AEROSPACE MEDICINE

Formerly THE JOURNAL OF AVIATION MEDICINE

Official Publication of the Aerospace Medical Association

VOLUME 32 FEBRUARY, 1961 NUMBER 2

Human Performance During Adaptation to Stress in the Pensacola Slow Rotation Room

BRANT CLARK, PH.D. and CAPTAIN ASHTON GRAYBIEL, MC, USN

IT HAS BEEN known for many years that stimulation of the non-acoustic labyrinth may produce stress of varying degrees in humans and animals and that head movements during bodily rotation are peculiarly stressful. Students of semicircular canal function have found, therefore, that it is necessary to control carefully head movements in all studies involving vestibular function. More specifically, it has been shown[5] that controlled head movements induced during rotation at constant speed cause severe "motion sickness" in healthy individuals. Studies of stress resulting from the stimulation of semicircular canals by head movements have important implications with regard to the psychophysiological mechanisms involved. They also have practical implications in connection with proposed orbiting vehicles because it has been suggested[1,2,7,9] that these might be rotated at a constant angular velocity in order to produce an artificial gravitational force.

In the part of the present investigation reported earlier[4] the authors described a method whereby the consequences of rotation for forty-eight hours in a slowly rotating room could be determined. The effective stimulus was the bizarre, aperiodic excitation of the semicircular canals associated with movement of the head out of the plane of rotation of the room. Comparisons were made between the symptoms exhibited by five normal subjects with those of a deaf subject with no vestibular function who acted as a control. The earlier report indicated that the control subject showed no significant symptoms associated with the two-day period of constant rotation at angular velocities from 1.71 to 10.00 rpm. The five normal subjects exhibited a variety of symptoms which the authors termed "canal sickness" since these had their genesis in the random stimulation of the semicircular canals. The symptomatology varied in these subjects and included anxiety, somnolence, sweating, oliguria, visual illusions and gastrointestinal disturbances. Moreover, although healthy subjects adapted readily to slower velocities of rotation, they experienced serious or incapacitating symptoms during the higher rates of rotation. Aftereffects following rotation also were noted at all velocities. In general, these aftereffects were less severe than the symptoms during rotation, but for some subjects they were equally as intense.

It is the purpose of this report to present the results of tests to determine any changes in the performance of subjects on a variety of tasks during a two-day period of constant rotation. Some of the tests selected were of such a nature

From the San Jose State College, San Jose, California and U. S. Naval School of Aviation Medicine, Pensacola, Florida.

Presented at the 31st annual meeting of the Aerospace Medical Association, May 10, 1960, in Miami Beach, Florida.

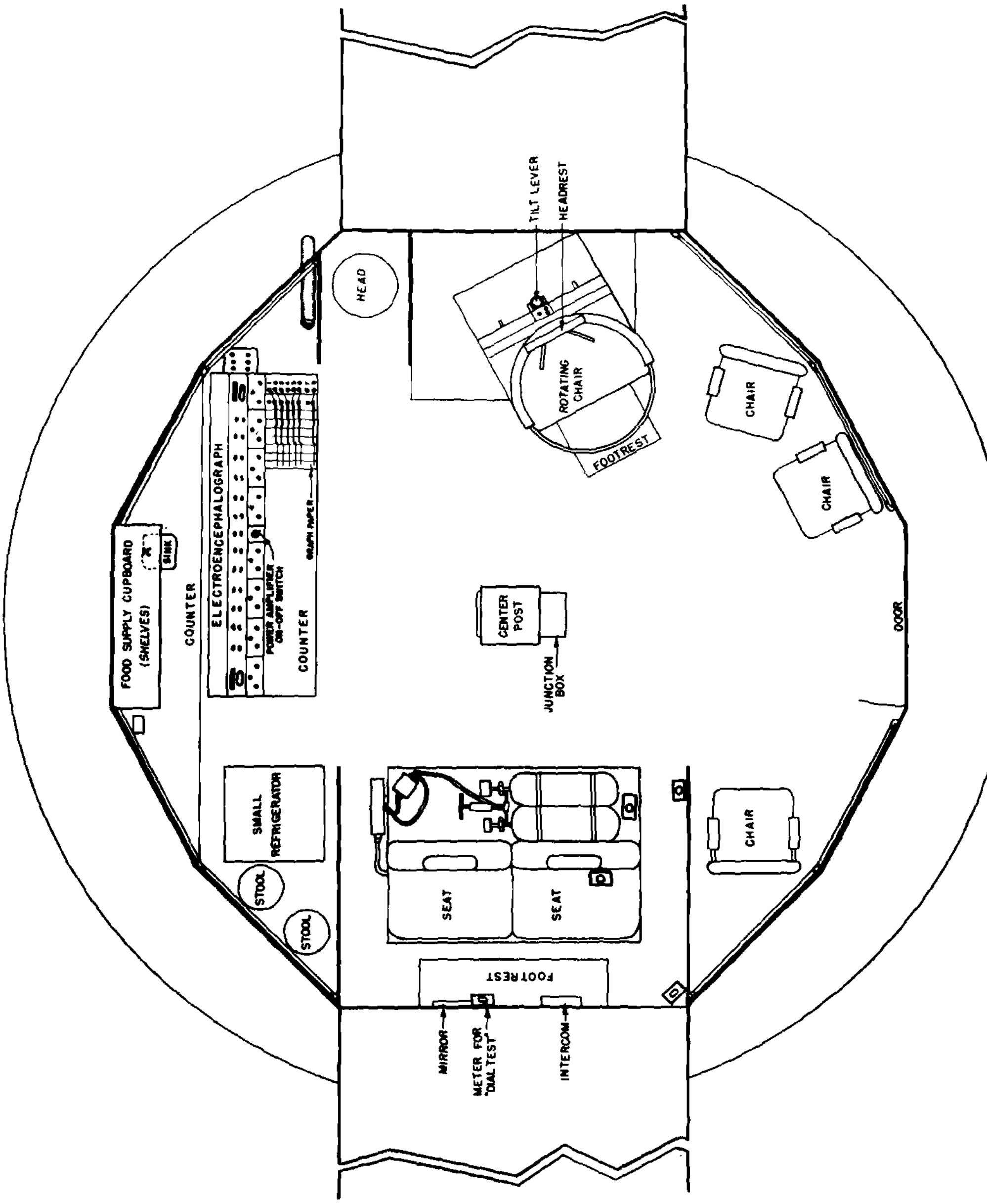

Fig. 1. Floor plan of Pensacola *Slow Rotation Room.*

as to impose a stress by requiring the subject to move his head to produce random, bizarre patterns of stimulation to the semicircular canals. All of the tests were designed to give gross measures of the subject's ability to function under prolonged constant rotation rather than to get minute changes in performance. As in the preceding study, the findings to be described are concerned with the function of the psychophysiological mechanisms involved, but they also apply directly to man exposed to slow rotation in orbiting satellites, radar domes, and the like. They also apply directly to motion sickness of all types insofar as the semicircular canals contribute to the symptomatology.

APPARATUS AND PROCEDURE

The procedure used in this study was designed to investigate the performance of a selected group of subjects while they lived in an experimental room which rotated at a constant angular velocity for two days. The procedure has been described in considerable detail elsewhere,[4] but a brief description emphasizing crucial experimental items is given below.

The Pensacola Slow Rotation Room.—The nearly circular, windowless room, having a diameter of 15 feet and a height of 7 feet, was constructed around the center post of the Pensacola human centrifuge. Because of the great inertia of the flywheel and superstructure of the centrifuge, the mechanism ran very smoothly throughout the two-day run, and variations in angular velocity were within plus or minus 2.5 per cent of the desired velocity. The rotation was completely free from abruptions, and the rotating platform was level and extraordinarily stable so that the subjects were usually unaware of any rotation unless they moved their heads. The room (Fig. 1) contained laboratory equipment, seats, refrigerator, sink, cooking facilities, toilet, and sleeping accommodations for four persons. Communicaiton with the control booth was available at all times throughout the run.

The Stimulus Pattern.—The semicircular canals were not stimulated so long as the subject's head was fixed, except at the beginning and ending of the run, because there was zero angular acceleration of the centrifuge at the constant velocities used. Movements of the head stimulated the canals by virtue of the angular acceleration incidental to this movement and by virtue of the change in the relation of the semicircular canals to the plane of rotation. The canals were not stimulated if the body (head) was displaced parallel to the axis of rotation or laterally in the same plane as the rotation. However, turning the head about an axis parallel to the axis of rotation would stimulate the canals in the normal fashion. On the other hand, turning the head about any other axis would result in a complex pattern of stimulation resulting from changes in the direction of the force with respect to the several canals. The magnitude of these effects depended upon the specific direction of movement, the velocity of rotation of the head, and the velocity of rotation of the room.[4] Although theoretically it was possible to move the head without stimulating the canals, it was impossible to execute the movements of the head perfectly enough to achieve this. Consequently, nearly all head movements resulted in an unusual pattern of stimulation of the canals, and the greater the angular velocity of the centrifuge, the greater the likelihood that the stimulus was above threshold. Although the actual forces involved could not be determined accurately, the important variables were: (1) the angular velocity of the room, (2) the nature of the head movement, and (3) whether the eyes were opened or closed. The random character of the movements involved and the fact that they were voluntary on the part of the subjects were important factors in the situation.

Constant radial accelerations were also generated on the human centrifuge, the magnitude varying with the angular velocity and the distance from the center post.[4] With the head fixed, the otolith organs were subjected to a constant force represented by the resultant of the radial and gravitational forces; thus, there would be a direction of resultant force which could deviate somewhat from the gravitational force, and the subjects would be expected to observe the oculogravic illusion.[3] Rotation of the head about axes parallel to the room axis altered the *direction* but not the *magnitude* of the resultant force with respect to the otolith apparatus. Complex accelerations were generated by movements of the head about other axes. These forces were small and probably below threshold.[4]

Subjects.—The clinical findings of the six regular, volunteer subjects who took part in the experiment are described in the previous report.[4] All save one were free of any serious defects or disease of the inner ear, the exception being a man (RG), forty-four years of age, who had had repeated infections of his inner ears, and bilateral mastoidectomy had been performed twice. Both his hearing and his semicircular canal function were essentially eliminated. There was some indication that the otolith apparatus was also not functional. This man served as a control subject at all rotational velocities.

THE EXPERIMENTAL PLAN

The experiment involved three distinct phases of observation: (1) a preliminary training period during which the subjects learned to do certain tasks to arbitrary levels of performance under static conditions and baseline data were obtained, (2) the rotation period during which performance measures were obtained at regularly scheduled intervals during a two-day period of constant rotation, and (3) the test period immediately following rotation when the tests were given under static conditions. Six separate runs were made to sample the range which might be used in generating an artificial gravitational field of force in orbiting satellites at the following angular velocities: (1) 1.71, (2) 2.22, (3) 3.82, (4) 5.44, (5) 5.44, and (6) 10.00 rpm. The subjects were divided into two groups. Group A lived in the experimental room for two days for run number one, and after an interval of one day Group B took its turn for run number two, et cetera. The control subject made all of the runs except number five which involved the same velocity as number four. Four persons lived continuously in the room during each run. One person was an inside observer whose primary job was to conduct the tests. Two persons were the normal experimental subjects who were tested on a regular, prearranged schedule, and the fourth person was the deaf man with effectually no vestibular function who served as the control. Each run normally began about 8:00 A.M. on the first day, at which time the subjects were locked in the experimental room, and the superstructure was clutched into the rotating flywheel. Shortly after the experimental room had reached the constant angular velocity, the inside observer began a series of tests and observations. These continued until approximately 11:30 A. M. when time was taken out for lunch. The identical tests were repeated in the afternoon, continuing until about 4:30 P.M. This schedule was followed very closely for the slower angular velocities, but at the higher angular velocities this was not always possible because at times the normal subjects were canal sick. In the evening the subjects occupied their time by eating, sleeping, reading, listening to the radio, and talking. As soon as the centrifuge was stopped on the final day, the outside observers went into the room and conducted a series of observations. Following these, the subjects were given a fifteen to twenty minute coffee break which was followed by a repetition of all of the tests while the centrifuge was not turning.

TESTS AND PERFORMANCE MEASURES

Tests of Muscular Strength and Coordination.—Three tests in this category were used: (1) The *strength of grip* was measured by a Stoelting Company Hand Dynamometer with the subject seated; he exerted a single maximum pressure which was read to the nearest kilogram. (2) *Body sway* was measured by a modified Rhomberg Test. The test was made for sixty seconds on both feet and thirty seconds on each foot. Performance ratings and a time score for the three parts of the test were obtained. (3) *Walking* was studied using two separate tests. The first of these involved walking heel-to-toe for about 79 inches, starting from the door and going directly toward the center post, and then from the center post to the door. The second walking test involved taking five regular steps in the area near the door, and then five steps in another trial in the opposite direction. Time to complete each trial was determined to the nearest second and a rating of performance was obtained for each performance.

Tests of Eye-Hand Coordination.—Six tests in this category were used: (1) *Ball tossing* accuracy was determined by having the subjects stand near the wall and throw 20 tennis balls into a basket. The score was the number of balls tossed into the basket for five series of twenty throws. (2) *Dart throwing* was studied using a standard Sportcraft Dartboard and five darts. The dartboard was mounted on the door and the subject stood nine feet from the door to throw the darts. The score was the sum of five series of throws using the numbering system on the dartboard. (3) *Hand steadiness* was measured with the Whipple Steadiness Test. This consists of a metal plate with nine holes of different sizes drilled in its face. The subject's task is to hold a metal stylus in each hole for fifteen seconds without touching the sides. Tests were made using the subject's preferred hand, and his score was the time he made contact with the side of the metal plate. (4) *Card sorting* involved sorting a deck of 52 playing cards using a special sorting procedure. The score was the time the subject used to sort the deck including time to correct his errors. Five sortings were made for each testing period. (5) *Opening locks* required the subject to open ten combination locks, the score being the time to open the ten locks. (6) The *dial test* involved setting five dials arranged around one of the seats so as to require maximum head and body movement. Dial 1 required the subject to turn left and lean back; Dial 2 required him to lean forward and up to his right; Dial 3 required head and body movement down and to his left; Dial 4 was read by leaning his head directly backward to look up; and Dial 5 required him to turn left and lean down to set a dial behind him. The dial settings were recorded on tape and reproduced on a tape recorder. There were two sets of twenty-five settings with a setting being made every four seconds. The deviation from the proper setting was recorded in the control room. This task was considered to produce a highly stressful situation.

Arithmetic Computation.—This test consisted of 827 items alternating addition, subtraction, multiplication, and division. The subject was instructed to work for both speed and accuracy. At the end of each two-minute interval, the subject was instructed to circle the problem on which he was working. The testing period was thirty minutes.

RESULTS AND DISCUSSION

The results to be described will be considered in terms of the variation in scores on the ten performance measures during the several experimental conditions with particular reference to changes occurring during and following rotation. The major comparisons will be made among scores during the final practice trials, scores during rotation, and scores following the run for both the experimental subjects and the control subject. The crucial factor in each case will be variations in performance associated with different angular velocities during the six runs. In evaluating the results, the variability of performance and the relatively small number of subjects should be kept in mind. In addition, it should be emphasized that these subjects were selected because it was believed that they were relatively low in susceptibility to canal sickness. The treatment of the data is complicated by the fact that at higher angular velocities, canal sickness occurred with sufficient force and regularity that scores were often not obtained for certain subjects. In other words, at the higher angular velocities the analyses were made of subjects who were actually able to perform the tests while those who had severe canal sickness were not tested. It should be noted also that the deaf subject was an excellent control subject for certain tests, e.g., the dial test, but for certain other tests, e.g., the test of body sway (standing on one foot), he did not serve as a control subject at all since he could not stand on one foot with his eyes closed under any conditions. Finally, it should be emphasized that there is some question whether all of the subjects reached a peak of performance on all of the tests during the practice trials. In certain tests, therefore, it is difficult to determine whether improvement in performance is a result of practice or increased motivation. These considerations make it necessary to present the data in very simple terms and in every case where statisical procedures are attempted, nonparametric techniques are used. More elaborate statistical procedures seem to be unjustified in the light of the limited number of subjects in this experimental situation.

Tests of Muscular Strength and Coordination

These are tests which are essentially measures of muscular performance as such rather than those involving higher levels of coordination.

Strength of Grip.—Three strength of grip scores were available for each subject during each test series, one before the dial test began, one after five series of settings, and one following the dial test. The results for the right and the left hands have been considered together for purposes of statistical analysis, and the sign test[8] was applied to determine whether there was a significant tendency for the hand dynamometer scores to be less during and following rotation than they were during the final six practice tests. Comparison of the data during the final practice tests with the combined data for the various angular velocities showed no significant difference ($p > .10$ in every comparison). However, the mean scores during the run at 5.44 rpm are consistently greater than they were during the practice series. In any event, it can be concluded that the strength of grip during and following rotation certainly did not show a decrement.

However, one may ask also if there is a decrement in hand dynamometer scores during and following the dial test when these scores are compared with scores obtained before the stressful dial test began. Analysis of the practice trials showed that there were no statistically significant differences among the three conditions ($p > .17$), though the tendency was for the scores to be higher after the dial test. The control subject tended to have lower scores following the dial test, though this was not statistically significant ($p = .06$). During the period of rotation, the experimental subjects made significantly higher scores following the dial test than they did before the dial test began ($p = .001$), and a similar thing was true during the static tests following rotation ($p = .03$). However, most of the differences were small, of the order of two kilograms, and a maximum difference of eleven kilograms occurred in only one trial. These results show quite clearly that the rotating environment did not produce a decrement in strength of grip *as long as the subjects were willing to attempt the task.* However, two of the subjects were so affected by canal sickness that they were unable to perform regularly at higher angular velocities.

Test of Body Sway.—The *test for both feet* showed relatively little variability, and no failures occurred for any of the subjects. The control subject made maximum ratings throughout all of the tests including practice tests, tests during rotation, and tests following rotation. All of the experimental subjects made maximum ratings during the practice trials. With the exception of one subject (RLE) who showed marked canal sickness, all of the subjects were given maximum ratings for velocities up to and including 10.00 rpm. When subject RLE was able to take the test, his ratings were either 1 or 2 (on a five point scale), and no failures occurred. For the post-tests following rotation, the ratings were essentially maximum for 1.71 and 2.22 rpm. At 3.82 rpm one subject showed a lower rating, and following rotation at 5.44 rpm only the control subject and one other obtained a maximum rating for performance. Following rotation at 10.00 rpm both of the experimental subjects showed a rating of 2 which corresponded with their subjective feelings of instability. Subject DH who was rotated at only 5.44 rpm was able to complete only the tests on both feet though he did not obtain maximum ratings. It can be said, therefore, that the test of body sway for *both feet* showed only slight deterioration at the higher angular velocities, and a small amount of instability was also present following rotation at the higher angular velocities.

The *tests on one foot* showed marked variability from subject to subject during the practice trials as well as on the tests during and following rotation. The control subject was unable to stand on one foot even with eyes open at any time. Subject JR found it necessary to hop on one foot during all of the tests in order to keep from falling. Thus, he made consistently poor ratings throughout the various experimental conditions. His failure rate was greater at 3.82 and 5.44 rpm than it was at 1.71 rpm. Subject KT's failure rate was low up to and including 5.44 rpm, but his performance ratings tended to become poorer. At 10.00 rpm his performance deteriorated completely, and he failed all of the tests. Subject RME also had to hop to keep from falling even during practice trials so his performance ratings were also uniformly low. However, his failure rate increased substantially during 5.44 and 10.00 rpm. Subject RLE showed a marked deterioration in performance even at 2:22 rpm, and at 5.44 rpm he failed all of the six tests he took. His performance measures were complicated by canal sickness and the fact that he had trouble with his hip throughout the run. Subject DH showed a high failure rate at 5.44 rpm but no control data were available so comparisons are difficult.

Aftereffects of rotation were clearly defined in the test of body sway on one foot. Subject JR showed clear deterioration in performance at higher angular velocities. Subject KT's performance deteriorated markedly following rotation for all angular velocities, and at 10.00 rpm he failed completely. Subject RME failed 50 per cent of the tests at 5.44 and 10.00 rpm. Subject RLE showed deterioration in performance after both of his runs, but canal sickness complicated his scores and his data were incomplete. Subject DH's performance was poor following the period of constant rotation at 5.44 rpm.

In general, it can be said that a prolonged period of constant rotation has substantial effects on a subject's body steadiness, as shown by this test of body sway. This is true not only while the subject is actually rotating, but aftereffects are clearly defined immediately following the cessation of rotation, and, indeed, these effects are as marked, and for some subjects even more marked, than the effects during rotation. One positive factor in causing the reduced performance on the body sway test is, of course, the movement of the head while the subject attempts to keep his balance. Another possible factor, particularly at the higher angular velocities, is centrifugal force. In order to check on the influence of centrifugal force, tests were made on two subjects at 5.44 and 10.00 rpm first at the periphery, as in the other tests, and immediately thereafter near the center post at which point the effects of centrifugal force would be minimal. The results were equivocal. One subject improved in performance at the center post as compared to the tests near the door, while the other subject showed complete failure in both cases. These data suggest, however, that the random stimulation of the semicircular canals during head movement occurring during the test is a sufficient stimulus to interfere seriously with bodily coordination necessary in standing on one foot.

Walking Tests.—The two tests involving walking heel-to-toe and normal walking will be considered separately since they are really quite different tasks. Walking heel-to-toe (Table I) was a very difficult task for the control subject RG, but no systematic changes were noted at the various angular velocities except at 10.00 rpm when his median rating dropped. It is noteworthy that he made quite poor scores at the beginning of the run, but his performance improved as the run went along. Subject JR showed little change in his median score for the heel-to-toe test during rotation, but, like the control subject, at 3.82 and 5.44 rpm, particularly at the former, he showed an improvement in his performance as the run progressed. Similar changes were observed in subject KT, except that there was no systematic change until the final run at 10.00 rpm and then, like RG and JR, he performed poorly at first, but his performance improved as the run progressed. Subject RME had no change in time throughout the various runs, but his ratings were poor at the higher angular velocities. Subject RLE showed little change at the lower angular velocity, but at 5.44 rpm canal sickness interfered substantially with his performance. Subject DH showed poor performance on his single run at 5.44 rpm.

TABLE I. HEEL-TO-TOE WALKING TESTS*

Subject	RPM																	
	Practice			1.71			2.2			3.82			5.44			10.00		
	N	T	R	N	T	R	N	T	R	N	T	R	N	T	R	N	T	R
RME	12	4.5	1.0	—	—	—	10	4.0	1.0	—	—	—	10	4.0	2.0	4	4.0	3.5
Post-test				—	—	—	2	4.5	1.5	—	—	—	2	5.0	4.0	2	5.5	5.0
RLE	16	4.0	1.0	—	—	—	10	4.0	1.5	—	—	—	3	5.5	4.0	—	—	—
Post-test				—	—	—	2	4.0	1.0	—	—	—	2	5.5	4.5	—	—	—
RG	8	6.0	2.0	10	5.0	3.0	10	4.5	2.0	10	4.0	2.0	10	4.5	3.0	10	6.0	5.5
Post-test				2	4.0	2.0	2	5.0	3.0	2	5.0	2.5	2	6.0	3.5	2	6.5	4.0
JR	12	4.0	1.0	10	4.0	1.0	—	—	—	10	5.0	1.5	10	4.0	1.5	—	—	—
Post-test				2	5.5	2.5	—	—	—	2	6.0	4.0	2	8.0	6.0	—	—	—
KT	16	4.0	1 0	10	4.0	1.0	—	—	—	10	4.0	1.0	10	3.5	1.0	10	5.0	2.0
Post-test				2	5 0	3.5	—	—	—	2	5.0	4.0	2	6.0	4.0	2	6.5	5.0
DH	none			—	—	—	—	—	—	—	—	—	8	5.0	2.0	—	—	—
Post-test				—	—	—	—	—	—	—	—	—	2	5.5	4.0	—	—	—

*The number of trials (N), the median time to walk (T) and the median rating of the inside observers (R).

In the heel-to-toe tests made immediately following the cessation of rotation, all subjects showed poorer performance than during the final practice trials. The control subject showed no changes whatever following rotation at the slower angular velocities, but at 5.44 and 10.00 rpm his ratings were poorer than the practice trials. Both subjects JR and KT made poorer ratings and required longer time to walk during the post-tests than during the practice series. Subject RME had no change in time, but his ratings were poorer than his practice trials while RLE had poorer ratings only at 5.44 rpm. His scores should be viewed with some reservations, however, since he had an injured hip which interfered with his walking. Subject DH performed more poorly following rotation than during his single run.

The regular walking test during the run produced results similar to the heel-to-toe test. The control subject performed equally well throughout. Subject JR showed no consistent change in time, but his ratings were poorer at the higher angular velocities. Interestingly, he showed clear improvement during the two faster rates of rotation as these runs progressed, but in spite of this, his median scores were much the same. Subject KT showed little change from his practice trials, except at 10.00 rpm when he showed improvement as the run progressed. Subject RME showed no change in time scores, but his ratings were poorer at the higher angular velocities, and subject RLE showed no decrement in performance at 2.22 rpm but made poorer ratings at 5.44 rpm than during his practice series. As in other tests, canal sickness interfered with his performance.

Following rotation, performance during normal walking was inferior when compared with the practice series for the experimental subjects, but the control subject had a performance about equal to his practice series. Subject JR made poorer ratings, and subject KT had both longer walking time and poorer ratings than during his practice runs. Subject RME showed poorer performance at both 5.44 and 10.00 rpm while RLE exhibited no change in time but had poorer performance for both of his tests. Subject DH had poorer ratings for regular walking during the post rotation tests than during his regular walking during rotation.

The sign test was applied to the combined data for walking *time* for all of the trials at the five different angular velocities, comparisons being made between these and the practice trials for the heel-to-toe test. No significant difference was found ($p > 0.40$). However, the median *ratings* for performance during heel-to-toe walking were significantly poorer during rotation than during the practice trials ($p < .01$). For the static tests immediately following rotation the median walking time was significantly longer ($p < .01$) and the median rating significantly poorer ($p < .01$) than during the practice series.

For the regular walking test, the median *times* during rotation were not significantly different from those during the practice trials ($p = .50$), but median ratings were significantly poorer ($p < .01$) during rotation. Similarly, following rotation the median walking time was not significantly different from the practice trials ($p > .05$), but the median ranks were significantly poorer ($p < .01$).

Generally speaking, then, these data tend to support the results on body sway; i.e., muscular coordination is poorer initially, but there is evidence of adaptation. In general, the reduction in performance was much more evident in the ratings of performance than for walking time. This was no doubt due in part at least to the short intervals involved. It is also noteworthy that both the median time and median ratings on the post-trials immediately following the cessation of rotation were poorer than the median times and median ratings during rotation ($p < .01$ in each case). In other words, the immediate aftereffects of rotation have a greater effect on the subject's ability to walk under these two conditions than does rotation itself.

Tests Involving Eye-Hand Coordination

These six tests were selected as tasks which required varying amounts of eye-hand coordination. Each of them involved a substantial degree of learning so that the practice series was particularly important to produce a satisfactory level of performance before the experimental runs began. However, the first two tests, ball tossing and dart throwing, were of such a nature that the practice trials could hardly be used for direct comparison inasmuch as a new task confronted the subject during each run because of the varied angular velocities.

Ball Tossing.—The most outstanding characteristic of these results is the extreme variability of the scores. A major contributing factor to this condition was the fact that throwing balls while being rotated at constant velocity placed a new task before the subject. If the ball was thrown straight toward the bucket during rotation, it appeared to curve sharply and missed the bucket completely, the degree of the curve being a function of the angular velocity of the centrifuge. Therefore, the subjects had to learn the proper correction during each run. Following rotation, the subject again had to learn to throw normally.

The control subject showed a decrement in ball tossing performance during the practice series and then some improvement during the runs at 1.71 and 2.22 rpm. His performance at the three higher levels was extremely variable and poor. His scores immediately following rotation showed some decrement. JR's scores were highly variable and showed no systematic change throughout the runs. This was also true of his scores following rotation when he showed a decrement as compared with the final score during the run. Subject KT showed great variability on all runs and at 5.44 rpm produced a fairly good learning curve, but interestingly enough the "improvement" continued through the post-tests when the conditions changed. At 10.00 rpm his scores were very poor. Subjects RME and RLE were highly variable at 2.22 rpm. There was an increasing score at 5.44 rpm following a siege of canal sickness and at 10.00 rpm no data were obtained since these subjects were sick. Subject DH was canal sick during his run and did not perform this task.

The data for ball tossing may be summarized by saying that the most characteristic thing was the great variability of the subjects within runs and from run to run. This was true of both the control and the experimental subjects. It should be pointed out, however, that the subjects were able to toss the balls without any difficulty whatsoever, but they were not given enough trials to establish the habit firmly and produce higher scores during each run.

Dart Throwing.—The scores for dart throwing followed essentially the same general pattern as was found in ball tossing. Again the most obvious result was the extreme variability of the scores and the lack of systematic change during the runs and from run to run. Little learning appeared to be taking place during the individual runs, the trials apparently being insufficient to develop a new habit. Some reduction in score actually occurred in the trials following cessation of rotation, but this was not consistent. Here again the subjects threw the darts with no difficulty, but they were unable to learn the task sufficiently well within the trials to obtain high scores. No clear trends were evident throughout the series.

Steadiness.—The sequence of the steadiness test was planned to obtain scores immediately before and immediately after the dial test which was considered to be a stressor. It was presumed that if this stimulation of the semicircular canals would affect muscular coordination at all, it would be reflected in inferior performance following the dial test. Therefore, the steadiness test scores before and after the dial tests were compared during the practice runs and for each angular velocity. The data for all of the subjects were combined for each condition, and simple counts were made to establish any trends, through use of the sign test. No significant differences were found before and after the dial tests during the practice series when the centrifuge was stationary ($p = .50$), and the differences were not statistically significant at 1.71, 2.22, 3.82, and 10.00 rpm ($p > .10$). However, at 5.44 rpm the performance was significantly *better* following the dial test than before the test ($p = .05$). It is worth noting that the control subject had a tendency to make better scores following the dial test and that the scores during and following rotation tended to be greater than during the final trials of the practice series. Presumably, practice effects were continuing beyond the practice series. A similar comparison was made of the tests immediately following cessation of rotation. An analysis was not possible for individual angular velocities because of the small number of observations; however, when all of the data were pooled, there was no significant difference between the test scores before and following the dial test ($p = .30$). In general, therefore, it can be said that this rather gross test of steadiness indicates that hand steadiness is very little influenced by rotation under the conditions described here.

Card Sorting.—This card sorting task is quite simple though it involves some practice to make maximum scores for the single time measure obtained. The results show clearly (Figure 2) that all of the subjects continued to improve their scores beyond the practice series. The control subject (RG) improved gradually throughout all of his trials, and his best single performance occurred in his final trial during rotation at 10.00 rpm. In his case it seemed clear that the learning was continuing during the rotation trials.

The two subjects non-susceptible to canal sickness (JR and KT) also continued to improve beyond their practice trials. This was particularly true of subject JR. Subject KT was considerably more variable, and his performance at 5.44 and 10.00 rpm was poorer than at 3.82 rpm. Subjects RME and RLE also continued to improve beyond their practice trials; however, canal sickness was completely incapacitating to them at times during the 5.44 and 10.00 rpm runs. Nevertheless, when these subjects were able to do the tasks, they performed well; e.g., subject RME's final two scores at 10.00 rpm were better than any performance at 2.22 rpm (Figure 2), and RLE's final score at 5.44 rpm was better than any of his scores at 2.22 rpm in spite of the fact that his canal sickness completely incapacitated him during the early part of the run.

and RLE were incapacitated due to canal sickness during some of the periods when these tests were scheduled. The control subject RG improved throughout his successive trials and

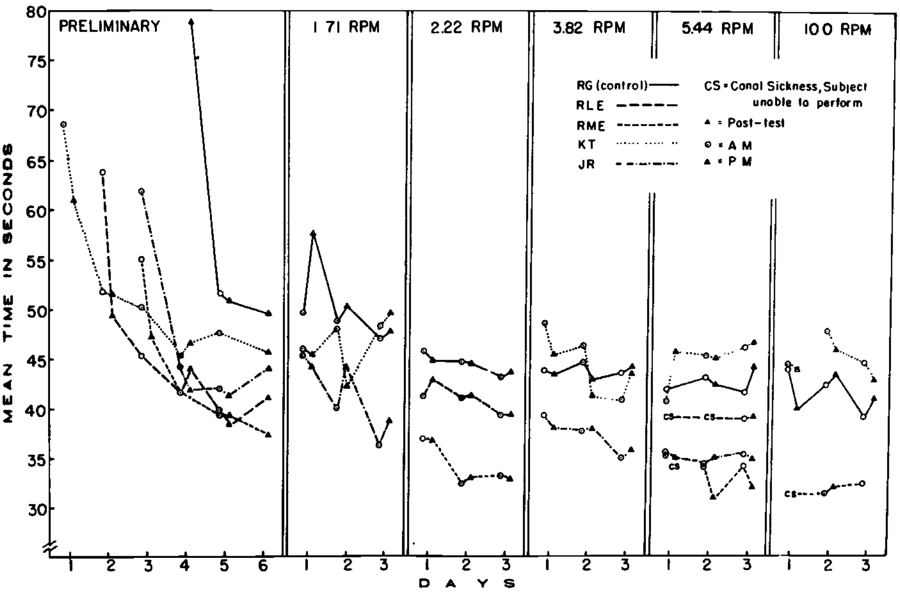

Fig. 2. Card sorting. Each point is the mean of five trials.

was much less variable at 5.44 and 10.00 rpm than during the earlier trials. JR showed similar improvements, but KT was highly variable throughout all of the tests, particularly at 5.44 and 10.00 rpm. As in the case of the card sorting task, RME and RLE tended to improve and performed fairly well when they were not incapacitated by canal sickness. In general, the same thing was true of subject DH during his single run at 5.44 rpm. An analysis of the plots of scores for this task indicates that the rotation had little effect on the performance of the task.

The control subject and the experimental subjects all continued to show improvement throughout the series of runs very much as they would have been expected to improve during successive practice periods on the task during static laboratory conditions. This, of course, was true when they were actually able to perform the task. Generally speaking, then, it appears clear that constant rotation does not interfere with such a task beyond incapacitating the subject generally or reducing his level of motivation.

Lock Tests.—Like several of the other tasks, variability of scores within runs and between runs was an obvious characteristic of the performance in opening the locks. This was an unstandardized task although it seemed to be a reasonable one for the subjects to undertake. On the other hand, the subjects themselves found it to be highly boring after the first few trials. It should also be kept in mind that RME

Dial Test.—This test was designed as much as a stressor for the subjects as it was as a test of performance. At the same time error scores were obtained for each setting the subject made, and these gave some measure of the performance under the experimental conditions. Since the test itself involved a highly stressful experience for the experimental subjects, the data were even more incomplete for RME and RLE than in preceding tests. These subjects found this task to be very stressful, and when they were canal sick, they often did not attempt it. Even if they were feeling fairly well, this test sometimes induced symptoms causing them to discontinue.

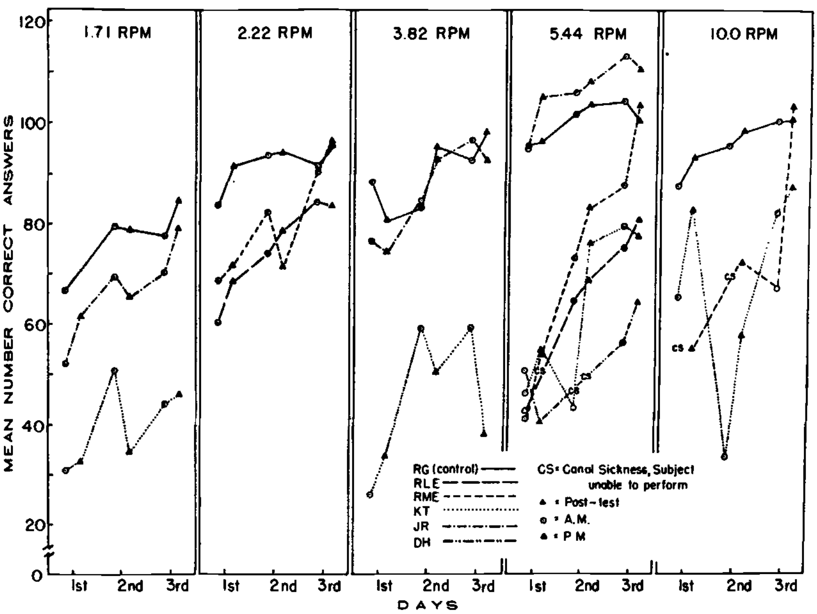

Fig. 3. Arithmetic test. Mean number of items right for each test.

As in the preceding two tests, the control subject (RG) continued to improve as the runs progressed since the task was no particular stress for him. JR also showed some improvement as the runs continued, but KT did not. Neither of these subjects made any consistent improvement or decrement within a given run. In general,′ such changes as did occur were small and there were no consistent trends, but in evaluating these results it should be noted that the data are based essentially on two subjects.

Arithmetic Computation

The number of items marked correctly was determined for each two-minute interval during the test, and the mean of these scores for the fifteen two-minute intervals was calculated. These mean scores served as the basis of the plots in Figure 3 which show the over-all performance for each subject under each test condition. An analysis of the plots of these data shows substantial differences in the performance from subject to subject. The control subject (RG) made a fairly continuous improvement throughout his first four runs and maintained his performance at 10.00 rpm. JR's performances followed the same pattern during his three runs. KT showed much greater variability than any other subject in the group; e.g., at 5.44 rpm KT's first score was 46.5 and his final score was 80.0 items correct.

The effect of the stress in decreasing performance of individual subjects is clearly indicated in the case of RME and RLE. At 2.22 rpm when the stress was small, the increase in performance was presumably the result of learning, but for the same subjects at 5.44 rpm the initial level is far below that at 2.22 rpm, and the increase must reflect not only learning but also adaptation to the stress. This is more clearly brought out in Figure 4 which compares the findings of RME and RLE with RG at 2.22 rpm and at 5.44 rpm.

One very evident conclusion from this experimental procedure is that the normal subjects were exposed to considerable amounts of stress whereas the control subject was essentially free of symptoms. The amount of stress varied from subject to subject, within each run, and increased as the angular velocity of the room increased on successive trials. Furthermore, the random stimulation of the semicircular canals is the dominant factor in producing the stress.[4] Thus, in the tests of standing (body sway) and walking which involve head movements, it is hardly surprising that some decrement in performance occurs. The head movements involved in these tasks necessarily produce bizarre stimulus patterns to the semicircular canals which, in turn, lead to a reduction in the effectiveness of the muscular coordinations involved in these activities. At the same time compensatory mechanisms were difficult. On the other hand, such tasks as squeezing the hand dynamometer, card sorting, and hand steadiness require minimal head movement and therefore show little change in performance. The dial test in the present study which required a systematic amount of head movement might be considered to be an exception, but the test was of such a nature that time pressures were put on the subjects and they were sufficiently motivated to try hard for a good score. Compensatory mechanisms were possible during these short test periods as has been widely observed during investigation of fatigue.[6,10] Such compensatory mechanisms were particularly easy during dart tossing and ball throwing where the subjects set their own pace.

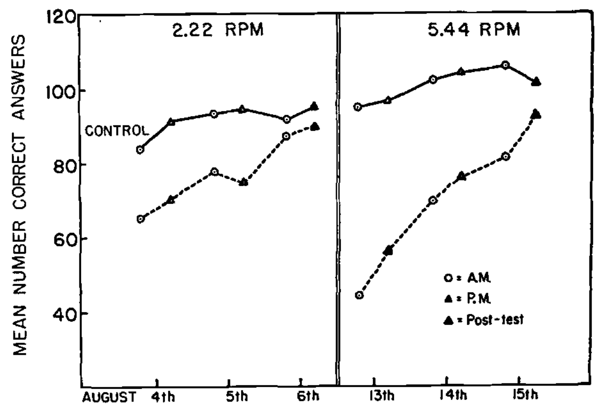

Fig. 4. Performance scores on arithmetic test at two velocities of rotation showing progressive improvement in case of control subject, RG, and temporary decrement in case of two healthy subjects.

A detailed comparison of the relationship for individual subjects between the symptoms reported in the earlier study[4] and the performance measures described in this study was also undertaken. As would be expected, the comparisons showed frequent occasions when severe symptoms were associated with poor performance, or, indeed, no performance. On the other hand, there were also many cases in which high performance was associated with such symptoms as nausea, dizziness, general malaise, and even vomiting. These comparisons further support the notion that canal sickness may reduce a subject's motivation to a very low level, but if the subject is willing or able to try, he can usually make good scores.

SUMMARY

One control subject with effectively no vestibular function and five healthy subjects were

subjected to constant rotations varying from 1.71 to 10.00 rpm for two days to determine any changes in performance on a variety of tasks. The control subject showed insignificant changes in performances associated with rotation. The most prominent change in the normal subjects was a change in motivation toward the tasks. Performance on tests of walking and body steadiness decreased substantially both during and immediately following rotation. No significant decrement was observed for strength of grip, ball throwing, dart tossing, hand steadiness, card sorting, and dial settings. These findings have practical implications inasmuch as the angular velocities used were within the range proposed to generate artificial gravity on space platforms.

ACKNOWLEDGMENTS

We are deeply grateful to the subjects, R. M. Every, R. L. Endicott, K. L. Tillman, D. L. Hawe, J. J. Repik, and R. M. Greenmun, and to observers R. E. Price and Robert Nelms who volunteered for this experiment. We are also grateful to the staff at the Acceleration Unit, particularly the exceptional efforts of Miss Mary Norsworthy, Chiefs Bergman and Peach, and to Mr. James Cloud whose skill and ingenuity were never wanting.

REFERENCES

1. Clark, C. C. and Hardy, J. D.: Preparing man for space flight. *Astronautics*, 4:18, 88, 1959.
2. Ehricke, K.: Manned outposts in space. *Astronautics*, 4:20, 42, 1959.
3. Graybiel, A.: Oculogravic illusion. *Arch. Ophthal.*, 48:605, 1952.
4. Graybiel, A., Clark, B. and Zarriello, J. J.: Observations on human subjects living in a "slow rotation room" for periods of two days. *A.M.A. Arch. Neurol.*, 3:55, 1960.
5. Johnson, W. H.: Head movements in relation to spatial disorientation and vestibular stimulation. *J. Aviation Med.*, 27:148, 1956.
6. Kleitman, N.: *Sleep and Wakefulness*. Chicago: University of Chicago Press, 1939.
7. Kreiger, F. J. (Editor): *Behind the Sputniks: A Survey of Soviet Space Science*. Washington, D. C.: Public Affairs Press, 1958.
8. Siegel, S.: *Nonparametric Statistics*. New York: McGraw-Hill, 1956.
9. Staff Report of the Select Committee on Astronautics and Space Exploration: Space Handbook: Astronautics and its Applications. Washington, D. C.: U. S. Government Printing Office, 1959.

Airline Safety and Financing

Airline safety is jeopardized by inadequate financing, according to Harry F. Guggenheim, aviation authority and chairman of the Cornell-Guggenheim Aviation Safety Center. He said that unless Congress takes immediate action to relieve the financial plight of the airlines, a major accident involving new jet airliners may cause an enraged public to demand action. Guggenheim said there is a connection between the financial plight of the airlines and the rise in airline accidents and if Congress fails to act it should then "deliberately slow down U. S. progress in the air in the interest of safety of the public." He pointed to the fact that one major airline is being sued by its creditors while net operating income has stood still for twelve other domestic trunk airlines. "Despite enormous growth in passenger traffic, the airlines as a whole are simply not earning enough money to permit them to obtain the capital they must invest to maintain service, get sufficient equipment and utilize all required safety devices and methods," Guggenheim said. "The same may be said for our airports and supporting services."—From *Flight Magazine*, June, 1960.