to the rotating environment, and 3) a higher level of performance up until the last five hours when performance of the two modes appears equal.

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* The performance of Subjects 2 and 4 will be discussed later.

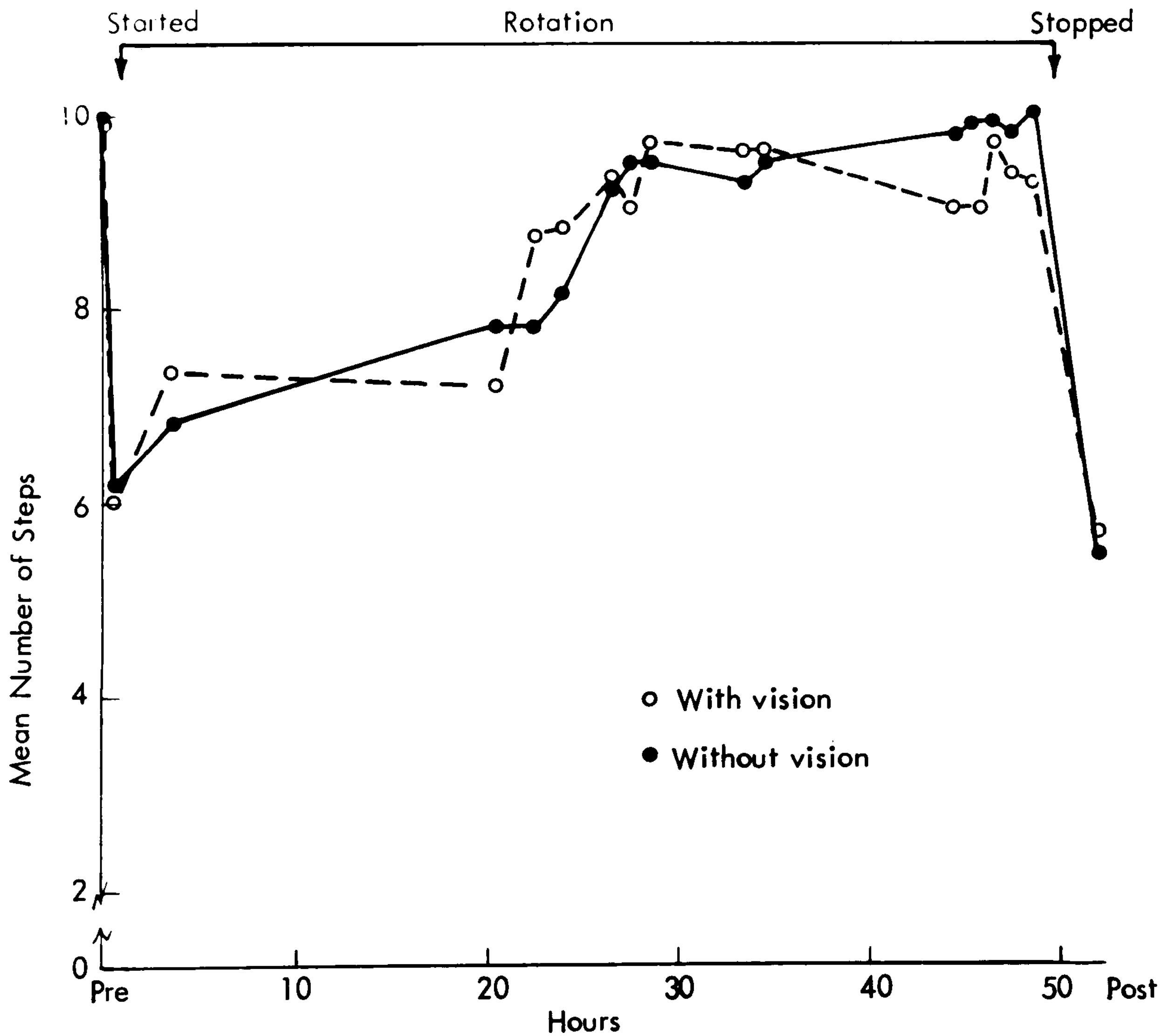

Figure 6a. WALKING TEST WITH AND WITHOUT VISION FOR 3 SUBJECTS.

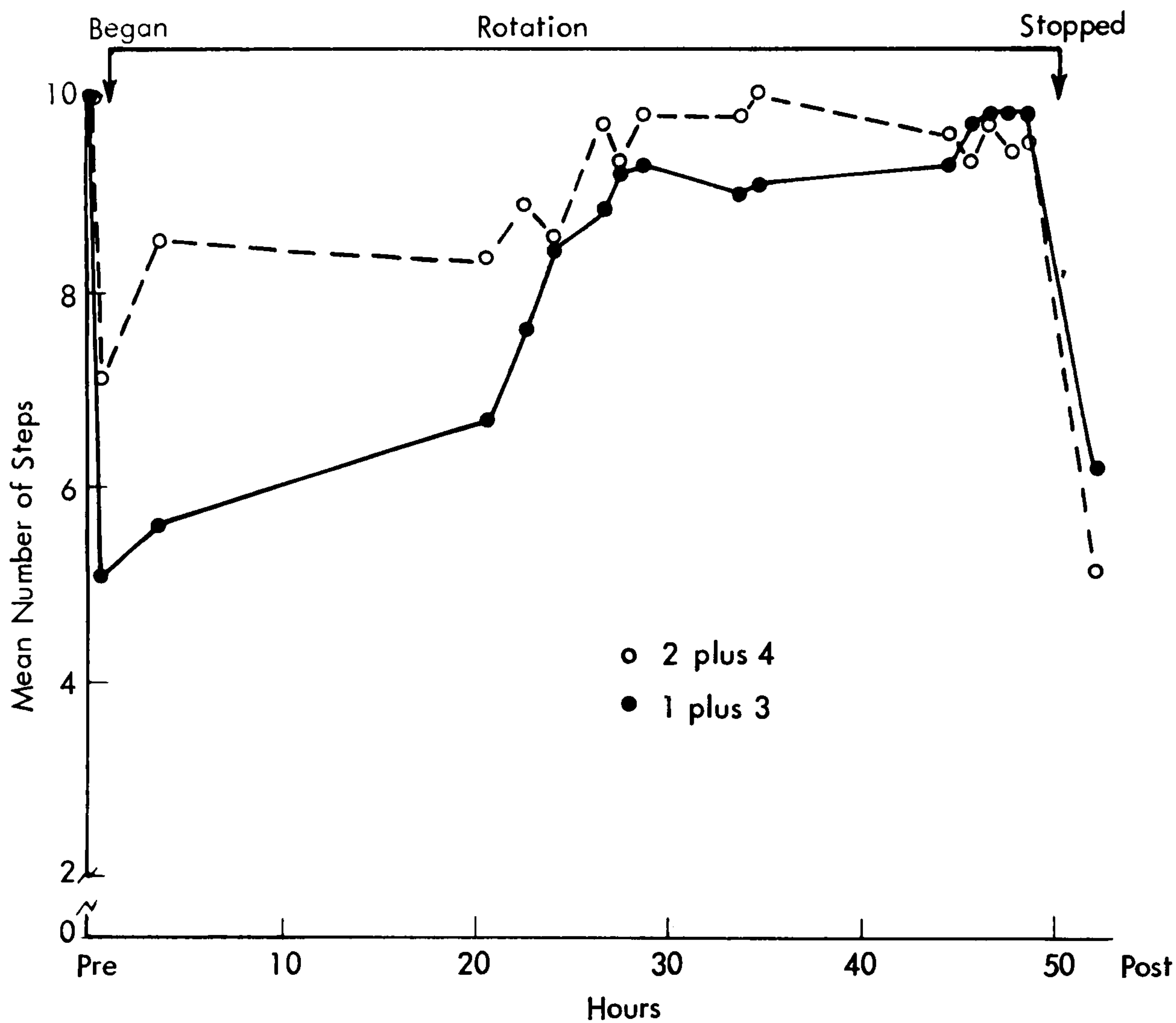

Figure 6b. COMPARISON OF WALKING TEST FOR 3 SUBJECTS OF RUNS 1 PLUS 3 WITH 2 PLUS 4.

The averaged data for the Standing Test appear as Figure 7 (a and b). In 7a improvement may be seen under both conditions. The "without" vision curve, however, improved at a more rapid rate and performance was always better throughout the first forty-six hours. The onset and cessation of rotation produced decrements in both conditions, and it is interesting to note that "without" was more affected by the start of rotation, but was less affected by the cessation. Figure 7b reflects the same data but the comparison is between runs 1 and 3 versus 2 and 4. The same transfer of training is seen here as was observed in Figure 6b, but the two modes become equivalent after about twenty-seven hours.

In the main, it would appear that adaptation to rotation as indicated by postural equilibrium is at least as good when visually deprived and in the case of static equilibrium, possibly better. Comparison of the data from runs 1 and 3 with runs 2 and 4 (four days apart) shows an habituation or learning effect. The learning effect was negligible when run 2 was compared with run 3 (> thirty days apart).

The Coriolis illusion data appear in Table III. The scores, in inches, reflect the magnitude of the perceived illusion, and the arrows indicate the direction of movement. The proper direction of the Coriolis illusion is predictable, so that for counterclockwise rotation the directions should be with head left, upward; head right, downward. The movement should be of opposite sign when viewed after adaptation to rotation (i.e., right, upward; left, downward), and this post-illusion is termed the postadaptation Coriolis illusion. It is believed that this postadaptation illusion is a result of a compensatory response which occurs in the course of adaptation. Similar phenomena have been reported by others (8-10,23-25,34,35,39,40,46,50,53-55).

In all cases where the subjects were permitted vision there is a reduction in the CI, and there is a definite reversal in the postadaptation illusion. For the visually deprived conditions there also appears to be a reduction in the CI. The postadaptation illusion, however, when it appears, is of very small magnitude except in one instance (Subject 5, run 3). The other data for this subject (No. 5) during run 3 also show no adaptation. Considering the data of Subject 5 in run 4, where he was permitted vision, it is interesting to speculate whether the compensatory reaction expected after rotation does not begin to appear even during the run. Guedry and Graybiel (20) referred to this phenomenon when nystagmus was measured in practiced subjects under similar experimental conditions. It should also be stressed that, in the perception of this illusion, large individual differences are observed. A score of 0 may be the "irreducible minimum" for one subject (cf. No. 3) and 3 or 4 the minimum for another. If this assumption is granted, perhaps Subject 5 was at this level at the beginning of run three and his CI was not modified by rotation. Unpublished data of the authors were obtained by having subjects view the CI when their rotation exposure was distributed in time. The data show that some subjects maintain a perception of the CI of small magnitude throughout their exposures whereas others see less and less with repeated trials.

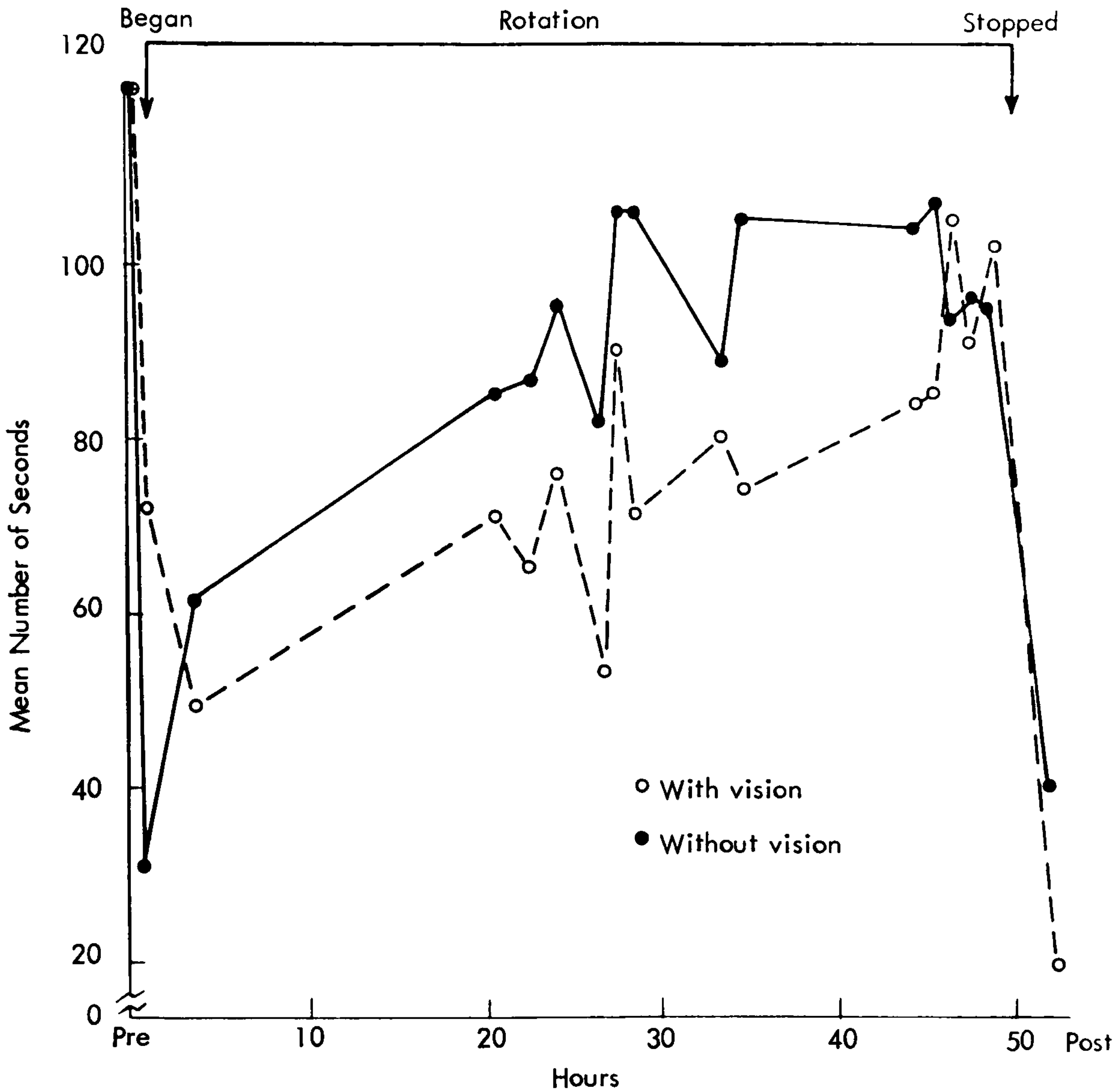

Figure 7a. STANDING TEST WITH AND WITHOUT VISION FOR 3 SUBJECTS.

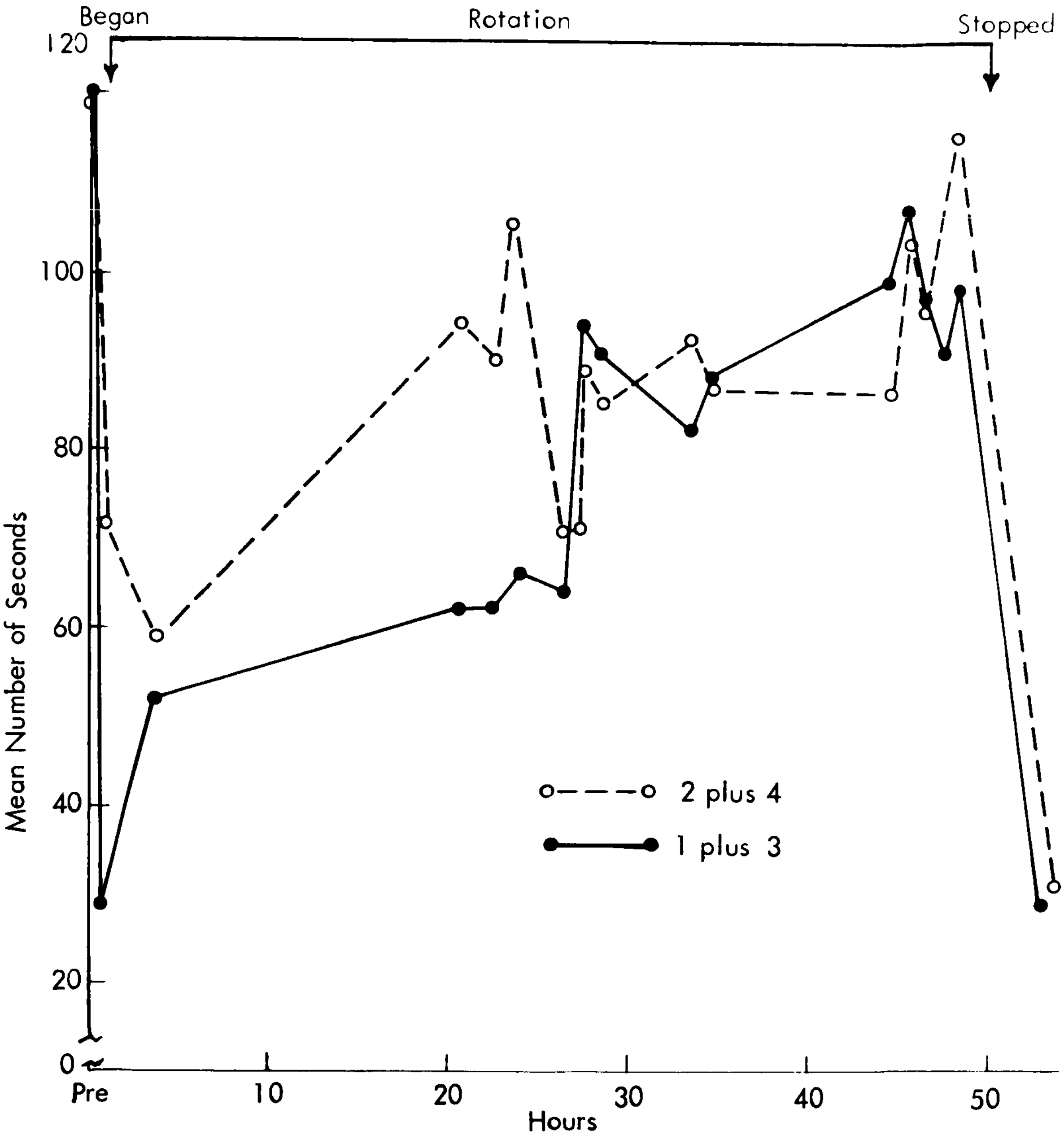

Figure 7b. COMPARISON OF STANDING TEST FOR RUNS 1 PLUS 3 WITH 2 PLUS 4.

Table III

Coriolis Illusion for Four Men Exposed to Fifty Hours of Rotation at 7.5 RPM: Experiment III

	Subject 4				Subject 3				Subject 1				Subject 5			
	Left	Return	Right	Return	Left	Return	Right	Return	Left	Return	Right	Return	Left	Return	Right	Return
Pre-Test Baseline	18↑	18↓	18↓	18↑	6↑	6↓	12↓	12↑	12←	12→	30↘	30↗	12↗	12↙	6↘	6↖
49 hours at 7.5	12↑	12↓	12↓↑	12↑↓	0.0	3.0↓	0.0	1.0↑	12↖	12↘	30↙	12↖	4↗	4?	0	3?
50 hours at 7.5	8↑	8↓	8↓	8↑	0.0	0.0	2.0↓	0.0	0	0	2↘	2↗	2→	2←	2↘	3↗
Postrotation	12↓	12↑	12↑	12↓	0.5↓	0.5↑	0.0	0.0	2↙	2↖	0	0	8↓	8↗	12↗	12↓
49 hours at 7.5					0.0	0.8↓	0.5↗	0.5↓	1↖	1↘	12↘	12↖	8↗	4↓	3↗	3↗
50 hours at 7.5					0.0	0.5↓	0.5↗	0.5↓	1↖	1↙	12↓	12↗	6↗	4↓	3→	3↗
Postrotation					3.0↓	3.0↑	3.5↘	3.0↑	24↓	24↑	24↗	24↓	2↗	2↓	3↗	6↓
Pre-Test					0.5↓	1.0↓	1.5↓	2.0↑	18↖	6↘	6↙	18↗	3↗	4↙	3↓	3↗
49 hours at 7.5					0.8↓	0.0	0.0	0.0	0	0	6↘	6↗	4↗	3↓	3↗	2↓
50 hours at 7.5					0.0	0.0	0.0	0.0	0	0	6↙	6↗	5↗	3↙	4↗	3←
Postrotation					1.0↓	1.5↑	2.0↑	1.8↓	12↙	12↗	12↑	12↓	6↘	4↖	5↗	3↓
Pre-Test					1.0↓	1.0↑	1.5↓	1.0↑	3↑	3↘	3↙	3↗	3↗	4↙	5↑	3↙
49 hours at 7.5					0.0	0.0	0.0	0.0	1↑	3↓	3↓	3↖	3↓	4↗	4↗	4↙
50 hours at 7.5					0.0	0.0	0.0	0.0	3↑	3↓	3↓	3↗	4↙	3↗	3↗	4↙
Postrotation					0.0	0.0	0.3↓	0.3↑	0	0	2↗	2↙	4↗	3↗	4↗	4↙

The "without" vision conditions are enclosed in boxes.

All measurements are in inches.

In summary, with respect to the CI, adaptation and postadaptation effects were demonstrated when the subjects were permitted vision during rotation. Although there may have been some adaptation under visually deprived conditions, the data are irregular. This suggests, but does not prove, that the adaptation which occurred during the "with" vision sessions was "deeper" and more complete than when vision was denied.

The signs and symptoms of vestibular sickness were recorded for each subject as they became evident. A special work sheet form has been designed for the purpose, and a sample is shown as Appendix B. Diagnostic terms for the evaluation of vestibular sickness are defined as follows: Vestibular Sickness (VS)--Vomiting or two major symptoms or one major and two minor symptoms; Malaise III--One major or two minor symptoms or one minor and two other symptoms; Malaise I--Any subjective symptom or any sign usually associated with any subjective symptom; Malaise II--All others.

Figures 8 and 9 contain the mean data regarding vestibular sickness symptomatology in the three men who participated in all four runs. Gradations of the symptomatology are expressed in the tables as defined above for Malaise I, II, and III. In Figure 8 comparative functions of the time-course of adaptation are seen for runs 2 plus 4 against 1 plus 3. These same data appear in Figure 9; however, they are combined to compare "with" and "without" vision. Without vision, symptoms of vestibular sickness are consistently less severe through the first thirty-five hours of rotation at which time both conditions are about equal. The rate of adaptation seems the same in both modes, but initial symptomatology is more pronounced when vision is permitted. The symptoms which occur after rotation ceases are of very small magnitude, and at that time no difference in conditions appears evident.

Because of the individual nature of their responses, the reactions of all five subjects are summarized separately.

Subject 2: This subject had a history of motion sickness (cf. Table I) and due to his pretest performance on the SRR was considered to have "greater than average susceptibility." During the first experiment, he was not blindfolded, and after only five sequences on the Bolt Test (stress test) he was forced to lie down. After one sequence (20 head movements) on the Coriolis illusion test, he vomited and requested nonparticipation. He exhibited the cardinal signs of motion sickness and was released. His total time on board was two and one-half hours. This subject expressed a willingness to serve on the next experiment and came on board with eyes covered. In the second experiment, he completed all the necessary head movements for the first day (cf. Table II). The testing on the first day occupied the first three hours under rotation after which this subject and the other subjects were permitted free time for listening to music, sleeping, et cetera. Subject 2 lay down and remained supine for another two hours. He continued to complain of a headache, he "felt miserable," and manifested aerophagia. There were no other characteristic signs or symptoms of motion sickness. In order that he not be 'lost' for the experiment he was advised to lie still and not move his head. Johnson and coworkers (27,28) have emphasized this method for controlling vestibular stimulation. This he did for another two hours, at which time, however, he

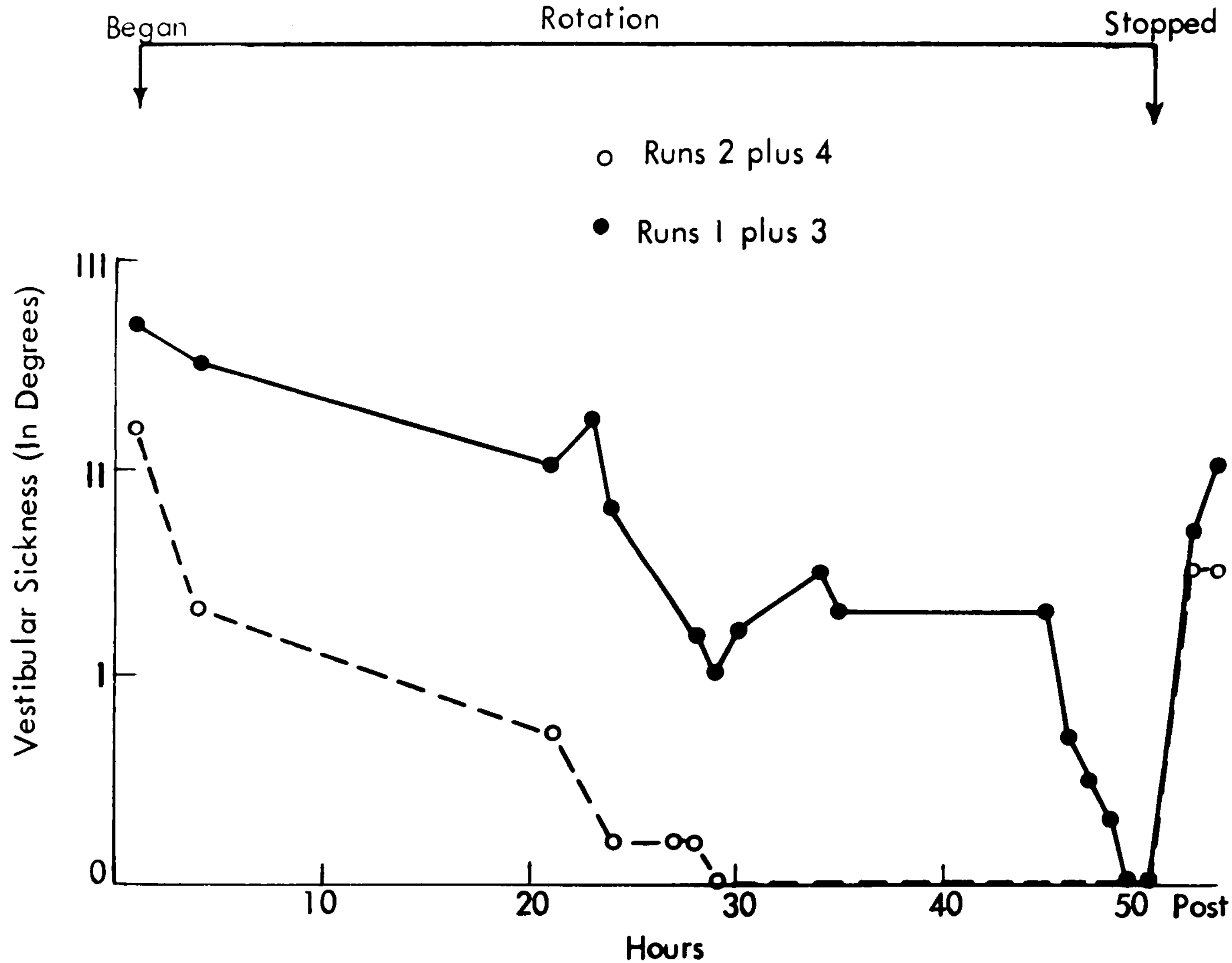

Figure 8. COMPARISON OF MEAN VESTIBULAR SICKNESS FOR 3 MEN DURING RUNS 1 PLUS 3 VERSUS 2 PLUS 4.

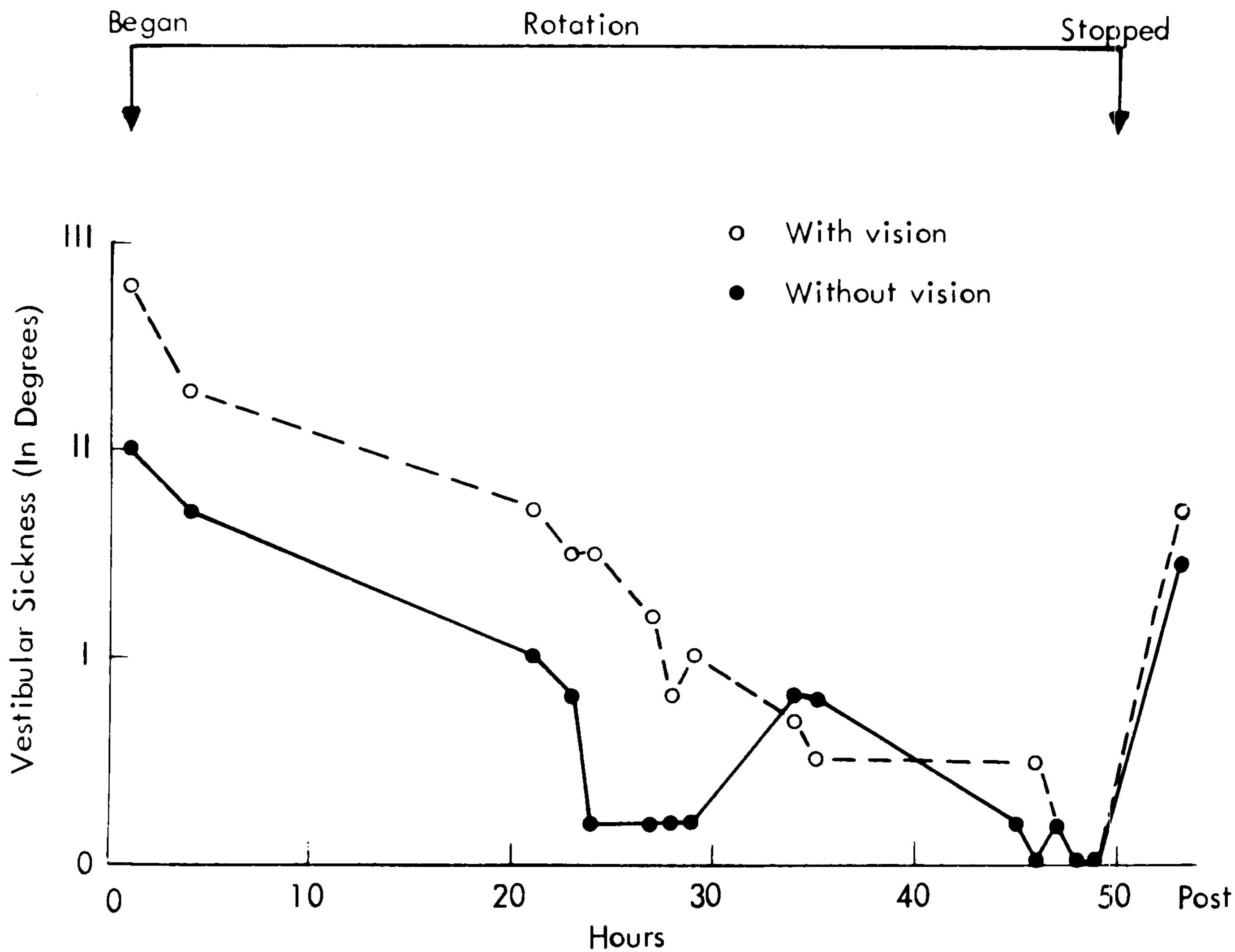

Figure 9. MEAN VESTIBULAR SICKNESS FOR 3 MEN DURING THEIR WITH AND WITHOUT VISION RUNS.

complained he was "incapacitated" and he was taken off the SRR. He did not vomit, and it does not appear that he exhibited characteristic vestibular sickness (cf. Appendix C). Total time on board was seven hours. It is felt that his previous exposure "with" vision contributed to his anxiety and that while rotation supplied the stress, anxiety was the predisposing factor (not canal sickness) in his reactions under visual deprivation. However, he did remain on board for seven hours with eyes covered compared to two hours when not covered.

Subject 4: This subject had a history of motion sickness and did not complete the screening procedure on the SRR prior to the first experiment. He was considered to have greater than average susceptibility. There was concordance of signs and symptoms during this screening test and his noncompletion at that time was considered to be warranted. During the first fifty-hour experiment at 7.5 RPM he was not blindfolded. He carefully restricted his head movements whenever possible and exhibited only aerophagia, pallor, and the characteristic facies of motion sickness through the morning of the second day. He appeared anxious and complained of gastrointestinal problems, dizziness, sweating, and depression until that time; he reported headache, dry mouth, and drowsiness throughout the experiment. Some of the above symptoms are associated with vestibular sickness.

Following adaptation to rotation, subjects frequently complain of symptoms similar (but milder) than those experienced at the onset of rotation. This man did not, thus indicating the possibility that his adaptation to the rotating condition was minimal. Despite the fact that strong and appropriate measures were made to induce him to serve as subject on the second run he absolutely refused.

Subject 1: This subject did not have a past history of motion sickness and from a preliminary exposure on the SRR was considered to be less susceptible than the average. During the first experiment, he was blindfolded and complained of vertigo and headache the first evening and, intermittently, drowsiness until the second evening. In the second experiment "with" vision he exhibited pallor and complained of general discomfort, dizziness, and vertigo through the first evening. He was asymptomatic for the remainder of the run. Following the second experiment, "with" vision he noticed more postrotation symptoms than after the first (i.e., "without"). The third run ("with" vision) followed the second run by more than thirty days. During this exposure Subject 1 developed Malaise III, and his main complaints were nausea, salivation, sweating, drowsiness, headache, and dizziness. In the fourth run, "without" vision, he mentioned drowsiness, and dizziness at the onset of rotation. These symptoms left after the first hour, and he remained symptom free for the duration of the experiment. Following fifty hours of rotation "without" vision the subject noticed increased salivation, yawning, burping, and dizziness. He vomited an hour after the room stopped. Following runs 2 and 4 he noticed his most complete adaptation.

Subject 5: This subject had no history of motion sickness and was judged non-susceptible from his pre-exposure performance. In the first portion of this experiment he was permitted vision, and he complained of nausea and cold sweating throughout the first evening. He was occasionally drowsy and noticed vertigo and dizziness through the second morning. During the second experimental session, and while blindfolded, he noted dizziness and vertigo and exhibited slight pallor throughout the first hour of rotation. Except for drowsiness the first evening, he remained asymptomatic for the remainder of the run. In the third run ("without" vision) he noticed some drowsiness the first afternoon of rotation and except for yawning was symptom free for the remainder of his exposure. On his fourth run "with" vision there was some pallor at the onset coupled with dizziness and the characteristic facies of motion sickness. These symptoms subsided rapidly and except for drowsiness he was without complaint until cessation of rotation. Following runs 3 and 4 headache and dizziness, respectively, were the only symptoms.

Subject 3: This man had a history of motion sickness and vomited very quickly during his short (ten minutes) pre-exposure test. He was considered to have greater than average susceptibility. In his first experiment, he was blindfolded and noted vertigo, headache, and slight nausea through the morning of the second day. He occasionally reported being drowsy. During the second fifty-hour session, he had essentially the same complaints; however, there was complete remission prior to the morning of the second day. Although his symptoms left earlier on the second rotational sequence ("with" vision), this subject remarked he had more dizziness than before. His post-rotation symptoms were similar to those during rotation. During the third run this subject was permitted vision. He vomited shortly after completing his first session on the Bolt Test. His canal sickness maintained (at Mal III or II) until the morning of the third day after which his symptoms became negligible. His postrotation symptoms qualified him for a Mal III rating. On his fourth run ("without" vision) he complained of nausea as well as other minimal symptoms at the onset of rotation. Remission was rapid, and he remained symptom free for the rest of the run. His only symptom postrotation was a headache which he obtained one hour hence.

CONCLUSION

Equilibrium

Examining the results of the tests for dynamic equilibrium, it appears that visual deprivation does not retard the adaptation process and in fact may even benefit it. However, it should be emphasized that the no-vision runs provided extra practice under conditions similar to that of the testing (viz., when performing other daily activities). The over-all decreased locomotion when blindfolded may not have controlled this factor.

A comparison of the four experimental runs indicates that some of the adaptation from the first and third runs is carried over to the second and fourth which began four days after one and three ended. No similar occurrence was noticed between runs 2 and 3 which were thirty days apart.

The results of the tests for static equilibrium are similar to those of the dynamic equilibrium, but individual differences are more pronounced. It appears that visual deprivation produces better performance, but considering the small number of subjects (counterbalancing of design notwithstanding), this interpretation must be made with caution.

Coriolis Illusion

Adaptation as measured by the Coriolis illusion was less pronounced, and there was greater individual variability during visual deprivation. In some subjects there was a pronounced reduction in the illusion and in others it was minimal. Those who were blindfolded were not so consistent in reporting a reduction in the magnitude of the illusion after forty-nine and fifty hours. Also the fact that the blindfolded subjects reported no consistent postadaptation illusion might indicate they did not adapt to the Coriolis illusion during rotation. In all cases the illusion showed a reduction between the forty-nine and fifty-hour trial, and this reduction probably cannot be accounted for on the basis of vestibular adaptation. It is perhaps best explained as "adaptation-to-the-illusion-as-an-illusion" and is very likely similar to the habituation reported with other visual illusions (37,41,42,47). An alternate possibility is that, as a result of all his other activities for forty-nine hours at 7.5 RPM, the subject was "poised" to adapt to the CI.

Vestibular Sickness

Although all subjects experienced some symptoms on all experiments two factors appear evident: 1) Adaptation during massed exposure on the SRR at 7.5 RPM minimizes the symptoms experienced at that rotation rate four days later, but this transfer of training is negligible for exposure > thirty days later. 2) Visual deprivation minimized the symptoms that would be predicted on the basis of the pre-exposure test. One subject lasted more than three times as long "without" vision and in fact was not considered motion sick when he did request to terminate his exposure. A very susceptible subject had relatively minor symptoms for fifty hours, whereas he had vomited previously "with" vision after only ten minutes. Another susceptible subject permitted vision in the first run refused a second exposure. The two nonsusceptible subjects complained of more dizziness and vertigo during the runs in which vision was permitted.

The observations of subjects "with" vision were similar to those observed in previous experiments, namely, a striking degree of adaptation to the illusion and, under postrotational testing, a compensatory conditioned response. In subjects with eyes covered, there was great individual variance in the degree of adaptation ranging from almost no adaptation to the illusion to nearly complete extinction. But regardless of the degree of adaptation in the "without" vision condition there was no definite evidence of a postrotation compensatory response. A larger experience may yield exceptions to this last generality.

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APPENDIX A

The Object Recognition Test: The subject sat on a stool 16 inches high within a rectangular frame. The wooden frame was 56 inches high and 30 inches wide. Attached to the frame were four shallow boxes two of which were positioned on the floor (right and left) and were 30 inches apart. The other two boxes were 52 inches from the floor (also right and left) and also 30 inches apart.

The subject's task was to reach, feel, and identify, reporting verbally, a small plastic object randomly placed (but with equal occurrence) in one of the boxes by the experimenter. The objects were 12 small plastic toys none more than 304 inches in diameter (i.e., aeroplane, automobile, horse, ball, whistle, etc.).

In order to pace the subject and to direct him to the appropriate target box, a magnetic tape recording was made. The directions for movement were played back (2 randomizations of 24 movements each) over a loudspeaker instructing him, "Right hand, left lower box." In three seconds he heard the recorded question, "What is the object?" Then in two seconds, a second instruction, "Left hand, right upper box."-- "Identify object!", etc., for 24 items. The subject replaced the object he had identified back into the box whereupon it was immediately supplanted with another toy. Each object was used twice during one test sequence.

The test was designed to be scored as to the number of movements each subject was able to complete before he stopped because of motion sickness, and the number of errors of identification. The task was rehearsed to reduce the effects of learning during an experimental run.

APPENDIX B

DIAGNOSTIC CATEGORIZATION WORK SHEET

Experiment III Run #3 c̄ Vision Name	Pathognomic Signs	Major Signs and Symptoms						Minor Signs and Symptoms				
	Vomit	Nausea II or III	Increased Salivation II or III	Pallor III	(cold) Sweating III	Drowsiness III	Retch	Nausea I	Increase Salivation I	Pallor II	(cold) Sweating II	Drowsiness II
1. Subject #3	+	3					+	+	+		+	
2.		2					+	+	+		+	
3.								+				
4.								+	+			
5.								+	+			
6.								+				
7.								+				
8.								+	+			
9.								+	+			
10.												
11.												
12.												
13.												
14.												
15.												
16. Post Immediate												
17. Post 1 hour								+	+			
18.												
19.												
20.												
21.												
22.												

		Predisposing Factors			Concordance of Signs & Symptoms	Noncompletion Warranted	Diagnosis
		Degree Unfit 0,1,2,3	Subject's Concern 0,1,2,3,4	Subject's Prediction -1,0,+1			
	1.	0	2	0	Yes	5 Bolts	VS c
	2.				"	15 "	VS
	3.				"	20 "	III
	4.				"	" "	III
	5.				"	" "	III
	6.				"	" "	III
	7.				"	" "	III
	8.				"	" "	III
	9.				"	" "	III
	10.				"	" "	II
	11.				"	" "	II
	12.				"	" "	II
	13.				"	" "	I
	14.				"	" "	I
	15.				"	" "	I
Post	16.				"	20 "	II
Post Post	17.				"		III
	18.						
	19.						
	20.						
	21.						
	22.						

Diagnostic Terms

Vestibular Sickness (VS):
Vomiting or
two major symptoms or
one major and two minor symptoms.

Malaise III:
One major or
two minor symptoms or
one minor and two other symptoms.

Malaise I:
Any subjective symptom or
any sign usually associated with
any subjective symptom.

Malaise II:
All others.

Note: In addition, an occasional diagnosis of "Anxiety Reaction" may be made when signs and symptoms warrant.

		Other Signs						Signs of Anxiety		Other Symptoms: Gastrointestinal				Mental		Cerebral			
		Pallor I	Sweating I	Drowsiness I	Characteristic Facies	Increase Yawning	Restrict Head Movement	Aerophagia	Character Facies	Stomach Awareness	Anorexia	Burping	B.M. Desire	Depression	Apathy	Headache	Dizziness	Vertigo	General Discomfort
	1.	+	+	+	2	+	+	+		+	+	+				1	+	+	3
	2.	+		+	2	+	+	+		+	+	+		+	+	1	+	+	2
	3.			+			+	+		+						2		+	1
	4.			+		+		+		+						2	+		1
	5.			+		+		+		+	+	+				2	+	+	1
	6.			+		+		+		+	+	+				2	+	+	1
	7.			+		+		+		+						2	+		1
	8.			+		+		+		+	+	+				2	+	+	1
	9.			+		+				+	+	+				2	+	+	1
	10.															2	+		1
	11.			+		+										2	+		1
	12.															1	+		1
	13.															1			
	14.															1			1
	15.															1			1
Post	16.			+		+				+						2	+		1
Post Post	17.		+	+		+				+	+	+		+	+	2	+	+	2
	18.																		
	19.																		
	20.																		
	21.																		
	22.																		

APPENDIX C

As an additional testimony to the possible differences of "with" versus "without" vision the subjects were asked to write about their impressions during their exposures. The experimenter requested only that they "...compare their experiences 'with' and 'without' vision." These paragraphs were written independently. These unedited impressions are reprinted herewith as a caution to other investigators who may believe that subjects do not become aware of experimenter's hypotheses.

Subject 3

On the third ("with" vision) run I got sick right away. It seems when you're not blindfolded your reactions are much different to the case of being blindfolded. On 2 runs I've made I was sick for at least six (6) hours and feeling uncomfortable for the next ten (10). But, when I wore the eye patches my reactions were entirely different. I felt only uncomfortable for four (4) hours at the most. On one of the runs I had a headache continuously. But that was caused by a little ear trouble I had before I went into the test. On my opinion I would say being blindfolded is the easiest way for adaptation to motion sickness. That is of course out of the results of my past runs.

My after effects when not--when I got off the wheel were of a different situation. I was always sick after a test for at least 24 hours without blindfolds. But when I wore the blindfold my reactions were of a different light. I felt no discomfort after the run and I think with eyes closed you are less apt to get sick.

Subject 1

First and Fourth Run (With vision)

When I moved my head I felt dizzy both with eyes open and closed. First bolt, head, and walking test I felt uncomfortable. I was hot, sick to my stomach and sweaty. Also, had a slight headache and was sleepy. When it was time to eat I was hungry until I took a few bites and then I felt like throwing up. I felt better when I laid down and went to sleep. Second bolt test, and walking test, I still felt hot, sick to my stomach. I didn't feel as dizzy as the first day. I ate a little more. The second night I felt pretty good. I didn't feel hot, sick to my stomach but still had a slight headache. Didn't feel dizzy either. When I got off the wheel (SRR) I felt dizzy both with eyes open and closed. Had a moderate headache. I did eat a little while after the run. The next day I still felt dizzy when I moved my head. Still couldn't walk heel-to-toe with my eyes closed.

Second and Third Run (Without vision)

When I moved my head I felt dizzy. No headache but a little sick to my stomach. The first night I felt good just sleepy. I ate good throughout the whole run. I didn't smoke much either run. Smoked less on the second run. When I got off I felt a little dizzy. I think being blindfolded you adapted a lot quicker and you also don't get sick.

Subject 5

First and Fourth Run (Without vision)

On the first run I was blindfolded and knew that it would only be for 50 hours. I think that if it had been for a week or more I couldn't have lasted more than 3 days without becoming grouchy and irritable. I think that would be the main trouble for me on this type of run because being blindfolded limits you in passing idle time whereas the man who isn't blindfolded can play cards, read books, watch TV or catch up on some letter writing and etc. All the man who is blindfolded can do is listen to music or the TV and this would be pretty boring to me after three or four days. After coming off of the wheel I had no ill effects whatsoever that I can think of.

Second and Third Run (With vision)

On the second run I was not blindfolded and the run was a lot smoother and faster than the first because not being blindfolded allowed me to play cards, watch TV and do the other things that seem to make time fly by. The only difference between being blindfolded and not is that I get nauseated for about 30 min. when I'm not blindfolded and after the run I'm dizzier than I would be if I had been blindfolded. That's about all I have to say on the subject except that I would rather not be blindfolded on a run for more than 3 days.

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Three experiments were performed in the Slow Rotation Room to evaluate the influence of visual deprivation on several indices of adaptation to rotation. Data were obtained on tests of postural equilibrium, the Coriolis illusion, and canal sickness symptomatology. Reduction in the magnitude of the Coriolis illusion was observed whether vision was permitted or denied, but there was more variability in the latter condition. Equivalent or better postural performance was observed "without" vision, and fewer symptoms of canal sickness were observed in this mode.

Author

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Canal sickness						
Coriolis illusion						
Rotation						
Visual factors						

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