Human Performance During Two Weeks in a Room Rotating at Three Rpm

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ABSTRACT

Four men were tested before, during, and after being rotated at 3.0 RPM for two weeks in the Pensacola Slow Rotation Room. The men also lived in the room preceding the commencement of the rotation. Tests of intellectual and and physiological function were included. The principal finding was that no serious psychological or physiological deficit was detected during two weeks of rotation or during the subsequent readaptation to normal environment. The only test showing pronounced deterioration of performance at the beginning of rotation and upon returning to normal environment was the Graybiel-Fregly Posture Test. This means that any task requiring ordinarily difficult locomotion would be disturbed at these critical intervals. Ordinary walking with adequate visual reference was not so obviously affected. Results are discussed in relation to: problems of rotating space stations, the vestibular system, and experiments involving optically distorted visual information.

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THE PRINCIPAL OBJECTIVE of this experiment was to measure the fitness of healthy subjects to accomplish a variety of tasks during and after prolonged exposure to a slowly rotating environment. Previous experiments [3, 7, 9, 11, 17] had demonstrated that exposure to constant rotation at 1.0 R.P.M. produced insignificant effects even in persons highly susceptible to motion sickness, that mild symptoms were experienced by some persons at 1.7 or 2.0 R.P.M., and that fairly severe symptoms were manifest in most persons at 5.4 R.P.M. prior to exposure sufficient for adaptation. In the present experiment 3.0 R.P.M. was chosen because it represented a good compromise between the conflicting desires to generate an adequate inertial force which might substitute for gravity in an orbiting spacecraft and to avoid unwanted side effects.[3, 9, 20-23] For a space platform rotating at 3.0 R.P.M., a radius of 60 feet would be required to simulate the gravitational attraction of the moon and nearly 82 feet to generate one-quarter the earth's gravity. The duration of the run was set at two weeks to test for any undesirable secondary effects which might occur after the initial period of adaptation and also because of the likelihood that future space flights might be of similar duration.

APPARATUS AND PROCEDURE

The device used in this experiment was the Pensacola Slow Rotation Room (SRR) which is a nearly circular

room (described in detail by Graybiel, Clark, and Zarriello[7]) 15 feet in diameter and completely enclosed (Fig. 1). It is capable of smooth acceleration and virtually vibration-free constant angular velocity.[10] Communication between the SRR and the control room was accomplished by a two-way interphone which also provided auditory monitoring by control room personnel of conversations within the SRR. An ice box, sleeping bags, a toilet, electric cooking utensils, a sink, a television set, and a tape recorder afforded living conveniences for four persons for the duration of the experiment.

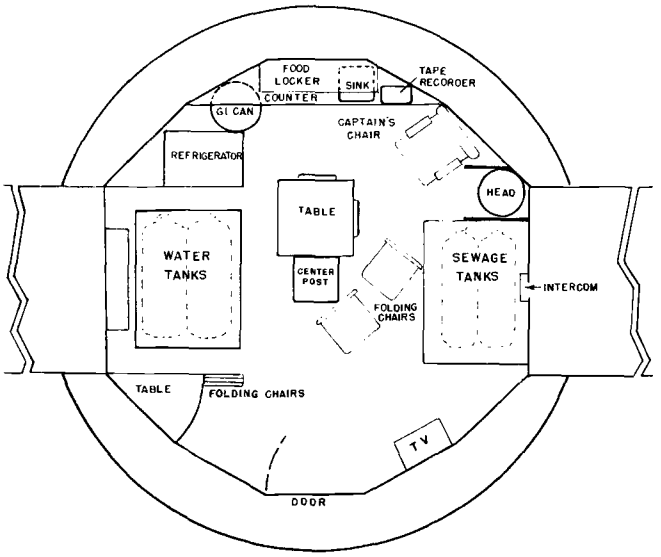

Fig. 1. Slow rotation room.

The three volunteer subjects for this experiment, aged 18, 18, and 19 years, were enlisted men in good health. None had any history of disease referable to the sensory organs of the inner ear. They exhibited usual sensitivity of the semicircular canals as indicated by caloric irrigation. Effort was made to ensure favorable motivation of the subjects by 1) explaining the importance of their participation, 2) providing a television set and recorded music on board for evening hours, 3) informing them of extra time "off duty" at conclusion of run, 4) arranging for publicity in local papers, and 5) permitting them their own selection of foods.

The experiment consisted of: 1) Four days of testing followed by three days of rest prior to the beginning of rotation; the subjects and the "on-board experimenter" lived on the SRR throughout the four-day testing period. 2) Fourteen days of testing aboard the SRR while it rotated at 3.0 RPM; all subjects and the on-board experimenter remained within the room throughout this period. 3) Three days of post-rotation testing; subjects were tested on board for the first eight hours after rotation stopped and returned for tests on subsequent days.

The list of tests and testing schedules are presented in Table I.

The fourteen-day rotation run began on a Monday afternoon with measurements being taken on the Dial Test, the Graybiel-Fregly Posture Test, and the Walking Test. Supper was then prepared and the evening hours spent listening to recorded music and watching television. Tuesday followed the planned test schedule (Table I). Although the order of tests was sometimes changed slightly, the plan of a usual day follows:

TABLE I. PROCEDURE FOR A ROUTINE DAY

1. Urine stop	0730
2. Weight and body temperature	0745
3. Coffee and roll	0800
4. Conceptual Reasoning Test	0800
5. Sequence Test	0830
6. Harvard Step Test	0900
7. EKG, respiration, and dials	1000
8. Midmorning meal	1130
9. Graybiel-Fregly Posture Test	1215
10. Walking Test	1245
11. Past pointing	1300
12. Accommodation and convergence	1330
13. Weight-lifting	1400
14. Achilles reflex	1430
15. Math Test	1500
16. Audio vigilance	1515
17. Secured testing and free time	1600 until retiring

The three subjects rose shortly after 0700 and washed, shaved, and voided urine into collection bottles. They then had a light breakfast of coffee or milk and rolls and secured their bedding. Body weight and room and body temperatures were recorded and the crew prepared for a stop by sitting motionless in a chair. They always remained motionless during stops. Supplies and the experimenter for the Conceptual Reasoning Test were taken aboard, and waste was removed. (All stops were limited to fifteen minutes except for one thirty-minute stop for drive mechanism repair). The SRR then accelerated to 3.0 RPM and subjects began moving about. The Conceptual Reasoning Test usually was completed by 0830 and the room again was stopped to allow the fifth man to debark. When rotation recommenced, the Sequence Test was performed. The two men not being tested cleaned the room. Following this the Step Test and the Dial Test were done. After these tests, a mid-morning meal was prepared. At this time, about 1130, there was a rest period for letter writing and log entries. The afternoon testing began with the Graybiel-Fregly Posture Test and Walking Test, as indicated in Table I. Between 1600 and 1800, the SRR occasionally stopped for a third time to take on supplies.

After the tests, subjects pursued their own interests. They assisted in preparing supper, listened to music, read, wrote letters, and relaxed. It was desired that all be in bed and asleep by midnight, but this condition was not always met.

TESTS AND RESULTS

Tests were selected to satisfy one or more of the following criteria: 1) indication of general physiological well-being, 2) indication of physiological function and reflex activity likely to be influenced by prolonged bizarre vestibular and proprioceptive stimulation, 3) indication of higher mental function, 4) indication of performance on well-learned complex tasks ordinarily accomplished by the subjects without difficulty, 5) apparent deficit in previous SRR experimentation, 6) feasibility of administration in the experimental situation.

1) The Conceptual Reasoning Test was developed and described in detail by Maag.[24, 25] It has been used primarily in demonstrating decrements in judgment and reasoning during hypoxia. The subject is presented with one of 32 stimulus blocks, each of which has 5 attributes, a) tall or short, b) black or white, c) round or square, d) hollow or solid, e) striped or plain. The subject's task is to select 7 other blocks which have two attributes in common with the stimulus block. The subject is therefore required to set up hypotheses and test them.

Results of this test, shown in Figure 2, indicate a learning trend during the four-day prerotation testing which was not disrupted by commencement of rotation. During the two-week rotation run intersubject differences declined and subject variability from day to day diminished. There is no evidence that the commencement of rotation or the readaptation period at the end of the fourteen-day run had any adverse effects on the performance of this test.

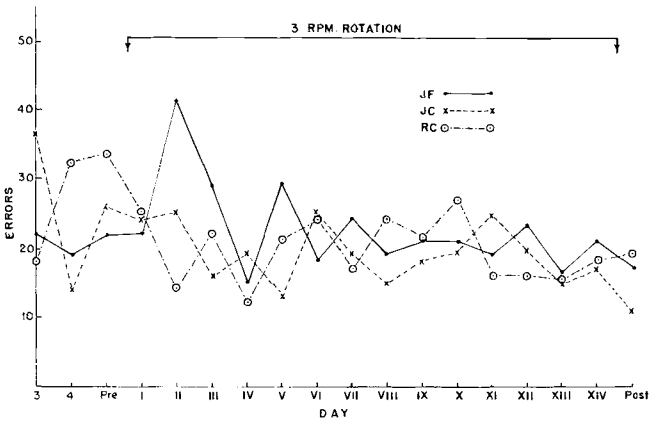

Fig. 2. Conceptual reasoning test—total errors on 10 trials for each subject.

2) The Sequence Test requires a subject to respond to a nixie light by depressing three of six toggle switches in a particular order. The nixie tube presents one of four different one-digit numbers, each of which requires a particular sequence response. A trial consisted of 32 stimuli programmed randomly and there were five trials in a session. Subjects were practiced to a criterion of 32 successive responses without error, prior to the actual experimental period. It should be mentioned, however, that within a session of five trials a few errors were permitted. The score was time and errors.

In the Sequence Test there were seven days of practice prior to the four-day "dry run." Although it appears that the error scores increased from the dry run to the rotation run, this increase was probably attributable to the increased speed of response of the subjects, which apparently caused malfunction of the device. Error scores are shown in Figure 3. There was no clear evidence that rotation or cessation of rotation influenced performance on this test.

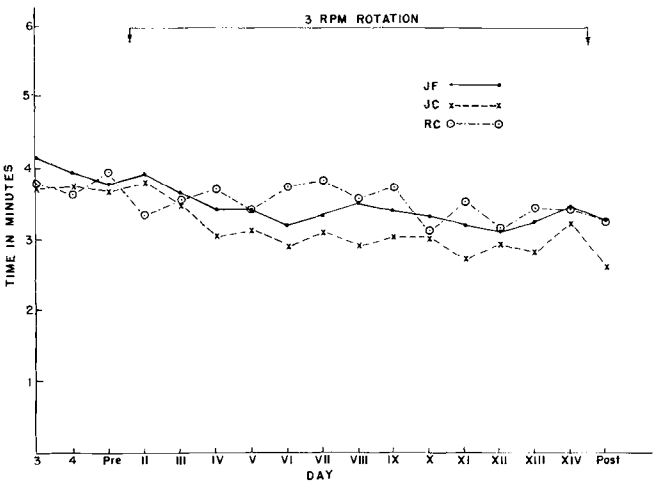

Fig. 3. Sequence test—total time for 5 trials.

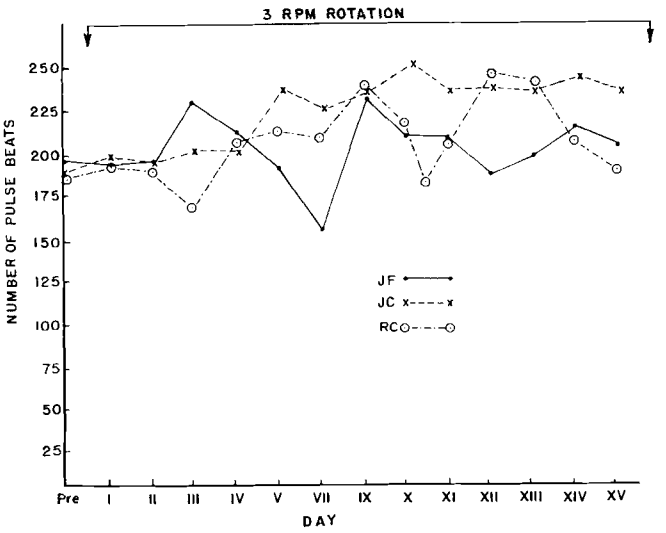

Fig. 4. Harvard step test—total pulse beats in four thirty-second intervals following the step test.

3) The Harvard Step Test described in detail by Brouha, *et al.*,[2] requires that a subject step up on a box 20 inches from the floor 30 times per minute for five minutes or until he can proceed no further; the subject's pulse is then taken at four thirty-second intervals. The intervals used in the present experiment were: 0 plus 30, 30-60, 90-120, 210-240. In addition, an oxygen mask was fitted with a sensor which in turn was connected to a single channel Sanborn recorder. The subject was requested to breathe normal ambient air through the mask which recorded his respiration by deflections in the recorder. Brouha, *et al.*, state that a subject's score reflects his physical fitness for hard muscular work.

Results of this test are presented in Figure 4. It appears that pulse rate increased during the second week. To a lesser extent, the same appears to be true for respiration. Because of increased efficiency of test administration, the entire testing schedule was concentrated into a shorter workday during the second week. However, even if the changes in pulse and respiration are not attributable to a more concentrated schedule or other experimental artifact, such changes are not necessarily indicative of physiological deficit.

4) The Graybiel-Fregly Posture Test [8] uses rails that are modifications of those originally used by Heath [14] in screening military personnel. In the present experiment only the two narrowest rails were used (1¼″ and ¾″). There were three trials on each of three tasks on the two rails: 1) walking heel-to-toe for five steps or until balance cannot be maintained with arms folded in front, 2) standing heel-to-toe for sixty seconds with eyes open or until the subject falls, 3) standing heel-to-toe for sixty seconds with eyes closed or until the subject falls. Score was the best two of three trials with a maximum score for walking 10 (steps) and for standing 120 (seconds). Subjects were given some practice on the rails prior to the static run.

Results of the Rail Tests are presented in Figures 5 and 5a and clearly reflect changes in performance with the onset of rotation and with readaptation to a static environment after rotation. By the fourth day the performance of all three subjects on the 1¼″ rail was equivalent to their performance prior to rotation. This in turn was superior to their performance in a static condition before the benefit of practice. Two of the three subjects required approximately eight days to reach their previous performance level on the ¾″ rail. Results of standing with eyes open on the 1¼″ rail ap-

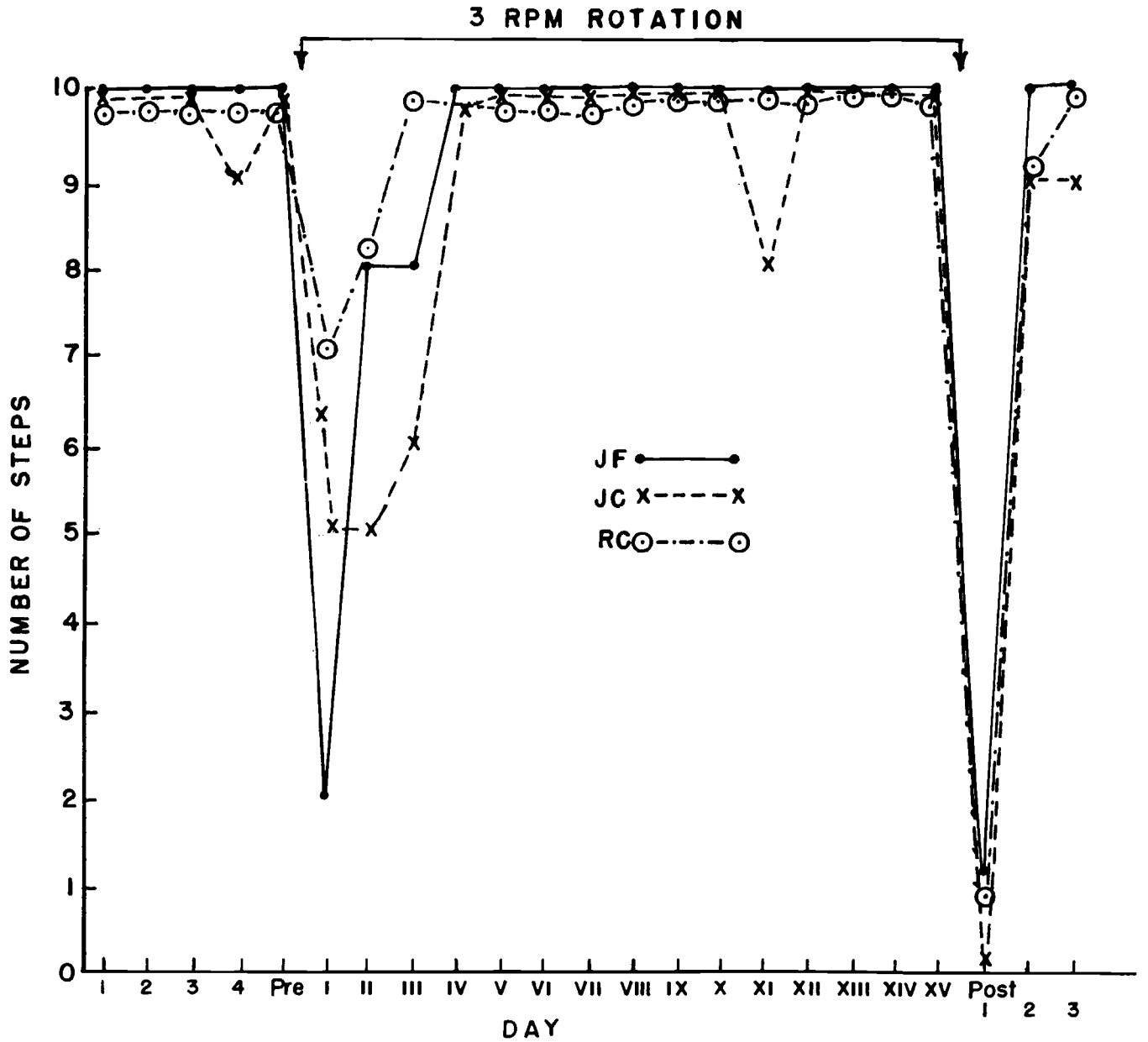

Fig. 5. Graybeil-Fregly posture test—total number of steps walking heel-to-toe on 1¼″ rail with eyes open.

proximate those of the Walking Test. Standing with eyes open on the ¾″ rail and with eyes closed on either of the rails showed variable results which were insufficient to show any adaptation effect during rotation or readaptation after rotation. After rotation, all performance on the rails declined and did not attain the maximum performance level until the afternoon of the third day of natural environment.

5) The Walking Test [17] requires the subject to fold his arms and walk heel-to-toe toward the center column from the periphery of the room and to return to the periphery. This test was then repeated with eyes closed. Each subject was scored on a five-point rating scale in unit deviations from his own norm prior to rotation. The deviation range is from 0 to 5 (no change, to inability to complete this task).

The Walking Test demonstrated a clear decrement in performance on the first day of rotation, with a gradual improvement through the first six days, after which performance attained the prerotation level (Fig. 6). This test was not given after the rotation ceased because of its similarity to the rail test and to economize on subject testing time.

6) The Past Pointing Test was introduced by Bárány (in Dorcus and Mowrer [4]) in 1911 and has long been used as a clinical index to the functional integrity of the vestibular apparatus and certain associated neural pathways. The subject was required to: a) blacken his finger with a grease pencil, b) fixate and point at a spot at eye level on a piece of graph paper, c) close his eyes, d) drop his arm, e) attempt to return to the target under four experimental conditions. The subject was given the following instructions: a) return to the target with straightened arm, b) return to the target in an arc to the right, c) tilt your head 45° to the left shoulder and return with straightened arm, d) tilt your head and bring your arm up in an arc, all with the intention of returning to the target. The head tilt was

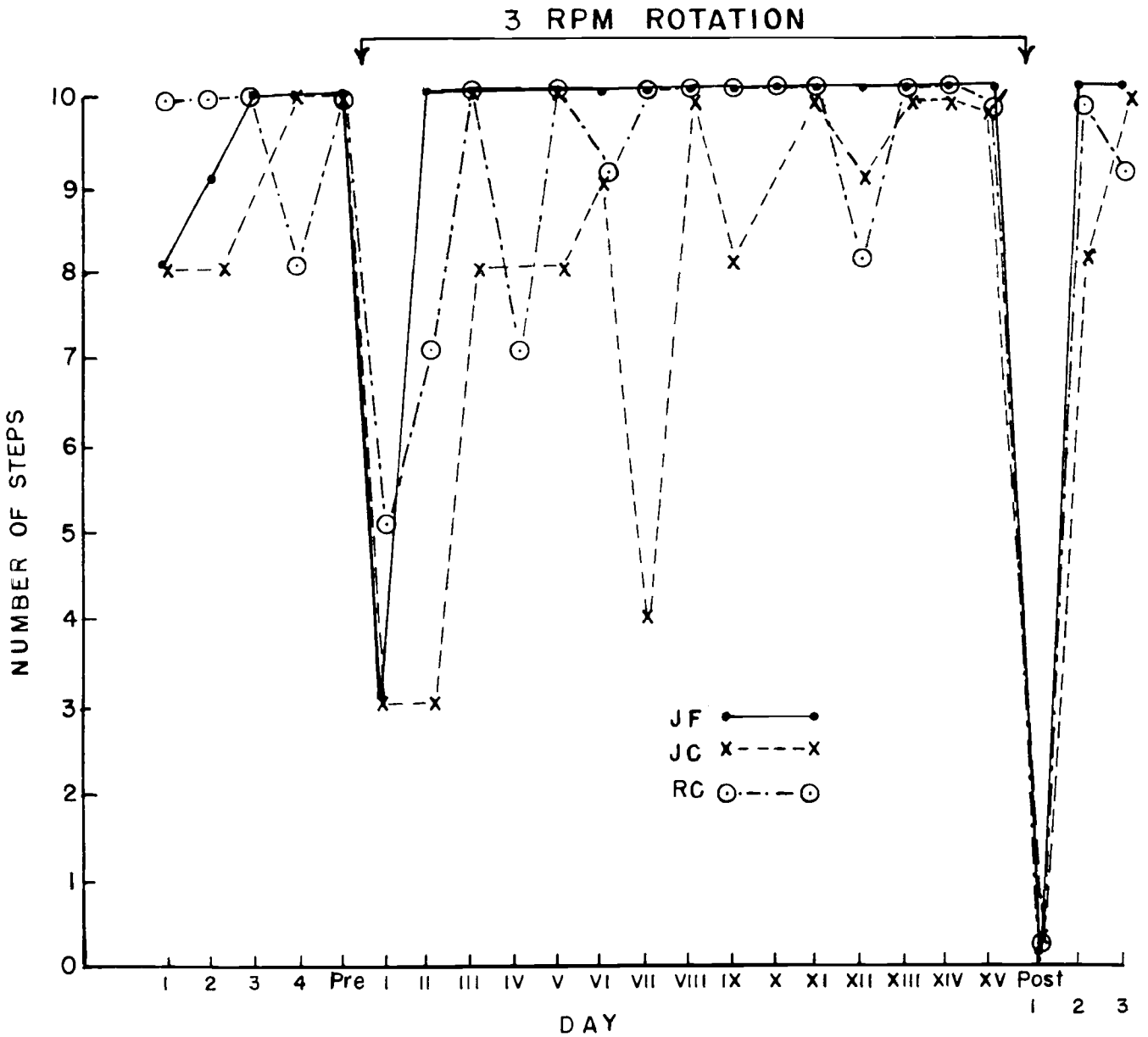

Fig. 5a. Graybiel-Fregly posture test—total number of steps walking heel-to-toe on ¾″ rail with eyes open.

employed to produce a Coriolis acceleration on the semicircular canals. The first procedure was repeated with a crayon attached to the foot (foot pointing). Each of the five procedures was administered five times and the score was the average distance deviation and its direction was identified. Knowledge of results was prevented by covering the recorded response before the eyes were opened.

The Past Pointing Test results were highly inconclusive due to the fact that there was no systematic shift from the static to the rotation condition. The inadequacies of this test had been commented upon by Dorcus and Mowrer [4] during conventional stimulation of the semicircular canal system by angular acceleration. Our results indicate that the test is inadequate even with the more disorienting stimulus produced by the Coriolis vestibular reaction.

7) Accommodation and Convergence tests were given. The method of limits was used in estimating the subject's visual accommodation. Convergence was measured by moving a pin point of light along a ruler held at the subject's nose and at a constant distance from the cornea in an otherwise darkened room until the eyes were observed to diverge. Scoring for Accommodation and Convergence was in centimeters.

Results indicate a gradual improvement in convergence throughout the two weeks of rotation, with no significant shift from the static run to the rotation period or from the rotation period to the postrotation static tests. The improvement in convergence over this period is to be expected on the basis of routine clinical findings, and hence should not be attributed to rotation exposure. In regard to accommodation, there was no shift in two of the three subjects; however, one subject who had poor accommodation initially showed a slight decrement in accommodation which continued throughout the fourteen-day period and also appeared to increase during the first day after rotation ceased. Results of these tests are shown in Figure 7. Unfortunately this gradual shift was not recognized until some time after the experiment was completed, and further post tests on this man are not available.

8) The Oculogyral Illusion [9] was observed during head movements while subjects were seated in a chair 3 feet from the center column of the SRR and while the room was rotating. The subject was required to make four discrete head movements; a) from upright to a position 45° toward the left shoulder, b) return to

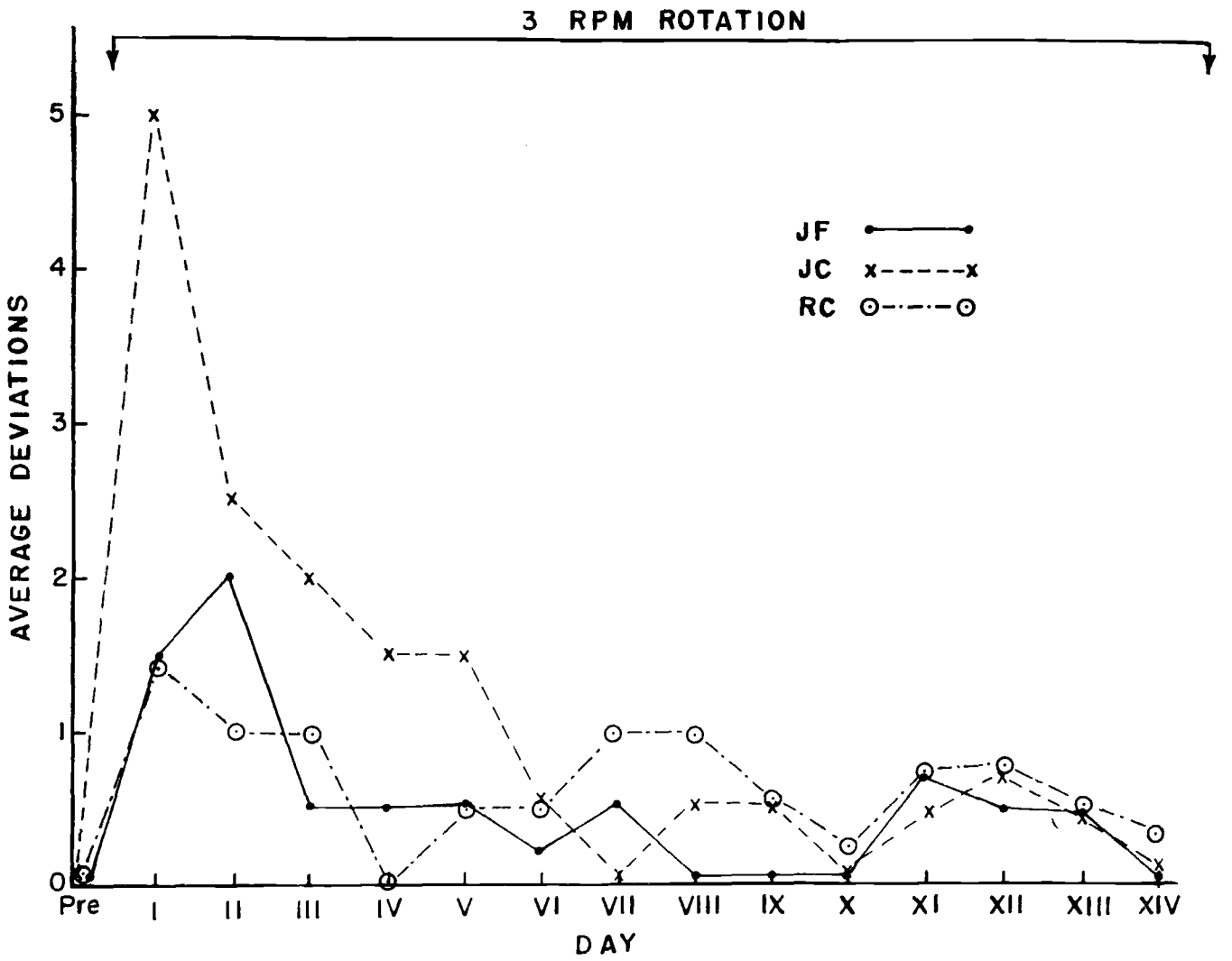

Fig. 6. Walking test—average deviation from the norm (O) walking heel-to-toe with eyes closed.

upright, c) 45° to right, and d) return to upright, and estimate the distance the visual target appeared to be displaced.

Results of this test were not meaningful. It is believed that the subjects were not sophisticated enough to make quantitative estimates of this complex illusion, an estimate known to be difficult [13] and particularly difficult in this experiment due to the low magnitude of the effect.

9) The Math Test, a simple tet of arithmetic computation, is composed of 560 simple items alternating addition, subtraction, multiplication, and division.[17] The subject was to work as quickly and as accurately as possible for ten minutes. In order to minimize practice effects eight different forms of the test were adminis-

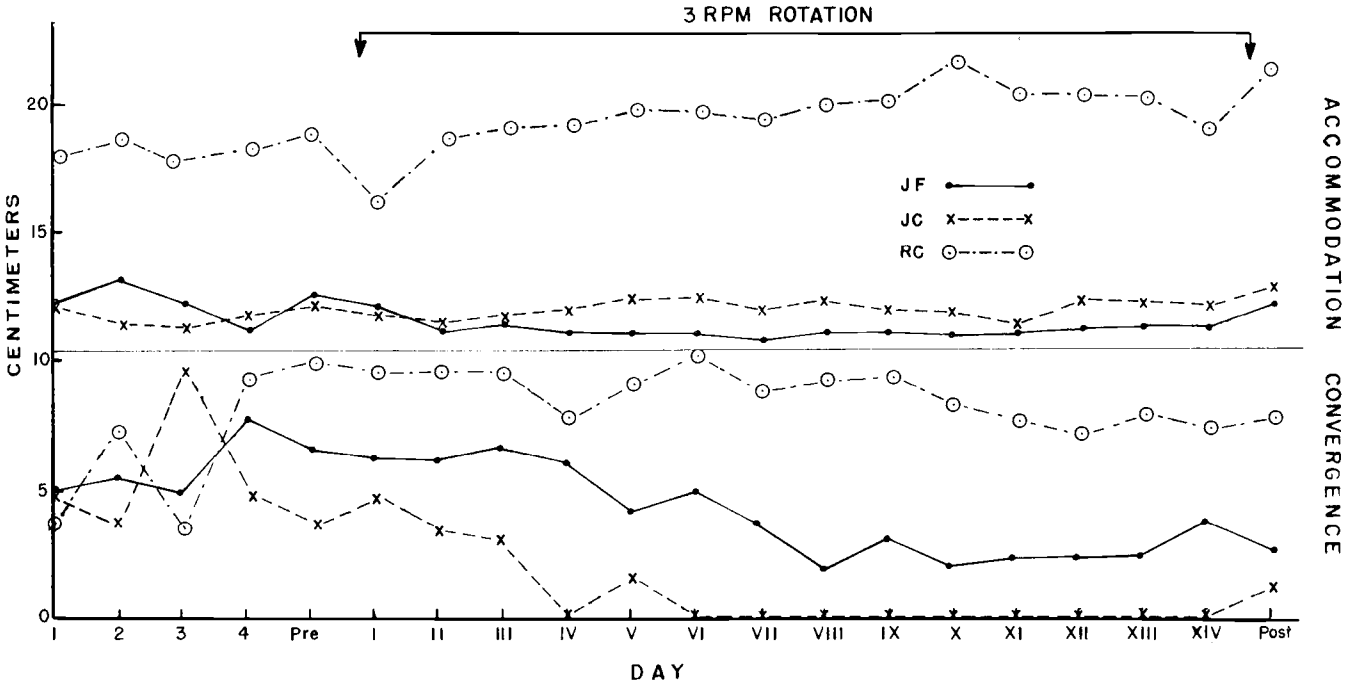

Fig. 7. Accommodation and convergence test—average accommodation (10 trials) and convergence (5 trials) in centimeters.

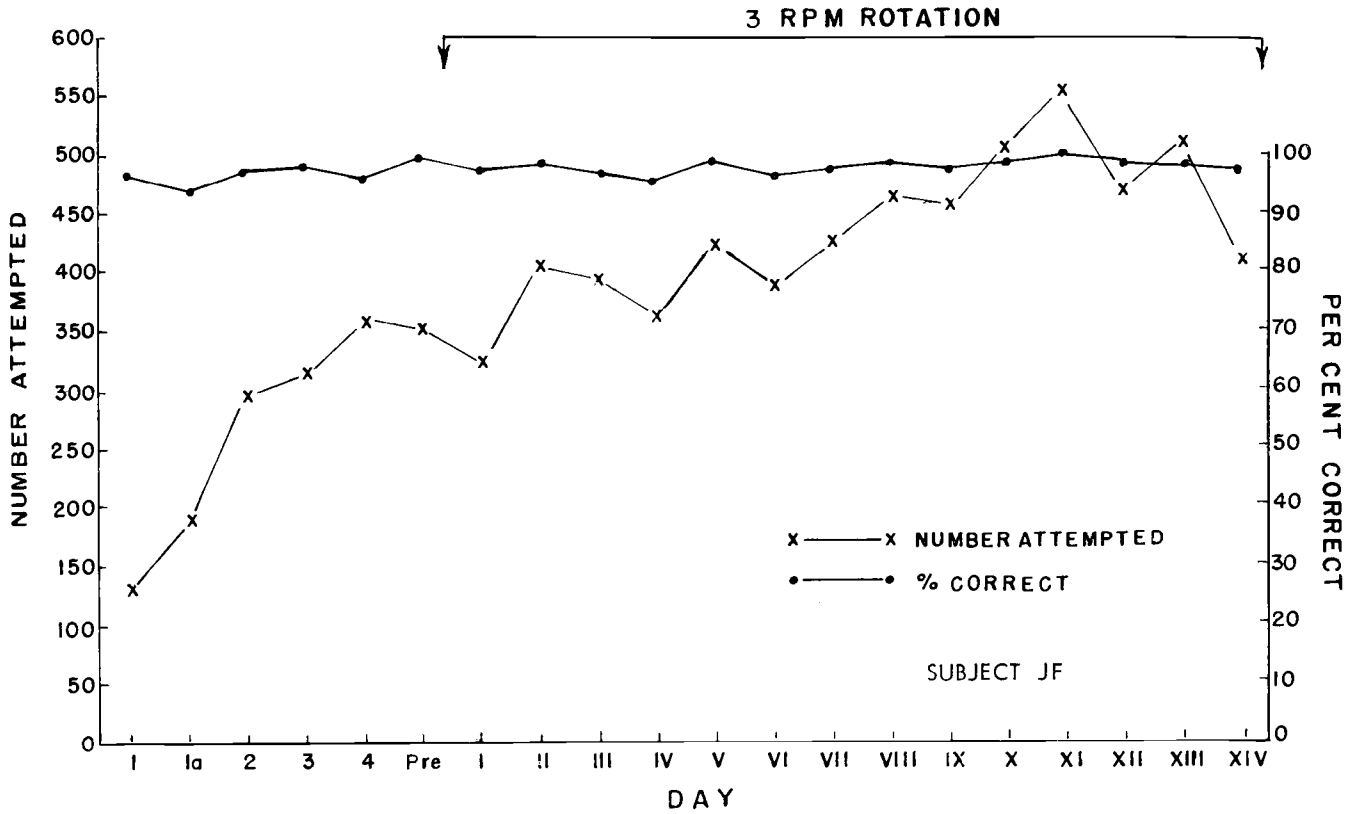

Fig. 8a. Math test—total number attempted and percent correct.

tered. Scores were total number attempted and per cent correct.

On the first day of rotation all three subjects showed a slight decrement in the number of problems attempted and in per cent correct (Figs. 8a, 8b, and 8c). This slight decline in performance may reflect a minor decrement in ability in this type of mental function as a result of the initial exposure to rotation. It will be

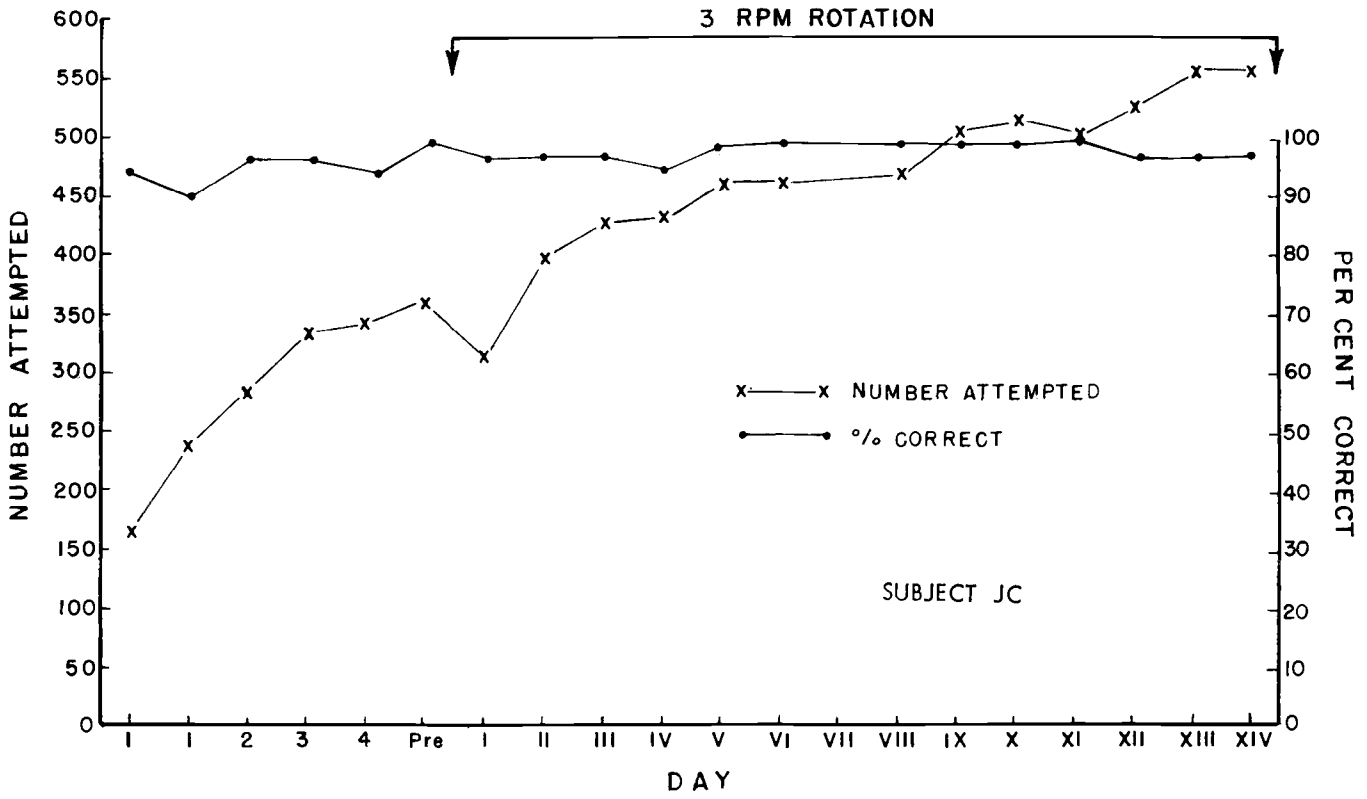

Fig. 8b. Math test—total number attempted and percent correct.

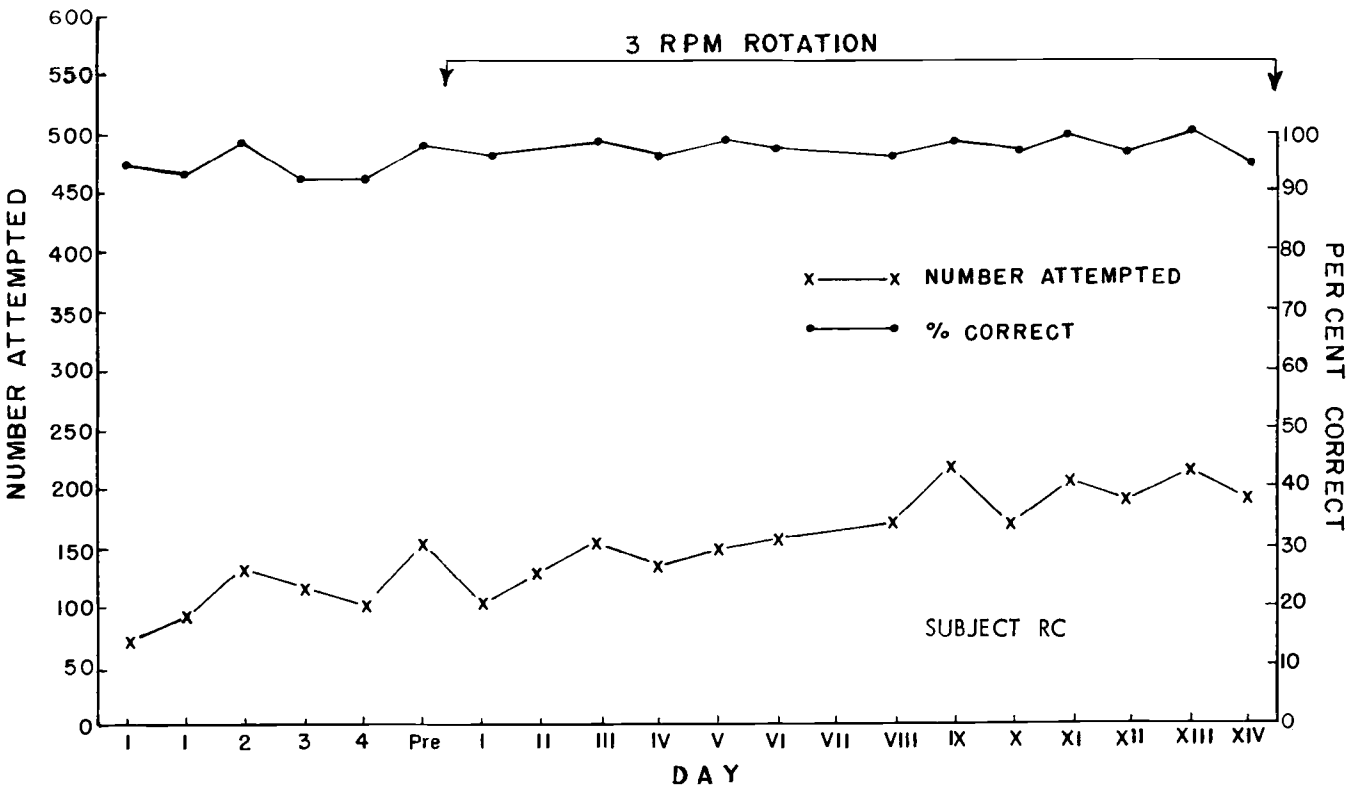

Fig. 8c. Math test—total number attempted and percent correct.

necessary to observe more subjects to confirm whether or not this shift is attributable to chance, but, irrespective of the outcome of further studies it is clear that, by the second day, performance returned to the level of the prerotation tests and continued to improve for the two-week period.

10) Electrocardiograms and blood pressure readings were taken immediately after the Dial Test which was used as a stressor. Five dials were placed so that the subject was required to rotate his head and body through different complex arcs in order to view the dial and adjust the dial indicator. At the conclusion of 20 sequences of five dials (100 settings) electrocardiograms and blood pressure readings were obtained with the subject inclined 75° from the horizontal plane on a tilt board. In previous experiments [3, 7, 9, 11, 17] the Dial Test was proven to be a stressor particularly when performed at higher angular velocities of the SRR. No indications of any changes in EKG or blood pressure were found before, during, or after the two-week rotation run.

11) The Achilles reflex was elicited with the subject kneeling on a platform and was recorded by means of a photoelectric cell aimed at a uniform white field (adhesive tape) on the subject's heel. The photocell signal was recorded by a Sanborn recorder. Records were examined for response delay as well as duration and intensity.

There was no change in latency between the stimulus artifact and the peak contraction. An apparent decline in the magnitude of the peak contraction was noticeable in the second week of rotation, but this is possibly attributable to change in recording technique and the force with which the reflex was elicited.[29, 30] This issue can only be clarified with further experimentation.*

12) The Weight-Lifting Test consisted of a heavy weight attached to a chain which ran over a sprocket to a handle on a table. The subject was instructed to brace his elbow on the table and "curl" (or lift) the weight rapidly until he could no longer produce a full excursion. Rotation of the sprocket was recorded on the Sanborn recorder and the score was the total number of hoists. This test was included as a measure of the subject's muscular stamina.

As shown in Figure 9, there was a gradual improvement in weight-lifting performance throughout the entire experiment. Hence, it appears that neither the commencement of rotation nor the readaptation period after rotation had any significant effect upon strength as measured by this kind of test. An apparent performance decrement in all three subjects on the first rotation day is probably attributable either to chance or to the fact that two Weight-Lifting Tests were conducted in the same day, one before and one after rotation started. The subject with the lowest score initially showed the least improvement throughout the two-week run, and this is the same subject who also showed the decrement in accommodation.

13) In the Audio Vigilance Test a 100 c.p.s. stimulus tone was mixed with broad-band noise at a signal-to-noise ratio of about 2.5 db. The listening condition was considered difficult unless the subject was fully attending. Each subject received a separate set of ear-

* That strength and reflex activity of the limbs might be affected by continual bizarre vestibular influx to the brain stem was suggested by the work of Gernandt.[6]

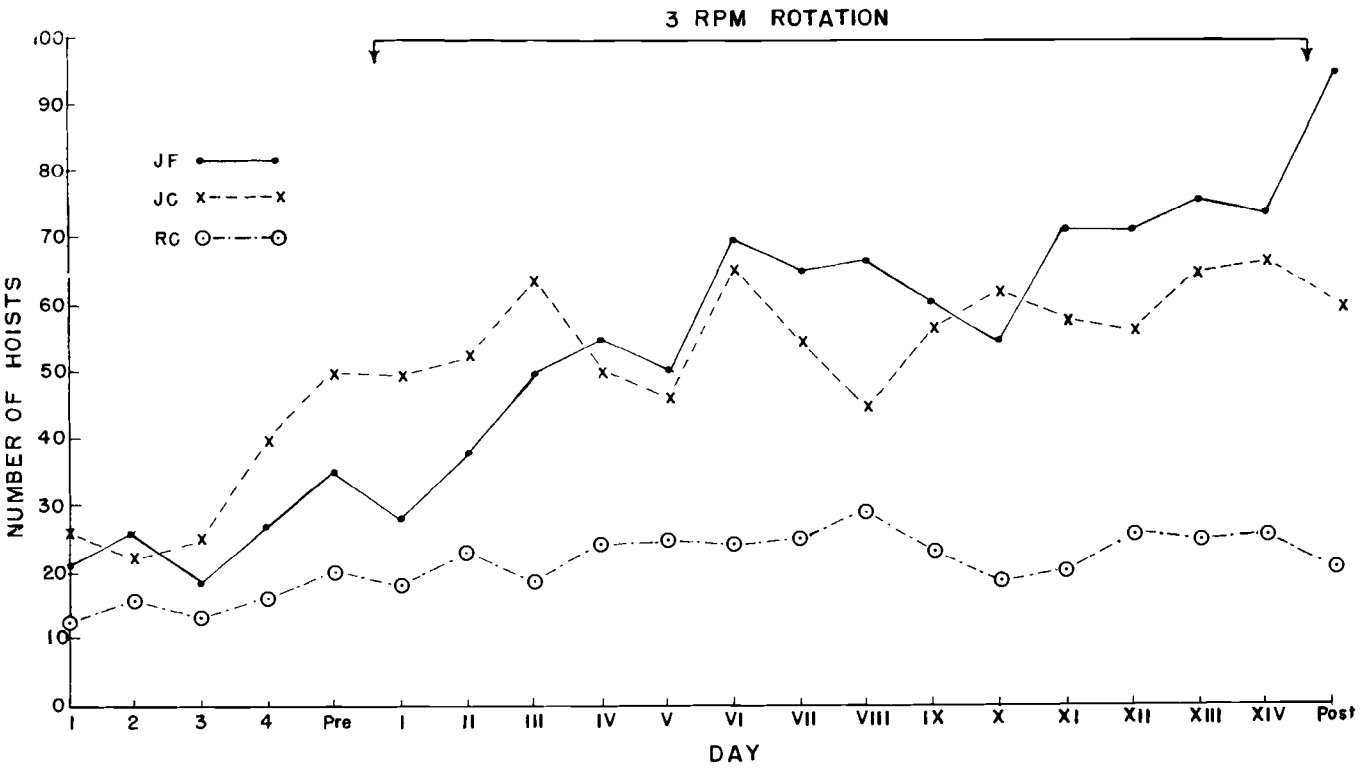

Fig. 9. Weight-lifting test—total number of hoists.

phones in order to minimize extraneous noise. The head set was attached to the external speaker of a Wollensak 1500 tape recorder. On a magnetic tape fifteen stimuli (of dots and dashes) were presented randomly during forty-five minutes (one within each three-minute interval). The score was the number of correct responses.

Results of the Audio Vigilance Test were highly variable, and no conclusions could be reached as to whether or not vigilance was impaired.

In addition, total urine output was collected and tested for the presence of Catechol amines and Cortico-steroids by methods described in Appendix A. There was no apparent effect of rotation on the results of Catechol amine and Cortico-steroids tests.

Room temperature, body temperatures, and body weight were recorded at regular intervals. Three of the four persons on board increased in body weight; the fourth individual maintained the same body weight throughout. Body temperatures remained within normal limits throughout the run. Room temperatures were maintained at a comfortable level throughout.

DISCUSSION

The principal finding of this experiment was that no serious disturbance of a psychological or physiological nature was encountered during the two weeks of rotation and during the subsequent recovery period. Either no change or a continued improvement was found in the Conceptual Reasoning Test, the Sequence Test, the Past Pointing Test, Weight-Lifting Tests, and the Accommodation and Convergence Test. Also there was no indication of any important changes in EKG, blood pressure, or respiration before and after stress during rotation.

The Math Test gave some evidence of a deficit during the first day of rotation. Although the decrement in performance was slight and the recovery took place by the second day of rotation, there are several reasons for careful consideration of this apparent temporary deficit. First, there have been a number of instances in which on-board experimenters have reported periods of apparent confusion. This has been particularly evident at higher angular velocities of the SRR. Second, if this effect is due to rotation, it occurs at a particularly critical time, namely, within the first day of exposure, a period which would presumably be of importance in establishment of an orbiting rotating space vehicle. Further systematic observation should be carried out.

The Rail Test and Walking Test showed great changes with the onset of rotation. There was a considerable deficit in these abilities with the onset of rotation followed by improvement in performance which eventually even surpassed performance before rotation commenced. Initial decrements in this kind of performance were to be anticipated from previous experiments and from an analysis of the conflicting sensory information which is presented in this unusual environment. For example, movement in a straight line relative to the floor of the room is actually movement in a curved path over the earth. Hence, the visual information conflicts with the proprioceptive information from the muscles and joints as a person attempts to move within the room. In addition to this, there is a gradient of centripetal acceleration which is detectable even though the greatest centripetal acceleration (at the maximum radius of the room) is of very small magnitude. These are seriously compounded by misleading information from the semicircular canal system whenever the head is tilted relative to the plane of rotation. The conflicting situation present here is analogous to that encountered in the inverted lens experiments.[5, 15, 18, 19] In the latter experiments visual information is distorted and made to conflict with normal proprioceptive and vestibular information. In the present experiments visual information about spatial relations within the room is essentially accurate, but locomotion within the room is accompanied by conflicting proprioceptive and vestibular information. As adaptation ensues, the intention involved in the movements permits learning of anticipated sensory conflicts from the proprioceptive and vestibular systems which apparently gradually results in a CNS reorganization. Within a few days, walking and all movements are made without difficulty and without apparent sensory-motor disturbance. Upon cessation of rotation this new state of adaptation is now a source of difficulty. With movements of the head and body in the normal earth environment, the expected proprioceptive and vestibular information[16] which was learned on the room is no longer elicited. (As has been shown in previous experiments[11, 12] these movements now elicit reflex activity and sensory events directionally opposite to reactions which occurred soon after the beginning of rotation.) With time these compensatory reactions appropriate to a rotating environment dissipate, and this period is analogous to the recovery period required after the removal of distorting visual lenses. Although this period of readaptation produced rather severe effects in past experiments[3, 9, 11] at higher RPM's in the present experiment all subjects were able to walk reasonably well and to perform all the specific tests, other than the Rail and Walking Tests, without any apparent effect. In the Rail and Walking Tests, the effects were quite apparent and marked, but it is to be noted that these tests require considerable skill and accuracy in walking and are normally difficult. Hence, any task which places any great demands upon postural equilibrium after a period of prolonged exposure to rotation could be affected adversely, but tasks requiring normally easy locomotion probably would not be seriously disturbed. Likewise, it is possible that any maneuvering in a vehicle which imposes unusual acceleration not encountered in a rotating environment might lead to less than average ability in maintaining control.

GENERAL COMMENTS

It is not possible to simulate perfectly in earth laboratories the rotating environment proposed for orbiting space stations. In an orbiting space station the direction of the artificial gravity vector would lie within the plane of rotation, and the individual would walk in this plane. On earth the direction of gravity is perpendicular to the plane of rotation of a vertical-axis rotat-

ing device.* Hence, it is particularly important to understand the manner in which the canals are stimulated when a person moves about in a rotating vehicle to provide a sound basis for estimation of effects in rotating space vehicles. Several articles have provided an analysis of events within the semicircular canal system during this kind of stimulation.[1, 13, 22, 26, 28] It is clear from these analyses that bizarre semicircular canal stimulation of the kind produced on earthbound rotating structures will occur in the rotational environment of a space station in that conflicting information from the semicircular canals, otoliths, visual and proprioceptive systems will be present. It is also clear from these analyses that the intensity of the bizarre information from the canals will be directly related to the rate of rotation of the space platform. Hence, although bizarre sensory patterns are not identical in the two situations, they are quite similar in nature, and there is a sound basis upon which to estimate from one situation to the other.

Although four men on board the room, three subjects and one experimenter, remained together night and day for more than two weeks, no problems from confinement were encountered. Possibly this is attributable to the constant availability of communications through a public address system and the outside experimenter entering once a day. Probably more important were instructions to subjects concerning the importance of their participation, and to ". . . assume the attitude of an astronaut and make the run without looking for personal difficulties." In addition, the subjects had television on board, were permitted to view favorite programs at night, and were aware of receiving news coverage in various media, which added a spirit of adventure to the experiment.

Many conveniences were made available to these subjects which would not be available to the space traveler. For example, subjects were allowed to eat food of their own choosing, including steak, pies, and cakes, as long as the foods were considered healthful. There was adequate room for exercise which permitted the subjects to actually improve on all of their strength tests. These factors were purposely varied from the restricted conditions which the astronauts will face in their first lengthy adventures into space in order to test the effects of rotation without side effects from restricted movement, unusual diet, et cetera.

One of the main problems which remains to be solved in regard to rotating space stations is the problem of transfer of habituation from one acceleration environment to another. It is clear, even at 3.0 RPM, that the habituation which takes place in this environment can produce minor disturbances upon returning to a normal earth environment. The magnitude of effects that will be produced by putting a person in a less stable environment after adapting to 3.0 RPM remains to be established by further experimentation. It will be a matter of practical importance to determine whether or not there is some program of acceleration exposure which will habituate a person to a rotary environment and also permit him to return from the rotary environment without the disturbing transfer effects which normally follow this exposure.

* If rotation rate is increased to make the resultant gravity and centripetal acceleration lie near the plane of rotation, then the greatly increased resultant G confounds and precludes adequate study of the subtle but potent effects of bizarre sensory stimulation. An arrangement like a Ferris wheel could be used to keep the subject and the gravity vector in the plane of rotation. However, if the carriage were freely pivoted to keep the person upright relative to gravity, then the counterrotation of the carriage would cancel the Coriolis vestibular effect. Conversely, with carriage locked relative to the wheel, the person would sometimes be inverted relative to gravity.

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APPENDIX A

Measurements of Catechol Amines and Corticosteroids

1. The amine and corticoid measurements were made on 24-hour urine samples which were stored in ice at pH 1. The samples were collected in two portions and then combined just before the determinations were started.

2. Free and conjugated corticoids were done by the method of Kornel.* Epinephrine and norepinephrine were determined by the method of Crout.#

3. Three test periods were used: (a) a 3-day period during which the men lived in the room while it was stationary, (b) a 14-day period following (a) during which the room was rotated at 3 RPM, and (c) a 1-day period similar to (a) after the rotation was stopped.

4. Variations in free corticosteroids, conjugated corticosteroids, epinephrine, and norepinephrine in the urine were plotted out throughout the course of the experiment, with the exception of two or three points. All measured values were within the limits found in normal urine.

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