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STUDY OF PHYSIOLOGICAL AND BEHAVIORAL RESPONSE TO TRANSITIONS BETWEEN ROTATING AND NONROTATING ENVIRONMENTS

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16. Abstract

Future manned spacecraft may be provided with artificial gravity although working areas with a weightless environment may also be provided. Transition between these two environments, which may be required during the course of a mission effectively represents transition between a rotating and nonrotating environment. The frequency and rate of such transition will influence the psychophysiological responses of man. This report examines abrupt transfers between such rotating and nonrotating environments on the physiological and behavioral responses of man. Five subjects were tested using rates of rotation up to 5 rpm.

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STUDY OF PHYSIOLOGICAL AND BEHAVIORAL RESPONSE TO TRANSITIONS BETWEEN ROTATING AND NONROTATING ENVIRONMENTS

By James F. Brady
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SUMMARY

Future manned space mission objectives emanating from NASA and aerospace industry studies have emphasized the probability that future spacecraft such as space station and space base may require both artificial-gravity (rotating) and zero-gravity (non-rotating) compartments within the same vehicle. Such an inertial mix would necessitate frequent transfer of crews and logistics material across the rotating/non-rotating interfaces encountered at various sites within the vehicle system. If abrupt transitions of crew members between the artificial-g and zero-g environments produced significant psychophysiological disturbances, special provisions — with their associated penalties — for staged crossing procedures would be required to passively transfer personnel at an acceptable rate. This study was conducted to provide data on the performance and physiological effects of abrupt transfers of habituated subjects across rotating/non-rotating interfaces.

Five subjects, psychophysiologically representative of the personnel that would man a large, mixed-inertial station, were tested for ten 8-hour days, using the same qualitative inertial profile and activity schedule — but different rpm — each day, covering a range from zero to five rpm. Testing was conducted using the Manned Rotating Platform (MRP), a 12 by 18 by 7 foot room mounted on a 22 foot diameter rotatable platform. The platform is supported by air bearings and is concentric with a central 6 foot diameter portion that simulates a zero-g hub. On each test day, the five subjects repeated the same test battery six times — the first time with the platform stationary to provide a static baseline, the second and third repetitions with the platform rotating, the fourth and fifth repetitions with the platform static, and the last with the platform rotating. The first two rotating repetitions and last two static repetitions were each separated by an exercise, the Sequential Head Turn Test, designed to produce complete vestibular habituation to the particular inertial mode. Complete vestibular habituation was determined by use of the Sharpened Oculogyral Illusion Test. These two pairs of repetitions were each also followed by an abrupt active transfer of subjects into the alternate inertial mode.

The responses of the subjects to the Sequential Head Turn and Oculogyral Illusion tests demonstrated that the head turn exercise was successful at all test conditions in producing complete vestibular habituation in all subjects and that the higher the rpm level used on a given test day the greater was the number of head turns required to effect habituation. Of the performance measurements — the Floor Ataxia Test Battery, the General Dynamics Response Analysis Tester, and the Langley Complex Coordinator —, only the Floor Ataxia Test Battery demonstrated significant decrement following transfers. One of the Floor Ataxia tests — "Walking with Eyes Closed" — was significantly degraded at 4 and 5 rpm. Another, which measured the time required for a subject to spatially orient and stabilize himself in standing position with eyes open, showed decrement starting with 3 rpm. These Floor Ataxia Tests, although sensitive indicators of subjects' response to inertial changes in the test environment, have questionable value relating to actual performance in an artificial gravity environment. In a real artificial-gravity environment at a location where the artificial-gravity level is sufficient to enable free walking, the subject's long body axis would be perpendicular to the axis of rotation rather than parallel to it as was the case in this test. In an actual artificial-g situation, therefore, postural disturbing forces are basically along the long body axis and may be less critical to postural balance than when acting transverse to the long body axis as was the case in this present study.

The comprehensive array of physiological testing was unremarkable in findings, suggesting only that the anxiety of anticipating each day's dynamic testing was more stressful than either rotation or transfer. Only slight malaise was experienced due to motion during the study. Subjectively, the consensus was that abrupt transfer into non-rotation was the most disturbing but non-rotation more readily adapted to than rotation. The afternoon's abrupt transition back into rotation was not considered to be as disturbing as the morning's gradual introduction to the same rpm level.

There is no indication — on the basis of comparison with the results of previous studies — that abrupt inertial transfers within this rpm range are more degrading to physiology and performance than are gradual transfers of short (minutes) duration. There is also no indication from the results of this study that abrupt active transfers of habituated personnel in either direction across the inertial interface of operational systems using spin rates as high as 5 rpm would not be acceptable if one assumes that a subject's response to a given acceleration or Coriolis force, when superimposed upon a background of zero g in space, is quantitatively and qualitatively the same as the subject's response to these same forces superimposed upon the background of one g in an earth-based environment. A battery of ground-based tests of crew responses in simulated artificial gravity, if repeated in a real artificial-gravity environment in space, would determine the extent to which ground artificial-g test data can be confidently applied to space planning.

NOMENCLATURE

ANOM	Analysis of Means
ANOV	Analysis of Variance
BP	Blood Pressure
FATB	Floor Ataxia Test Battery
GDCA	General Dynamics Convair Aerospace
HR	Heart Rate
LCC	Langley Complex Coordinator
MRP	Manned Rotating Platform
NAMI	Naval Aerospace Medical Institute
NR/SD	North American Rockwell Space Division
OGY	Oculogyral Illusion Test
RATER	Response Analysis Tester
SEC	Standing with Eyes Closed
SHTT	Sequential Headturn Test
SUT	Set Up Time
WEC	Walking with Eyes Closed

CONVERSION FACTORS

To convert from the customary units of measurement contained herein to their preferred (SI) counterparts:

FROM U.S. CUSTOMARY UNITS	TO INTERNATIONAL SYSTEM OF UNITS (SI)	MULTIPLY BY*
Btu/hr	watts	0.292875
calorie	joule	4.184
degree (angle)	radian	0.01745329
Fahrenheit (temperature)	Kelvin	K = (5/9) (F+459.67)
foot	meter	0.3048
hours	second	3600.0
inch	meter	0.0254
lb_f	newton	4.4482216
ml	$meter^3$	0.000001
mm Hg	$newton/meter^2$	133.3224
mph	meter/second	0.44704
rpm	radians/second	0.1047
weeks	second	598800.0
years	second	31536000.0

*Reference NASA SP-7012.

SECTION 1

INTRODUCTION

Advanced concepts for future long-duration manned space missions have emphasized the possibility that these future spacecraft will contain both zero-gravity (non-rotating) and artificial-gravity (rotating) compartments. These requirements are generated by provision of zero-g volumes for space research and manufacturing operations, a zero-g hub for crew and cargo transfer to and from a logistics shuttle vehicle, and by provision of rotating artificial-gravity compartments for crew quarters and spacecraft operations. These operations necessitate frequent transfer of crew and logistics material across the artificial-g/zero-g interfaces encountered at various sites within the space vehicle system. If abrupt transition of crew members between artificial- and zero-g environments produced significant psychophysiological disturbances, special provisions for staged crossing procedures would be required to carry a crew member through the angular velocity change required to spin down to zero-g or spin up to artificial-g at a physiologically acceptable rate. Such requirements raise pertinent questions that should be answered prior to the initial artificial-g station design.

These questions concern problem areas which may be categorized as to their phase of occurrence:

1. Transfer Phase — the immediate problems of effecting the physical transfer across the inertial interface.

2. Zero-G Phase — crew function problems in the nonrotating environment that may be related to prior rotational habituation.

3. Artificial-G Phase — crew function problems in the rotating environment following return from a nonrotating environment and related to the stay-time in that precursive inertial mode.

Under each category, problem areas in turn may be considered as to their pertinence to personnel safety and/or mission success, with the latter factor being separable into crew and other subsystems, performances, and operational costs.

The transfer phase poses problems of personnel safety. How does the individual, encumbered or unencumbered, effect the physical transfer between the rotating and non-rotating environments such that he is in harmony with the relatively moving structural elements and maintains personal orientation and equilibrium to the extent that mechanical trauma are avoided? And how can he, from the performance standpoint, effect this transfer, either alone or in collaboration with other crew members, to move cargo items of varying sizes, shapes, consistencies, and mass distributions across the interface in an efficient manner?

1.1 BACKGROUND

Ground-based research has effectively documented the psychophysiologic effects of activities in the rotating environment and in either the nonrotating or rotating environmental mode following gradual transfer across the interface from the obverse mode.[1,2,3,4,5] The magnitude of the effects for the nominal subject tends to be directly related to three factors: (1) rate of rotation, (2) duration of habituation to the preceding mode, and (3) rate of transfer across the interface.[1] Extrapolating from these transfer rates to the abruptness of a square-wave transfer would suggest that considerable stress might be experienced.

Human response to a rotating environment is characterized by three processes related to duration of exposure and tending to occur in the following order.

The first consists of a loss of attention corresponding to the reduction in novelty of a repeated stimulus. It is a very labile phenomenon, which may fluctuate in significance as the subject's arousal varies with slight changes in the stimulus or with extraneous or cognitive alerting events. It is stimulus-bound and is manifested within minutes of rotational exposure, following a few repetitive environmental interactions.

The second process consists of a conditioned reaction which competes with the subject's normal, but during rotation, conflicting response. It is not a labile effect, and with sufficient environmental interaction it can completely nullify all untoward subjective and vestibulo-ocular responses. It does, however, require many stimulus events to complete this adjustment. Moreover, its development is also stimulus-bound to a homologous pattern of vestibular, visual, and proprioceptive cues. A rapid transfer into a nonrotating environment may be characterized by the rotationally habituated subject becoming disoriented and possibly ill due to the conflicts produced by the then inappropriate compensatory reactions.

The third process is a general, chiefly centrally mediated, suppression of conflicting response not only to homologous but also to some analogous patterns of stimulation. This process is not labile, requires substantial environmental interaction of a voluntary and variegated quality for development, provides significant reduction of inappropriate response, and tends to persist long after the rotational exposure has ended.

Studies performed at the Naval Aerospace Medical Institute and General Dynamics Convair Aerospace Division[2,4] were the first to demonstrate that the previously noted psychophysiologic problems associated with substantial angular velocity changes could be attenuated by slowing the rate of such changes. Considerable work in the refinement of rpm step sizes and personnel activity per level has subsequently been conducted at NAMI to maximize the rate of permissible angular velocity change.[6,7,8] Prior to this present study, however, the potential problems involved in executing very abrupt, "square wave", angular velocity changes remained essentially uninvestigated. A precursive literature search disclosed only one such consideration, a small company-funded pilot study at GDCA. The need for empirical data in this area was underscored by several participants in the panel discussion concluding a recent national meeting considering weightlessness and artificial gravity.[9]

1.2 CURRENT STUDY

The problematical implications of the above considerations relative to the design and operation of future manned space stations and bases, as they are presently envisioned, include these: As the habituation of a crewman to rotation will be complete and consist at least in part of the compensatory responses discussed above, what will be the impact of these responses following rapid (especially square-wave) transfer of such an individual into the zero-g hub? Will the man's psychophysiologic decrement be such that the transfer rate will have to be effectively slowed by providing a variable spin device between the two volumes or by prehabituating the man on a short-radius centrifuge prior to his transfer into the zero-g volumes? In considering the probable effects of rapid transfer of a rotationally habituated subject from rotation to nonrotation, it must be emphasized that the complete and abrupt removal of all background accelerative forces from the subject upon transition into true zero g may provoke different psychomotor responses than if the same transfer had been made into Earth's one g. Likewise, transition from zero g to rotation in space may evoke different responses than transition from Earth's g to rotation. A ground-based study of effects of transition between rotating and nonrotating environments, if faithfully repeated in a space vehicle, would assess these differences and provide guidelines for applying ground test data to space systems design.

Whatever the magnitude of the interface transfer effects within the range from incapacitating to non-significant, they require delineation by ground-based research early in the development program of the space station/space base. It should be determined as soon as possible what inertial interface transfers do to the functional capabilities of habituated subjects so that tolerance limits and optimization procedures can be elaborated and converted into useful design criteria. The current study was designed to provide answers to these questions.

1.2.1 STUDY OBJECTIVES. The first objective of the current study was to use ground-based tests to determine:

1. The nature and intensity of the untoward effects on the psychophysiology and performance of the rotationally habituated individual following a square-wave transfer from rotation to nonrotation.

2. The same information for function upon square-wave return to rotation after a nominal zero-g (nonrotating) sojourn.

A second objective was to select ground simulation test environments and experiment designs which would yield data for maximum relevance to manned space operations and which would generate guidelines for future groundbased and flight test requirements.

1.2.2 TECHNICAL APPROACH. This study was designed to measure the physiologic and behavioral changes resulting from timed transitions of rotationally habituated subjects between rotating and nonrotating environments. Transitions were made with the rotating portion of the test environment at from 2-5 rpm to encompass the range of spin rates currently considered for space artificial gravity systems operations. Emphasis was placed upon demonstrating full habituation of subjects at each rotation rate prior to transitions. The study was designed to demonstrate the acceptability of abrupt zero-g/artificial-g inertial changes, and in so doing define the requirements for optimization through improved interface design, crew training, and task procedures and scheduling. The results of this study were meant to relate in a meaningful way to the transfer event itself, and also to crew functions that might be performed during the adjustment periods precipitated by the transfers. This study was planned to initiate the definition of the duration of these adjustment periods and man's functional capabilities during their interim. The tests were performed in Convair's groundbased artificial gravity system simulator equipped and instrumented for physiologic and performance monitoring of subjects.

It had been previously demonstrated that vestibular habituation to rotation transfers fully from the horizontal mode of subject orientation (long body axis radial) to the vertical mode (axis with the normogravitational vertical) and vice versa.[10] Therefore, it was possible to habituate subjects to rotation while they were in the vertical mode and measure the effect on their degree of habituation retention of subsequent transfers to and from, and their interim stay in, the static (simulated zero-g) hub, and use this data in predicting responses of analogous trans-inertial interface activities for personnel in the horizontal mode (the usual space station orientation).

SECTION 2

METHOD

Convair's Manned Rotating Platform was instrumented as required for safety and performance monitoring of subjects during exposure to transitions between simulated zero-g/artificial-g space environments while executing tasks chosen for their relevance to realistic crew requirements for space operations. The interface between zero-g and artificial-g space environments was simulated by the junction between a six-foot diameter nonrotating (zero-g) central hub and a twenty-two foot diameter rotating (artificial-g) platform. Convair research personnel were trained to serve as subjects. The study was designed to encompass a range of angular velocities (2 to 5 rpm) currently under consideration for space artificial gravity systems design.

2.1 EXPERIMENTAL DESIGN

The test design relates to an operational model involving three inertial transition events as reflected in the inertial profile depicted in Figure 1, with T_n indicating the battery of tests which the subjects repetitively performed, and H_n indicating the headturn sequence used to habituate the subjects to each inertial environment. Representative subjects were trained to an asymptotic level of execution in the selected performance tasks and their physiological baselines established. Then, at each rpm ranging from 2 through 5, they were exposed to the indicated inertial profile, with the transitions T_1-T_2, T_3-T_4, and T_5-T_6 simulating operational crew transfers from, respectively: long-duration nonrotation (e.g., groundbase) to artificial-g, from artificial-g to zero-g, and from a nominal sojourn in zero-g back to artificial-g. The repetition of the performance battery and physiological monitoring before and after each transition provided indices of its physiological and behavioral effects on personnel, with the habituation headturn sequences being used to accelerate the psychophysiological adjustment to each inertial environment.

In selecting the performance tasks and parameters for physiological monitoring, two primary constraints were used: one, to limit the time-duration of the battery performance to approximately one hour so that the total test day — including subject preparation and cleanup — would not exceed eight hours, and two, to choose tasks that were relevant to immediate post-transfer operational requirements. In regard to the second constraint, task selection was predicated on the premise that self-locomotion to duty station would be required immediately following transition, succeeded by either a display/control task involving headturns but simple perceptual motor responses or a more sophisticated psychophysiological task requiring cognition and complex coordination.

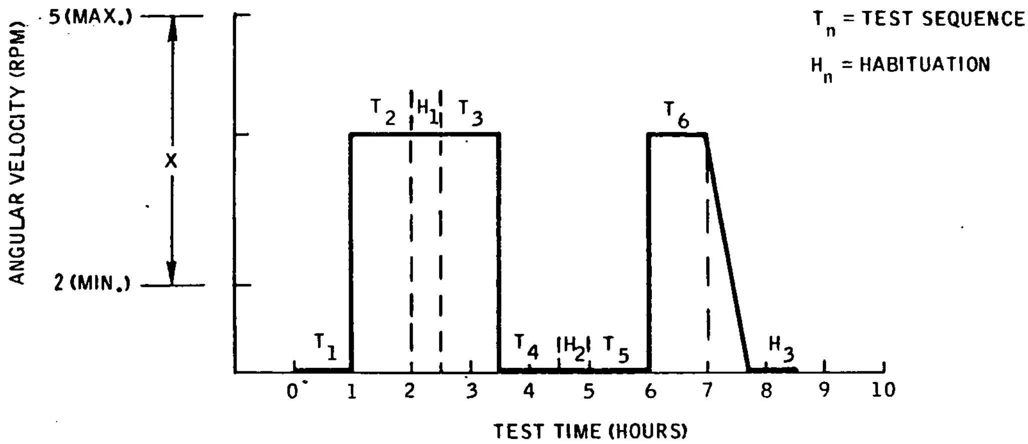

Figure 1. Daily Inertial Profile.

2.1.1 PERFORMANCE MEASUREMENTS. The test battery was designed around the tasks selected to determine capabilities for performing self-locomotion, perceptual motor responses involving headturns, and combined cognition and complex coordination. The tasks chosen to measure these functions were, respectively, a Floor Ataxia Test Battery, the Response Analysis Test, and the Langley Complex Coordination Test.

Floor Ataxia Test Battery. The use of elements of the NAMI Floor Ataxia Test Battery (FATB) was recommended for several reasons: (1) its precise constraints make it more quantifiable and more sensitive to equilibration dysfunction than conventional locomotion tasks; (2) it makes available a large body of normative and experimental data against which to compare spacebased results; and (3) it presents some advantages over the NAMI Rail Ataxia Test Battery, with which it shares the above virtues, in that a rail is not required for conduct of the test, and the hazard of falling when balance is lost is thus reduced.

The equipment items required are the sound equalizer and floor grid shown in Figure 2. The sound equalizer consists of the ear pieces of a stethoscope integrated by a plastic tee, with the tee open to the environment. This item is worn by the subject during the testing, to distribute all sounds, from whatever direction, symmetrically to his right and left ears. This prevents tropic imbalance due to asymmetric sound. The floor grid consists of a five foot by five foot area marked off in six inch squares, the walking axis of the grid is oriented radially.

The tests making up the battery are performed with the subject facing radially outward in the stringent body position of arms folded against chest, feet (shoes on) heel-to-toe and tandemly aligned, and body erect or nearly erect. Administered in the following order, they consist of:

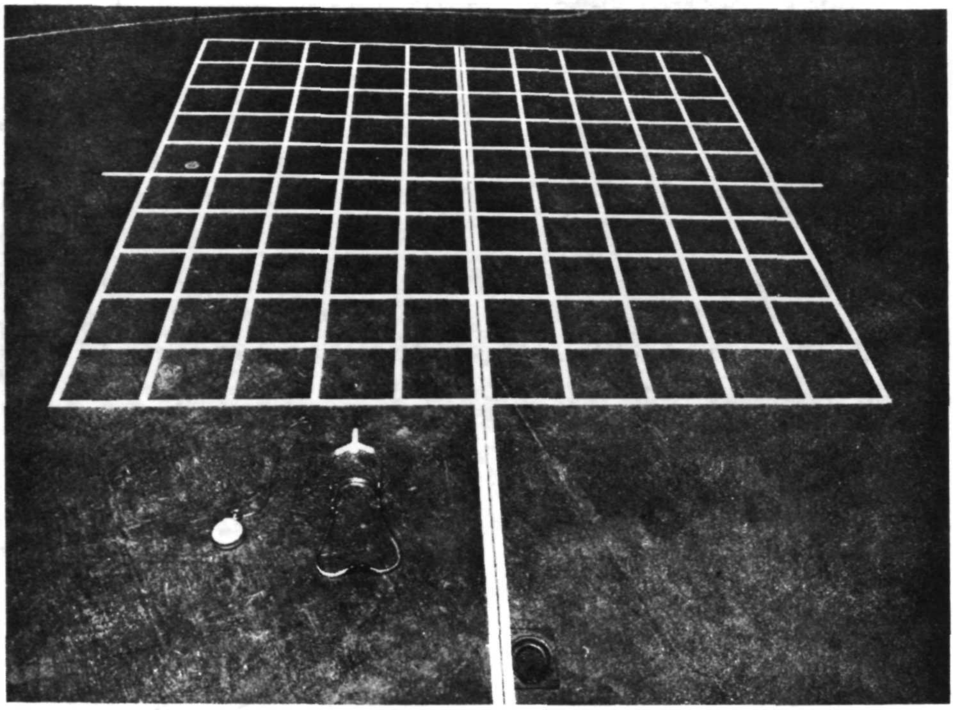

Figure 2. FATB Equipment.

1. Standing With Eyes Closed (SEC) — Standing with eyes closed for a period of 60 seconds.

2. Walking With Eyes Closed (WEC) — Walking five steps in a straight line.

Standing With Eyes Closed (SEC). Three trials are administered to each subject during a single test repetition with 60 seconds being the criterion score. Subjects are permitted to close their eyes at any time after assuming the correct body and foot positions. The best two out of three trials are used to score performance.

Walking With Eyes Closed (WEC). The task consists of walking, as straight as possible, five heel-to-toe steps beyond the first two starting steps. Figure 3 shows a subject performing the WEC task. Two parameters are measured: the number of completed steps and the deviation from the straight line. Three trials are administered, with the best two out of three used to score performance. The maximum test score obtainable is 10 (5 steps x 2 trials). In addition, the position coordinates of the toe on the floor grid at the completion of the last heel-to-toe step are recorded, and the deviation of that point from the coordinates representing a perfect performance is determined as part of the post-test data reduction. Measuring deviation from the intended goal provides information on spatial orientation in addition to ataxia.

Both SEC and WEC performances were recorded manually by the onboard Test Conductor.

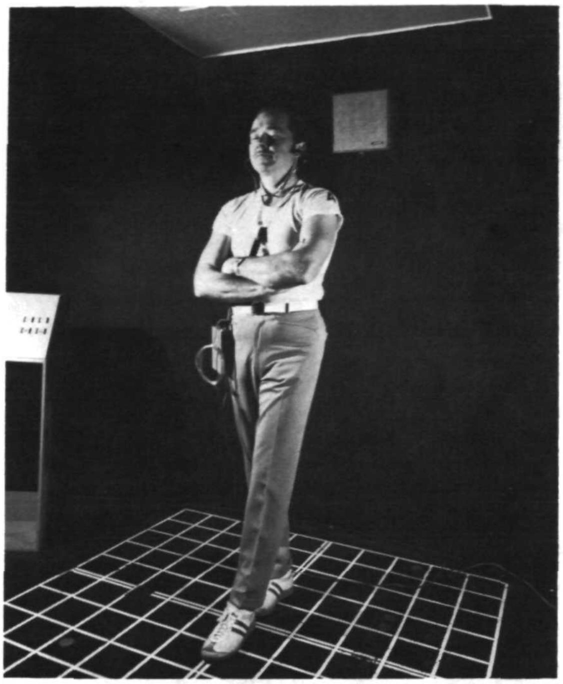

Figure 3. Walking with Eyes Closed.

Response Analysis Test. Control/display tasks typically require multiplanar headturns, visual acuity, and reach speed and accuracy. As performance requiring headturns out of the plane of rotation and/or radial reach components tends to be sensitive to environmental rotation when habituation is incomplete, a control/display task performed directly following abrupt inertial transitions could be degraded if such transitions were characterized by significant requirements for subsequent rehabituation.

The Convair Response Analysis Tester (RATER) was employed to provide a relatively worst-case — hence, high-sensitivity — control/display task for this test. It was recommended for use on the basis of its appreciable bank of normative and experimental — particularly in groundbased rotational studies — data. In studies at Convair, the RATER has demonstrated a nearly linear task sensitivity to vestibulogenic stress. The basic RATER is shown in Figure 4. It consists of a subject's console containing

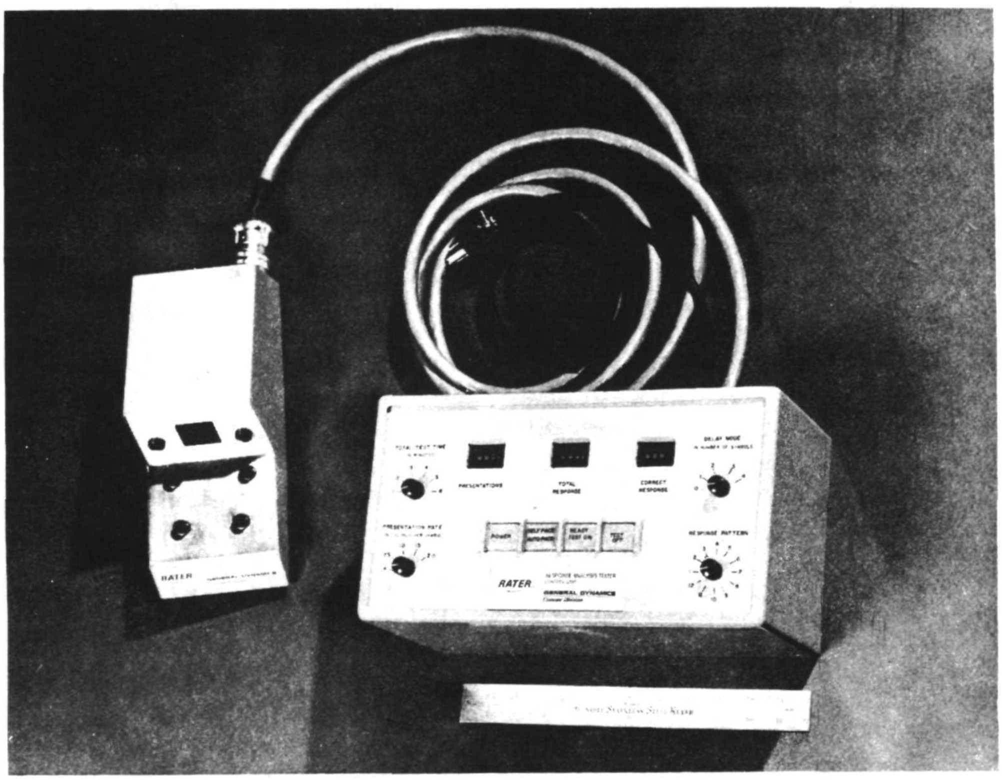

Figure 4. Response Analysis Tester (RATER).

a display screen and four response buttons, and an examiner's console that includes the test controls and digital performance counters. The RATER task requires that the subject respond to the display of each one-of-four symbols (circle, square, diamond, or triangle) by pressing the appropriate one-of-four buttons. When the correct button is pressed, the next symbol is displayed in a random, non-repeating order. To meet the task requirements of this study, the basic RATER was modified. The display screen was collimated and mounted in a panel forward of the subject as shown in Figures 5 & 6. The four response buttons were deployed — two in an overhead console, one in a lateral console, and the fourth in the forward panel —, with each button being included in a separate one of the four tetrads of microswitches. Satisfactory performance required that the subject correctly perceive the displayed symbol, reach toward the appropriate response tetrad, and strike the correct microswitch in the tetrad. Errors were committed by responses in a wrong tetrad and/or wrong responses in the right tetrad. Only the preferred hand was allowed for control responses (Figure 7). The combination of the collimated display and the deployed buttons forced the subject to perform major head and arm movements in all planes (Figure 8). Each test repetition consisted of a pair of two minute trials separated by one minute of rest. The subject's net score for each trial was the total correct responses minus the total incorrect responses. Response totals were automatically displayed by the counters on the examiner's console and were manually recorded by the onboard Test Conductor. In addition, a d-c signal indicating the latency of response to each display was transmitted through the MRP sliprings and recorded on

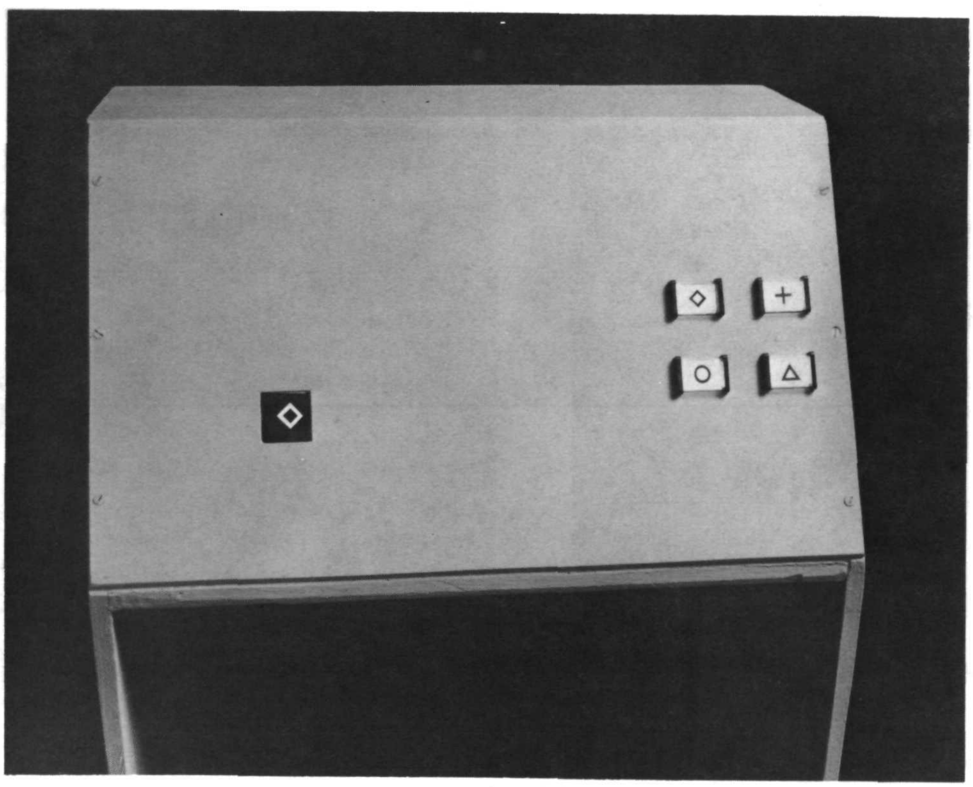

Figure 5. Modified RATER Display on Left, Response Buttons on Right.

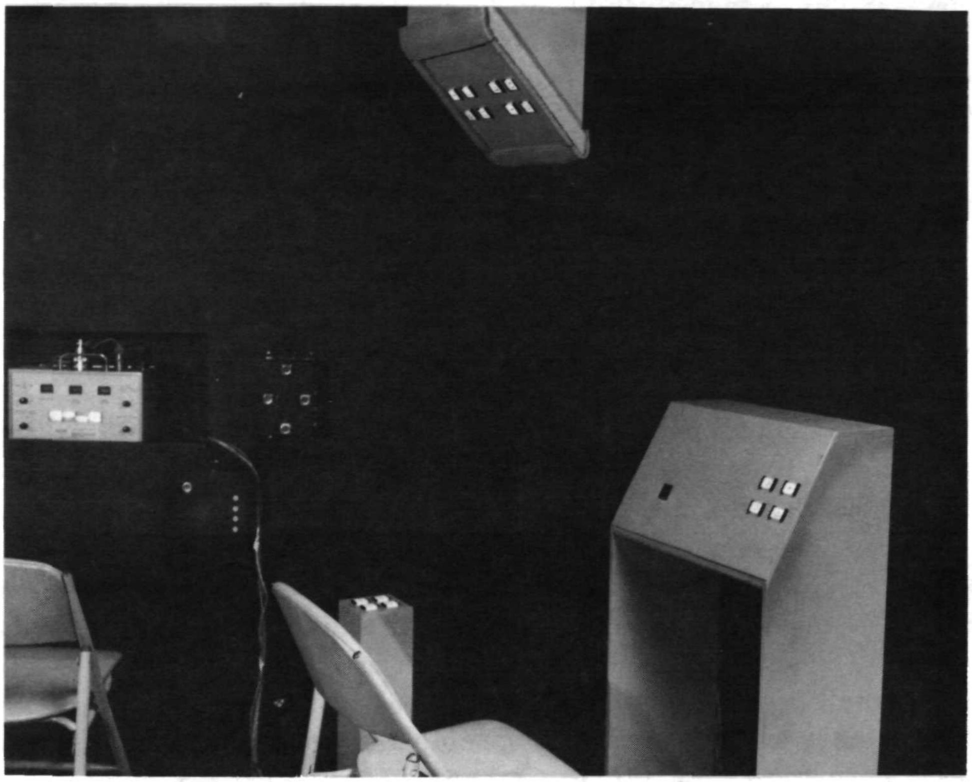

Figure 6. Modified RATER Layout.

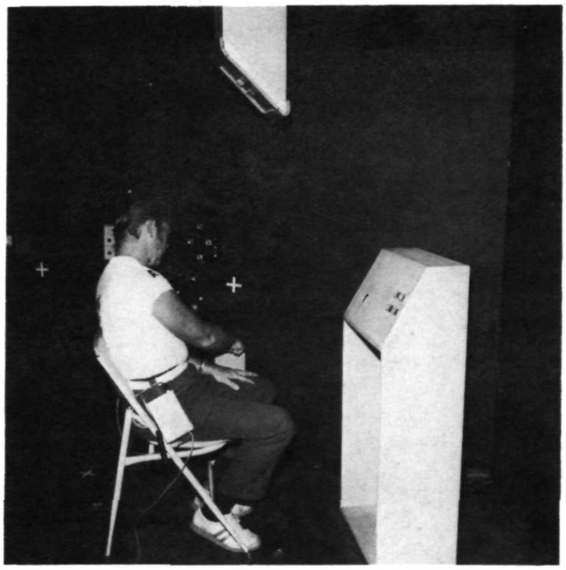

Figure 7. Control Response Using Lateral Console.

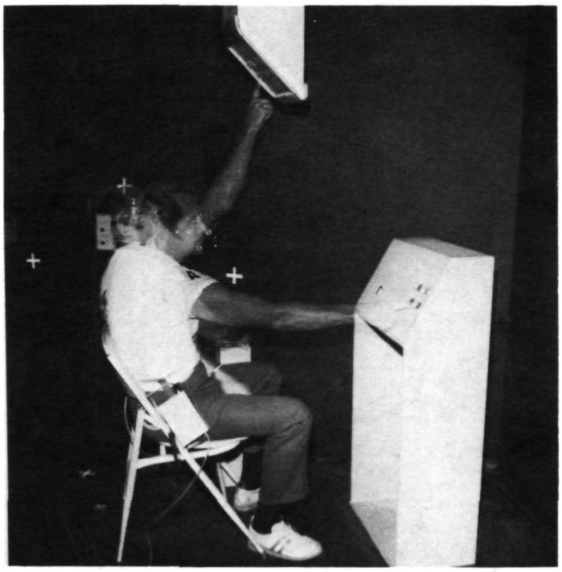

Figure 8. Head and Arm Motions Required for Control Responses Using Forward and Overhead Consoles.

magnetic tape at the Data Station. The response latency traces are used to determine the distribution of performance decrement throughout each performance trial.

Langley Complex Coordination Test. A substantial amount of performance data has been accumulated from tasks using the Langley Complex Coordinator (LCC), both in normative and experimental environments. Performance on the LCC in a recent NR/SD groundbased rotational study showed a significant correlation with the degree of subject perrotational habituation. The LCC is one of the devices being considered as a flight test to help determine the condition and capabilities of astronauts during long-duration space missions.

The LCC test can be described as a self-paced, serial reaction, complex coordinator psychomotor performance test. It is presented with the subject seated. The LCC (depicted in Figure 9) presents to the subject a set of predetermined stimuli (a pattern of colored lights presented on the subject's display panel). The subject responds to these stimulus lights by manipulating four limb controls which cause response lights to glow on the subject's display panel. One set of stimulus lights plus the correct set of response lights is called a problem. A test consists of sets of 50 problems each.

The subject's display panel is seen in Figure 9. The 45 problem lights on the panel are arranged in four quadrants, as shown in Figure 10. Each quadrant represents the stimuli and responses of one limb: the top left quadrant for the left hand, top right for the right hand, bottom left for the left foot, and bottom right for the right foot. The five colored lights in the left-hand column of each quadrant are the stimulus lights and the five lights in each right-hand column are the response. The white light in each quadrant located directly below the two columns is an additional stimulus light for that limb and is used to give the subject additional information regarding the correct response he should make. The white light in the center of the four quadrants is an additional stimulus light which gives the subject information regarding the correct response for all four limbs. The stimulus lights are controlled by an electro-mechanical programmer. Each problem of the preprogrammed test is presented to the subject by various combinations of stimulus lights being illuminated. The subject must respond by moving his four limb controls to activate the four correct answer lights and maintain all four limb controls in the correct position for a predetermined period of time (0.25 sec for this test) before the programmer advances and presents a new trial for solution.

Directly below the problem lights on the panel is an interval timer ('L' in Figure 9) which can be preset to any time up to 15 seconds. It resets automatically when each problem is successfully completed. If the subject does not complete the problem in the preset time, the two red lights 'K' adjacent to the timer go on and remain so until the problem is successfully completed. Each time the interval is exceeded, counter 'I' records an error.

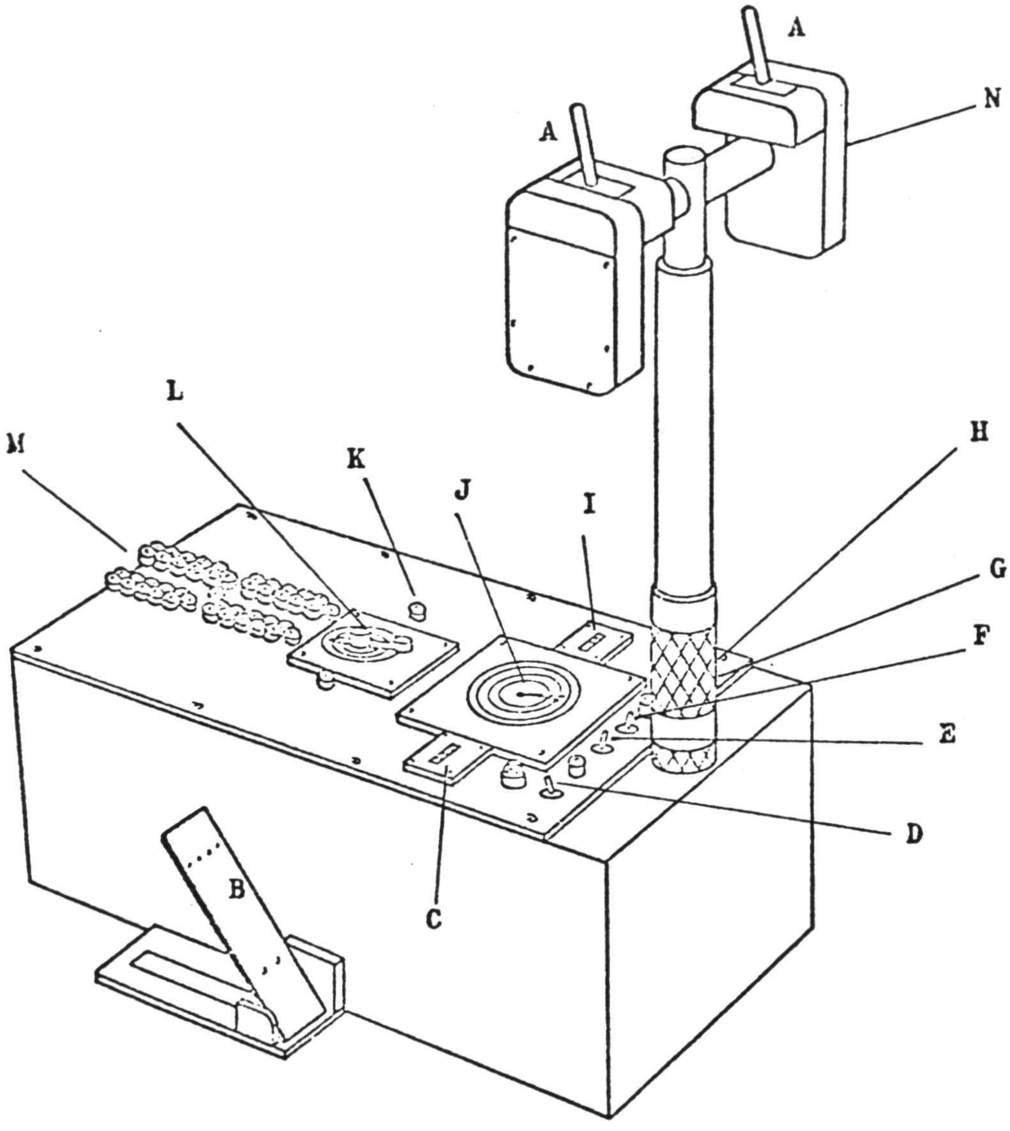

Figure 9. Langley Complex Coordinator (LCC).

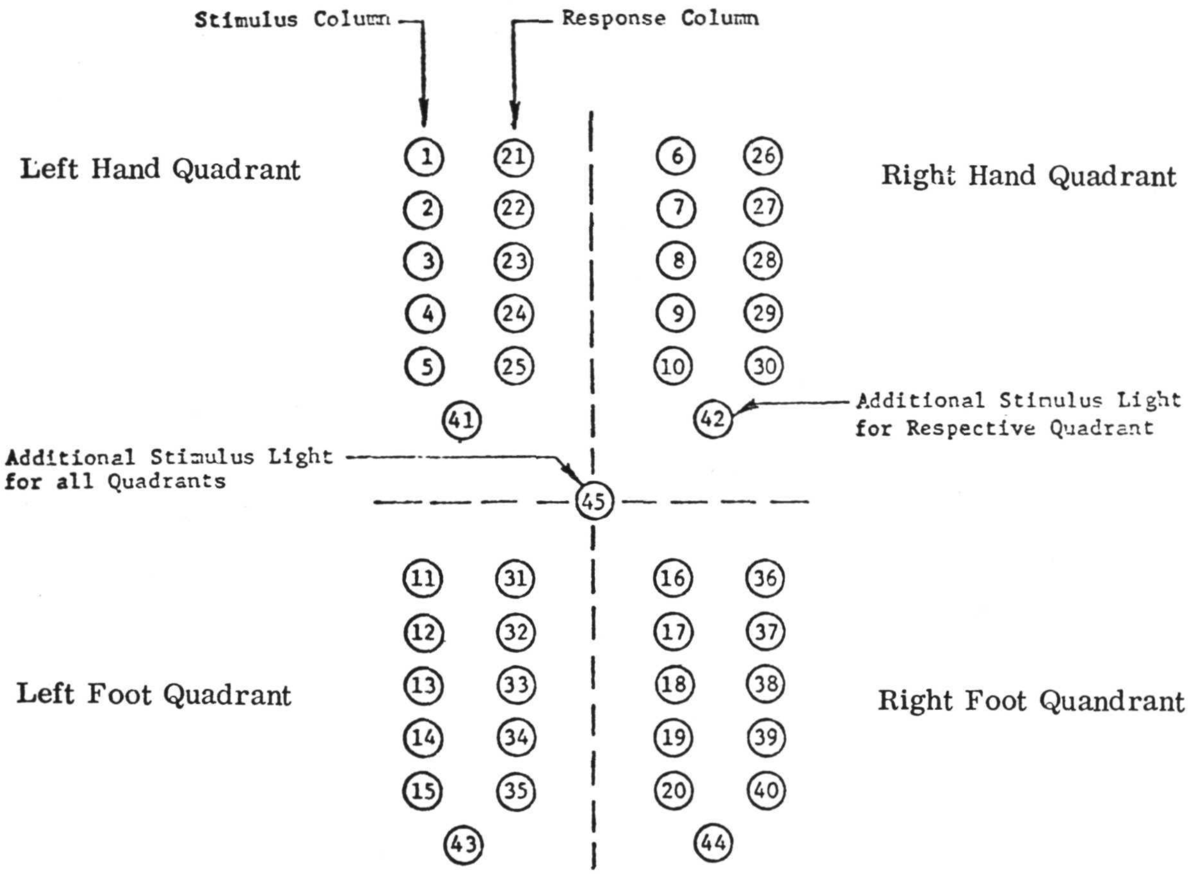

Figure 10. Numbering System for Lights on LCC Display Panel.

The LCC test, therefore, is characterized by each new problem being presented only after the successful completion of its predecessor (self-paced), in consecutive order (serial reaction), each problem requiring the correct positioning of all four limb controls for successful response (complex coordination), thereby assaying the subject's ability to correctly and rapidly see and interpret the combinations of problem lights and execute the appropriate limb control responses (psychomotor performance).

Once the problem set is initiated, the correct solution of each problem automatically brings on its successor, the task of the subject being to complete the entire set as rapidly as possible.

Only one programmer drum was used in this study, the one designated as the MII (complex mixed) test. It is the most difficult test option and therefore would be the most sensitive to the functional state of the subject.

In the complex mixed test, the presentation of each problem's stimulus lights requires one of four response combinations of the four limb controls, the required combination being indicated by the lights 41 through 45 (in Figure 10). Figures 11 and 12 include examples of the four possible responses, the black circles indicating illuminated lights:

<u>Response One (lights 41 through 45 off)</u>: response light is opposite stimulus light as in example G, Figure 12.

<u>Response Two (any of lights 41 through 44 on)</u>: response lights in those quadrants are one below stimulus light as in examples B, D, and E in Figures 11 and 12. When the stimulus light is at the bottom of its column, the top of the response column becomes the 'below' position.

<u>Response Three (light 45 on)</u>: response lights are one above the stimulus lights as in example A in Figure 11. When the stimulus light is at the top of its column, the bottom of the response column becomes the 'above' position.

<u>Response Four (light 45 and any of lights 41 through 44 on)</u>: response lights in those quadrants are two below the stimulus lights as in example F in Figure 12. When the stimulus light is at, or second from the bottom of the column, the response light is positioned correspondingly at the second from, or at the top.

Combinations of Responses Three and Four are sometimes required in examples 'C' and 'H'.

With the completion of problem #50 (a complete set), the timer measuring total elapsed test time ('J' in Figure 9) stops.

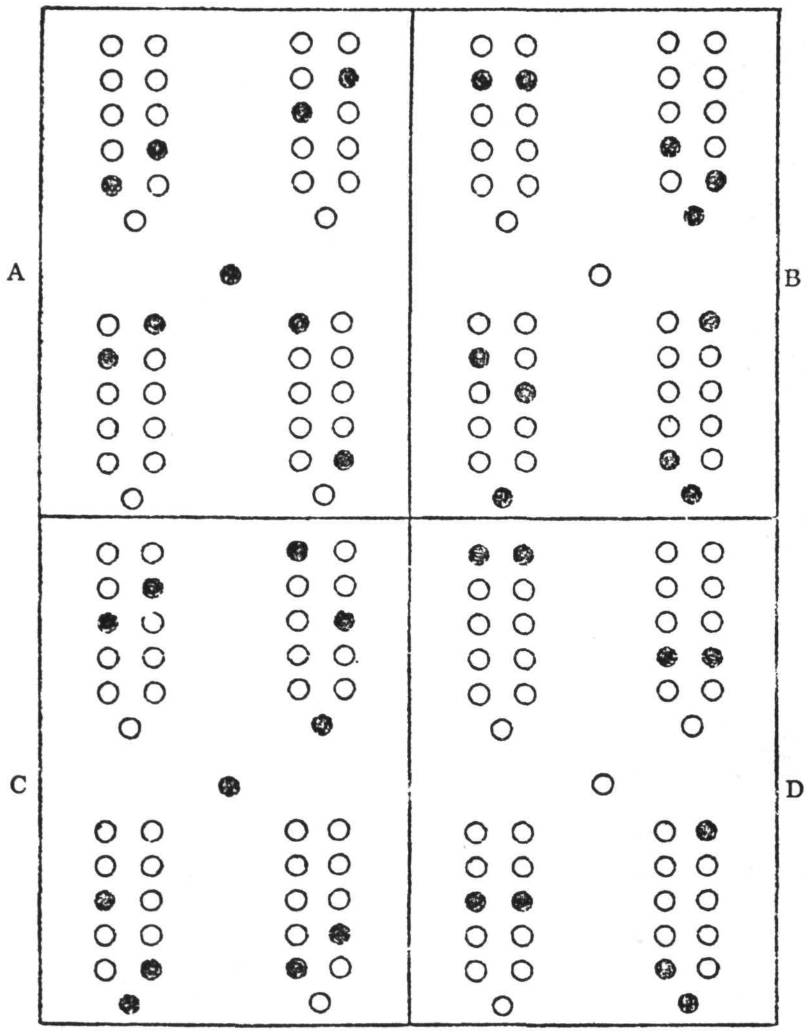

Figure 11. Typical Problems From the LCC Complex Mixed Test

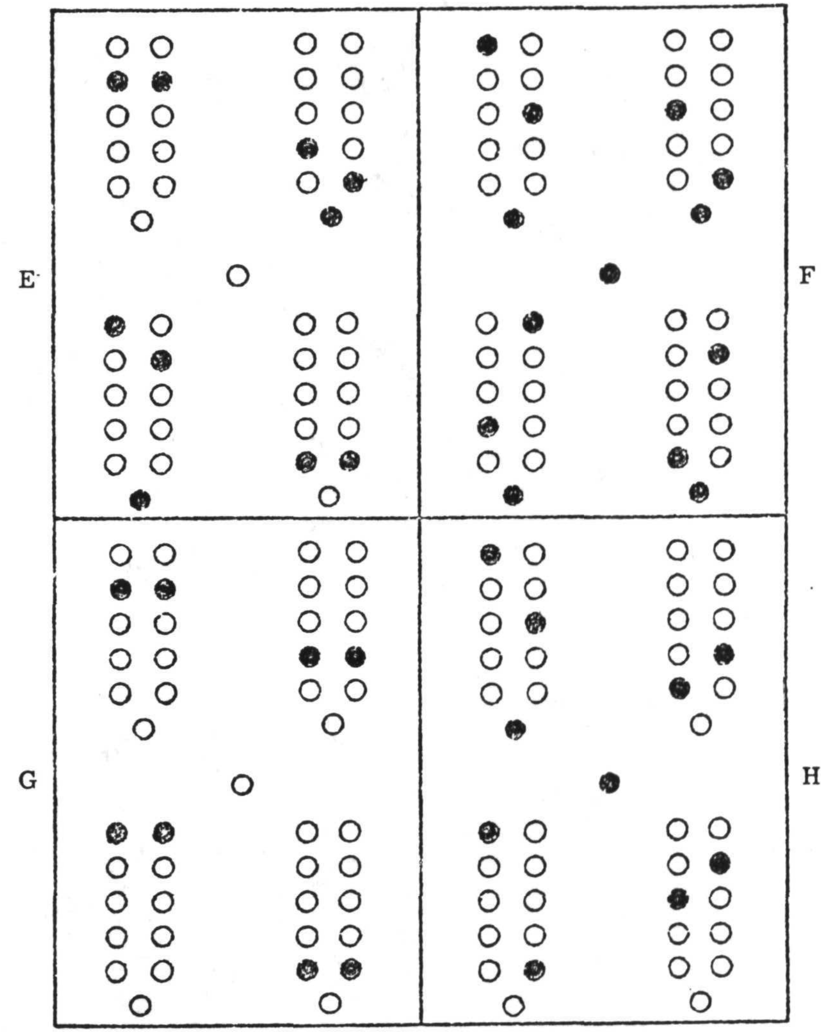

Figure 12. Typical Problems From the LCC Complex Mixed Test

For each testing sequence, the subject was required to perform two 50-problem sets in succession, with his total performance being graded on two parameters: time for completion and number of errors. As the baseline abilities of all subjects were similar, the Interval Timer setting (2.75 sec) was not changed throughout the formal testing, approximating an average baseline commission of 25 errors per set of 50 problems. Each pair of subjects alternated as performer and examiner — controlling the test and manually recording data. The Langley Complex Coordination test device, as used in this test, is shown in Figures 13 and 14.

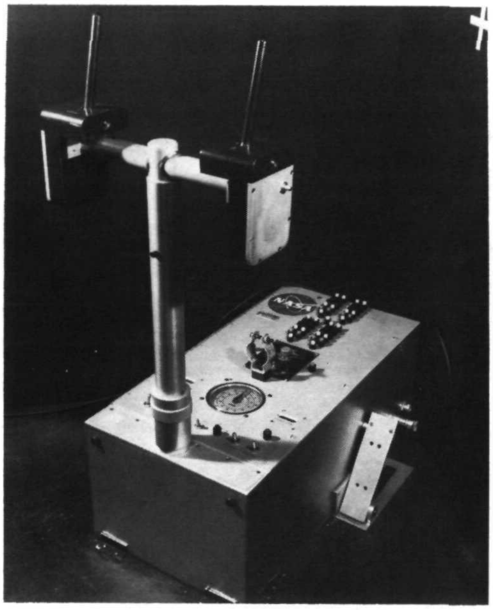

Figure 13. Langley Complex Coordination Test Device.

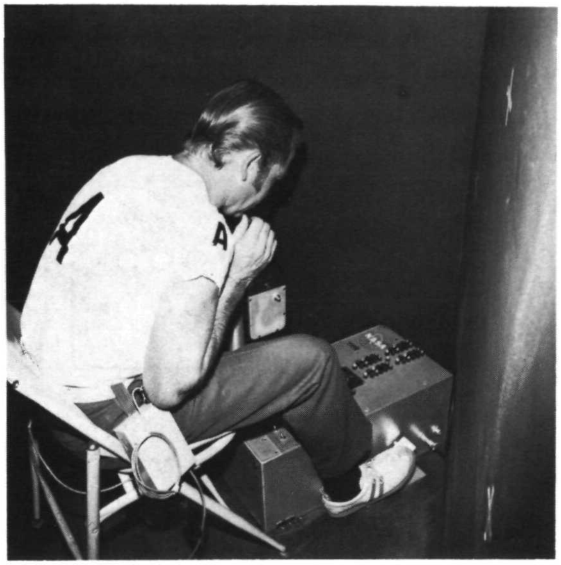

Figure 14. Performance Testing with Langley Complex Coordination Test Device.

2.1.2 HABITUATION MEASUREMENTS. Two measurements relating to the habituation of the vestibulogenic systems to the environment were required to implement this test plan: one, the NAMI Sequential Headturn Test — a series of programmed head turns performed with ambient illumination that simultaneously accelerate the habituation process and provide an index of the progression of that process, and two, the Sharpened Oculogyral Illusion Test — the classical OGY test performed with an illuminated target in an otherwise unlit environment, which provides the most sensitive measure of vestibulo-ocular response. The tests, in concert, produce habituation and measure its completeness.

NAMI Sequential Headturn Test. (Note: both this test and the sharpened OGY test were designed to minimize the number of equipment restraints, hence, the setup and cleanup time, in contrast to the usual design. This was required to prevent the time penalties from becoming prohibitive and did not jeopardize the effectiveness of the tests.) The subject was seated in a chair approximately 4 ft from the spin axis. From this seated position, a combination of neck and torso movements produced 90 degree movements from 'center' (upright looking straight ahead) to nod 'forward', nod 'back', roll 'left', and roll 'right', Figures 15 and 16. To provide the subject with a structured visual field together with a fixation point at each head position, five targets, each a 3" by 3" cross, were placed at appropriate positions on the MRP deck, overhead and bulkhead relative to the subject. One cross fixed the center position, two others the 90 degree nod forward and nod back positions, and the last two the 90 degree roll left and roll right positions. The head and body movements were carried out at the direction of instructions delivered from a tape recorder situated outside the room and under the control of the test conductor. Head and body movements were grouped into sequences of eight discrete movements: the four movements away from center, and the four return movements to center. For each movement, the head passed through an arc of 90 degrees, and the commands to move occurred at 2-second intervals. An interval of 4 seconds occurred between the final movement in one sequence and the first movement in the next. The order of the four movements away from 'center' was randomized within each sequence. At the completion of each discrete movement, the subject was required to make a forced-choice judgment, using a thumb switch, as to whether or not he experienced apparent visual motion (an OGY) within the appropriate test patch. If he began to experience any stomach awareness (incipient nausea), he was to rest until the symptoms passed, signaling his stopping with three passes of the thumb switch.

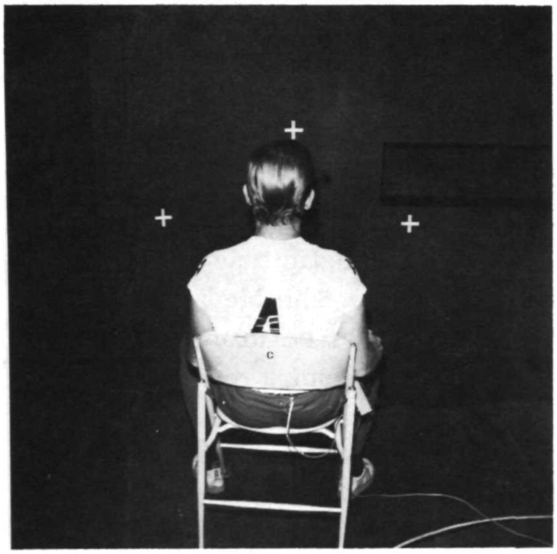

Figure 15. NAMI Sequential Headturn Test, Forward Looking Position.

Figure 16. NAMI Sequential Headturn Test Showing 5 Test Positions.

Regardless of a more rapid completion of habituation, all subjects were to execute a full set of 15 eight-turn sequences (120 headturns) at each test repetition — unless prevented by nausea —, a number of headturns that has established criterion with all normal subjects tested to date. A set required five minutes to complete.

Sharpened Oculogyral Illusion Test. The Measured Phenomenon, the OGY, consists of the perception, by a subject exposed to angular acceleration, of the illusory movement of a viewed target fixed relative to him. The mechanism, as yet undefined, of the illusion seems best explained on the basis of the motor theory of egocentric visual localization, that is, upon the eye reflexes elicited by stimulation of the canals and counteracted by voluntary innervation of the eye muscles during fixation on the target. The threshold of stimulation of the OGY is the lowest of the three psychophysical manifestations of canalicular stimulation.

The test procedure required that the subject be seated facing perpendicular to the room radius. The room light was then extinguished, the only illumination remaining being the OGY target light — a three-inch cube, edge-lighted at minimal intensity — mounted directly facing him on the room bulkhead. At audio command from an instruction tape, the subject closed his eyes. At a second command, he performed a rapid nodding headturn 90 degrees upward, signaling with his thumb-switch the start and duration of any illusion of postural rotation (Figure 17). Thirty seconds after the turn upward, the subject was commanded to open his eyes. A minute following the turn upward, the subject was commanded to rapidly nod his head back and fix on the OGY target (Figure 18). This time the thumb-switch was used to signal the start and duration of any illusion of target movement. That completed a repetition of the Sharpened OGY Test, and the room lights were turned back on.

2.1.3 PHYSIOLOGICAL MEASUREMENTS.

Electrocardiogram (ECG). Biaxillary transthoracic ECGs were displayed continuously for all subjects while testing was in progress. All four subject ECGs were displayed simultaneously in realtime on a Sanborn 769R CRT at the Medical Monitor Station (cf. Figure 19). Displayed on the CRT below the lowest realtime ECG was a continuous playback of the same ECG being recorded on magnetic tape at the Data Station (Figure 20) to provide a check on the latter procedure. The Medical Monitor also had the continuous option of writing out any of the ECGs for scrutiny on either an eight-channel Sanborn or a backup two-channel Brush strip-chart recorder.

Blood Pressure. Indirect brachial blood pressures were determined sphygmomanometrically, by the Test Conductor, once during each one-hour testing repetition. Blood pressures were manually recorded.

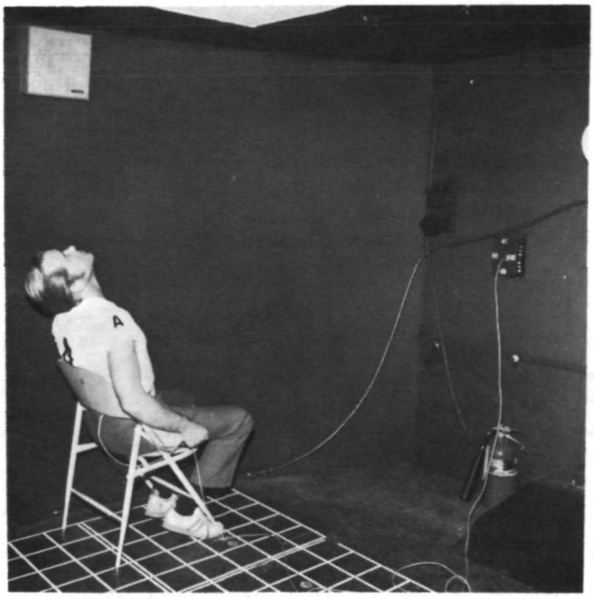

Figure 17. Sharpened Oculogyral Illusion Test 90° Upward Head-turn Position.

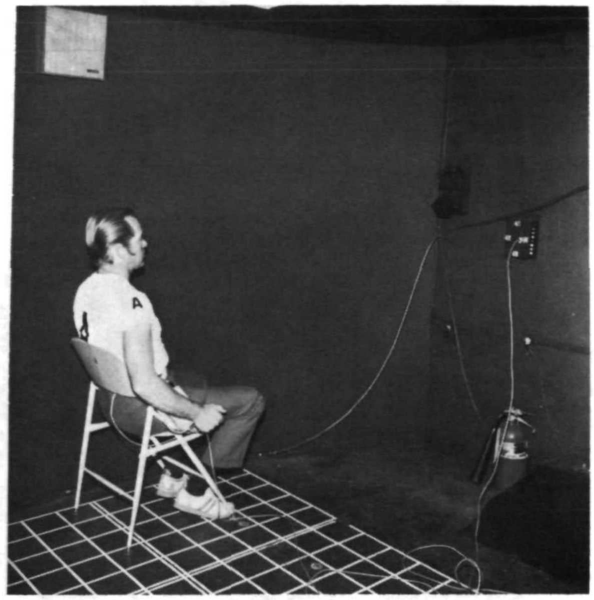

Figure 18. Sharpened Oculogyral Illusion Test - Subject Facing Oculogyral Target Light.

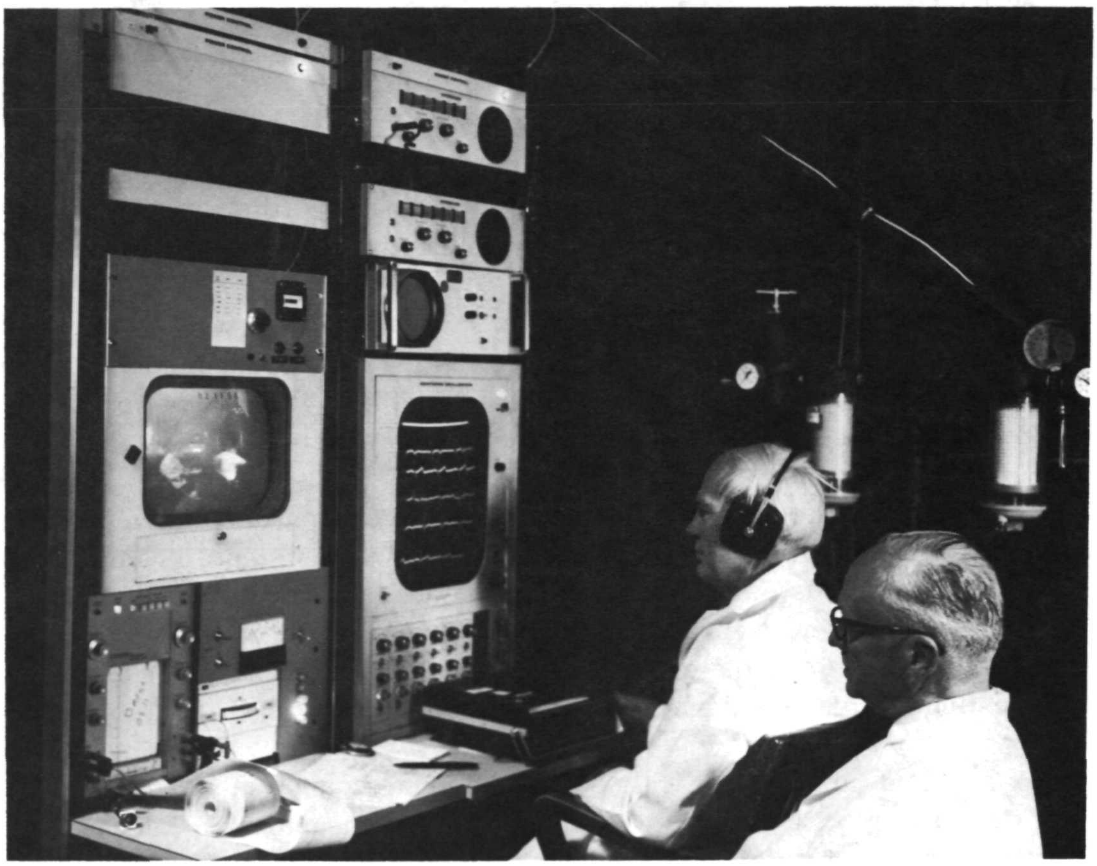

Figure 19. Medical Monitoring Station.

Figure 20. Central Data Station.

Respiratory Rate. This was determined once per testing repetition, each subject measuring his own rate. Determination was by count over a thirty-second duration and was manually recorded on the subject's data sheet.

Body Temperature. Determination was once per testing repetition, using a Yellow Springs oral thermister and analog meter. The subject kept the thermister in his mouth for one minute, recording the reading on his data sheet.

Caloric Requirements. The only constraints on the subject's alimentation before and after each day's testing were that it be reasonably bland, consistent in quantity from day to day, and that records be kept of the types of foods ingested for supper and breakfast. Following pre-test voiding of bowels and bladder, each subject was weighed, and weighed again at the end of the test day. The only nutrition allowed during each testing day was a balanced 250-calorie food at noon.

Fluid Balance. Fluid intake was regulated to a nominal volume of 100 ml/hour during the test day with both intake and output being measured. Each subject imbibed 100 ml of water during each of the six daily test battery repetitions at that time in the test sequence when his colleague was performing the RATER test. Each subject emptied his bladder once during each testing repetition, at that time measuring the volume, decanting a 20-ml aliquot into a provided test tube for onboard refrigeration, and recording the volume on his data sheet. This was done while his colleague was performing the RATER test.

Urinalyses. Urine aliquots from each subject/repetition/test day were analyzed for sp. grav., pH, glucose and protein.

Visual Monitoring. All subjects were under constant visual surveillance via closed-loop TV to monitors at the Medical Monitor Station and the Data Station. The single video camera in the MRP can be panned and tilted through servos controlled at the Medical Monitor Station to provide a total scan of the MRP interior.

Voice Communications. The MRP contains an omni-directional open microphone and two speakers which are hardwired through the slip rings to facilitate two-way audio communication between the subjects and the Medical Monitor Station. All audio in and out of the MRP was recorded in realtime on magnetic tape at the Data Station. Hallicrafter CB-11 Transceivers provided wireless backup channels.

2.1.4 TESTING SCHEDULES. Each day of pilot and formal testing followed the clock time schedule listed in Table 1, with each test battery repetition (T_n) following the schedule shown in Table 2. Figure 1 presents the inertial profile that was used in pilot and formal testing, with the daily rotation rate for the three days of pilot testing being 0, 1 and 2 rpm, in that order, and for the two weeks of formal testing being ordered 0, 4, 2, 5, 3 and 3, 5, 2, 4, 0 rpm, respectively. Figure 1 is highly schematic, as each habituation headturn test (H_n) required only five minutes, the 15-minute lunch period preceding H_2 is not shown, and the MRP spindown following T_6 did not exceed five minutes.

2.2 APPARATUS

2.2.1 SIMULATOR. Manned testing required for this study was conducted aboard Convair's Manned Rotating Platform (MRP), a facility developed and equipped specifically to support groundbased testing of crew responses to inertial transitions. The MRP, shown in Figure 21, consists of a 12 by 18 by 7 foot test room mounted on a rotatable platform 22 feet in diameter. The platform is anchored by a central spindle and supported by four air bearings. The rotatable platform is concentric to a static platform 6 feet in diameter that simulates a zero-g hub. Figure 22 shows a subject making an abrupt transfer from the rotating to the static platform. The MRP is driven by a 1/3 HP Diehl motor through a peripheral friction drive, the combination of drive and air-bearing support providing a smooth, noiseless rotation with an accuracy of $\pm$ 0.05 rpm. Rotation was constantly displayed by meter and strip-chart trace at the Medical Monitor Station and was recorded, in real time with other test data, on magnetic tape at the data station (see Figure 19).

TABLE 1. DAILY TEST SCHEDULE

Clock Time	Activity
0700 — 0800	Checkout of MRP, data and power systems. Provision of expendables.
0800 — 0845	Ss fill out pre-test questionnaires. MM certifies Ss for run. Ss don test clothing. Ss instrumented for ECG. Ss void bladder and bowels Ss weighed.
0845 — 0950	T_1 in static MRP.
0950 — 0955	MRP spinup to day's RPM. Ss make abrupt transition from static center to rotating platform.
0955 — 1100	T_2 in rotating MRP.
1100 — 1105	H_1 in rotating MRP.
1105 — 1210	T_3 in rotating MRP.
1210 — 1215	Ss make abrupt transition from rotating platform to static center. MRP spindown to static.
1215 — 1320	T_4 in static MRP.
1320 — 1335	Lunch
1335 — 1340	H_2 in static MRP.
1340 — 1445	T_5 in static MRP.
1445 — 1450	MRP spinup to day's RPM. Ss make abrupt transition from static center to rotating platform.
1450 — 1555	T_6 in rotating MRP.
1555 — 1600	MRP spindown to static.
1600 — 1605	H_3 in static MRP.
1605 — 1615	Ss fill out post-test questionnaire. Clean up of Ss. MM certify Ss for departure.

MM = Medical Monitor T_n = Test Battery Repetition
Ss = Subjects H_n = Headturn Test Repetition

TABLE 2. TEST BATTERY SCHEDULE

Time	Subject	Activity	Data Acquisition
0000 — 0005	A — D	Sharpened OGY	Illusion duration: thumb switch signal to mag tape and strip chart. Illusion direction & magnitude: manual record.
0005 — 0015 0015 — 0025	A & B C & D	FATB	Duration SEC: voice log on mag tape, TC manual record. No. steps & terminal coordinates WEC: voice log on mag tape, TC manual record.
0005 — 0015 0015 — 0025	C & D A & B	Blood Pressure Oral Temperature Respiration Rate	Voice log on mag tape, TC manual record.
0025 — 0030	A — D	Sharpened OGY	
0030 — 0045 0045 — 0100	A & B C & D	RATER	Total responses, total correct responses: TC manual record. Response latency: signal to mag tape & strip chart.
		(NCTE: Alternate subject drinks 100 ml. H_2O and provides urine specimen.)	
0030 — 0045 0045 — 0100	C & D A & B	LCC	Total time, total errors: subject manual record.
0100 — 0105	A — D	Sharpened OGY	

TC = Test Conductor

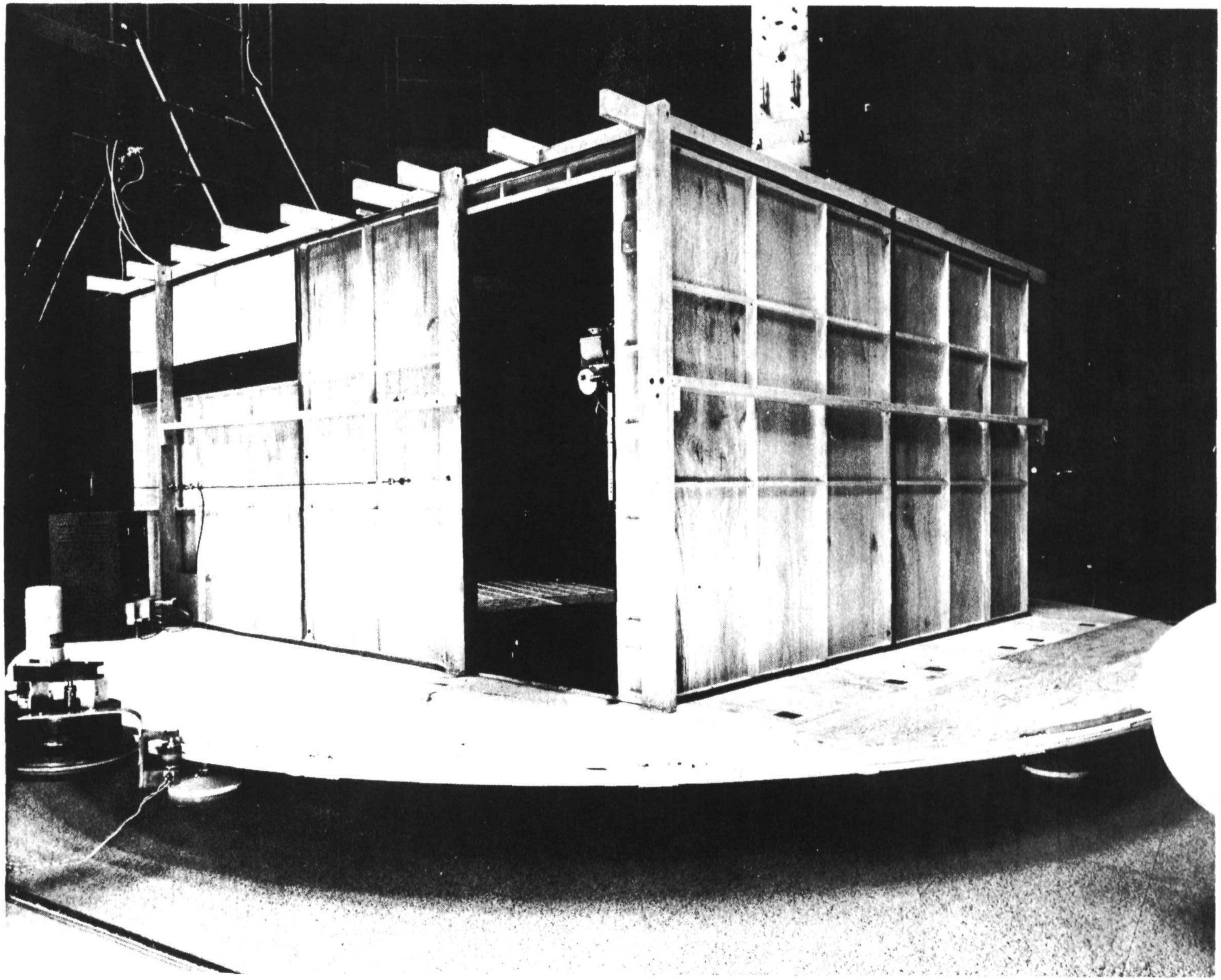

Figure 21. Manned Rotating Platform (MRP).

2.2.2 DATA AND POWER SYSTEMS. Figure 23 is a block diagram indicating the data and power links designed into the MRP and its support hardware. Each subject wore a signal conditioner pack on his belt (Figure 22). To the pack were connected the subject's ECG leads and his thumbswitch lead, the conditioner providing amplification of the ECG signal. The umbilical from the beltpack plugged into Stations "A", "B", or "C" (Figure 23) from which the analog signals were transmitted to VCO's for conversion to FM and subsequent multiplexing. The multiplexed FM signals were transmitted through the slip rings to be recorded on magnetic tape at the Data Station and also converted back to analog by discriminators (DCSC) for CRT and strip-chart display. Audio communication and video channels were transmitted directly through the slip rings, as was the TV scan control, and the a-c and 24v d-c power. The MRP drive control and the MRP emergency stop (located at the static hub) do not require slip ring transmission. Not indicated in Figure 23: all MRP audio was recorded in realtime on one channel of the same magnetic tape recording the multiplexed data, as was a coding of digital time — the same time that was displayed at the Medical Monitor Station for use by personnel in identifying log entries and strip-chart records; also, one subject's ECG was continuously played back from the magnetic tape and displayed on the CRT in juxtaposition to its realtime display to provide constant check on the recording system.

Figure 22. Subject Transferring from Rotating to Nonrotating Platforms.

2.3 SUBJECTS

In keeping with the contract requirement to utilize selection criteria which would ensure that the subjects were representative of potential users of combined artificial-g/zero-g space systems, the candidate subjects recruited may be characterized as follows:

> <u>Number</u> — five candidates (a sample of four — the largest number compatible with the testing constraints and the smallest number that would facilitate evaluation —, and one backup) were fully trained and evaluated for testing.
>
> <u>Age</u> — ranged from 38 to 48 years.

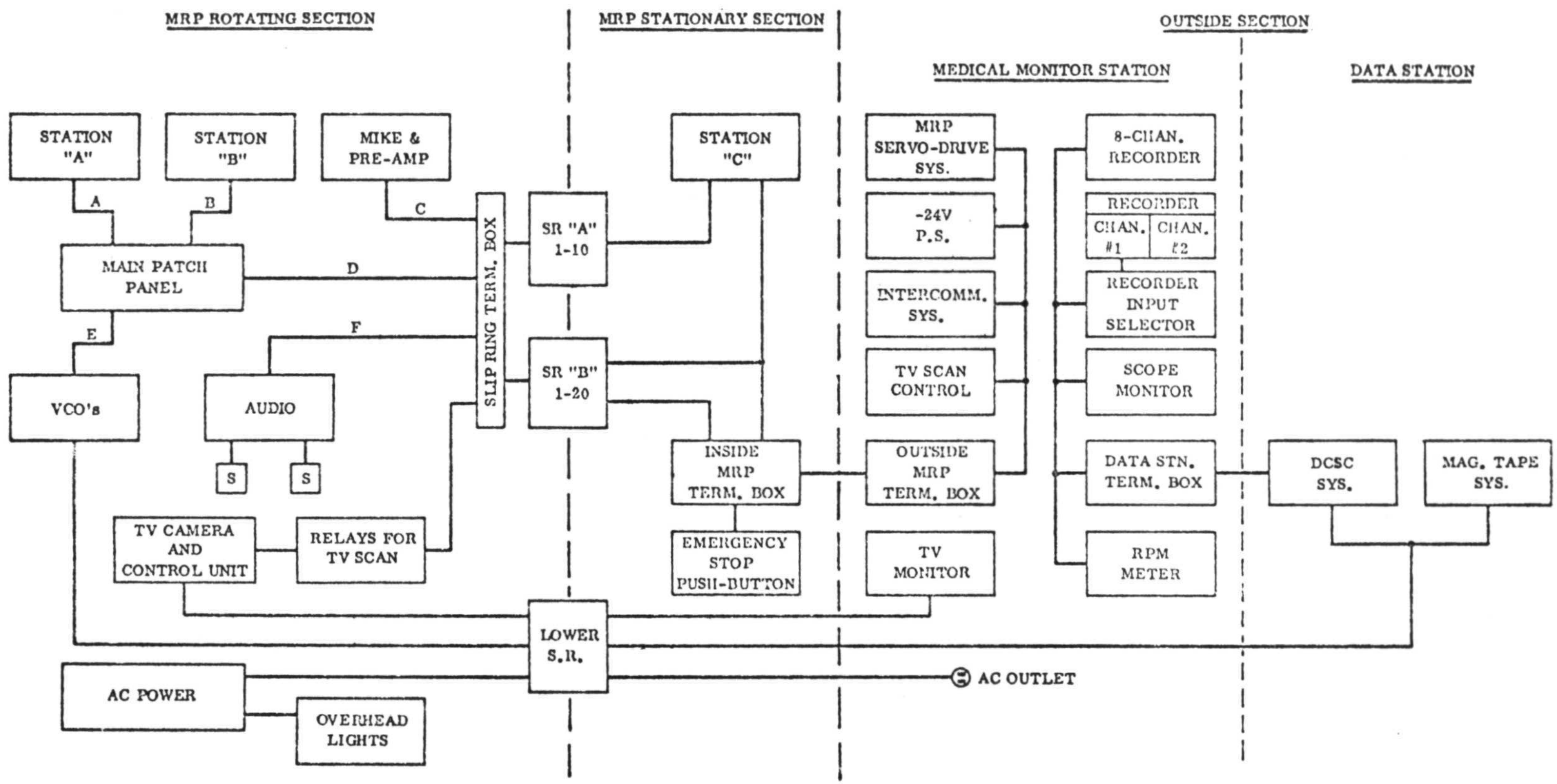

Figure 23. Data and Power Systems.

Academic Training — four of five were college graduates — including one with a doctorate.

Work Experience — all were employed by Convair in R&D and three had substantial experience in manned testing.

Motion Tolerance — all had histories of low susceptibility to motion sickness, with all having extensive aircrew experience. Two had substantial experience in rotational environments — all at Convair — with the remaining three being naive to such environments.

The schedule of participation for the candidate subjects was as follows:

Weeks 1-4. Each of the candidates spent four hours being evaluated for acceptability as subjects. They were screened using, in the order given, the FAA Class II Airmen Physical Examination, a cardiovascular challenge involving continuous ECG while walking a 10% treadmill grade for ten minutes at rates ranging from 1.7 to 5 mph, bilateral canalicular caloric stimulation using the OGY as the response index, and, lastly, the NAMI Sequential Headturn Test within the MRP rotating at 5 RPM, the maximum rate tested.

Weeks 5-11. Each of the five candidates spent two hours each day training on the performance measurement tasks.

Week 12. Each of the five candidates spent three hours on Monday and on Tuesday being trained in their formal testing duties, with the prime sample of four subjects being trained as a unit and the fifth as a backup. Each of the five candidates spent eight hours on each of the remaining three days performing a pilot study consisting of a complete testing schedule each day, with the MRP providing spin rates of, respectively, 0, 1 and 2 rpm. The backup subject was required to be in attendance outside the MRP during all testing, maintaining his familiarity with the testing procedures by assisting the Test Conductor.

Week 13. Each of the five candidates spent 2 hours each day maintaining his proficiency in the performance tasks.

Week 14. Four subjects spent eight hours each day in formal testing with the MRP providing spin rates, respectively, of 0, 4, 2, 5 and 3 rpm. The same four subjects were used as in the pilot study with the backup assisting external to the MRP.

Week 15. Each of the five candidates spent 2 hours each day maintaining his proficiency in the performance tasks.

Week 16. Four subjects spent eight hours each day in formal testing with the MRP providing spin rates, respectively, of 3, 5, 2, 4 and 0 rpm — reversing the order of Week 14's testing to provide an overall reduction in data bias due to sequential effects. Due to factors unrelated to the program, Subject B from Week 14 could not participate in this week's testing and was replaced by the backup subject.

The first two weeks of training were restricted to practice on the Langley Complex Coordinator. During subsequent weeks of training, one hour per day was spent on the Langley Complex Coordinator and the other practicing the RATER and performing the Floor Ataxia Test Battery.

For pilot and formal testing, subjects wore sneakers, light-colored slacks, and white T-shirts. Each T-shirt had the subject's designator (A, B, C or D) boldly marked on its front, back, and both sleeves. Short-sleeves were used to expedite the blood-pressure determinations.

SECTION 3

RESULTS

Data during the formal testing were recorded by test subjects working on the buddy system, by the onboard test conductor and the medical monitor, and by the automatic recording equipment. The Daily Activity Schedule provided the primary format for the manual recording of data. Data from the Daily Activity Schedule sheets, from the subjects' data sheets, and from the magnetic tape and strip chart records were transcribed on matrix sheets for initial reduction and normalization. Copies of the matrix sheets containing all of the raw data subjected to statistical analysis have been assembled in a separate document available upon request.

Subjects A, C and D were tested during both weeks of formal testing, Subjects B_1 and B_2 being tested during one week only — respectively, the first and second weeks of testing. The individual averages ($\bar{X}_1$'s) for Subjects A, C and D were combined with the one-week scores for Subjects B_1 and B_2 to provide overall means ($\bar{X}_2$'s), which were then normalized for inter-rpm graphic comparison by expressing each repetition's $\bar{X}_2$ as percent of baseline (Repetition #1).

Data from each physiological, performance and habituation measurement were subjected to an analysis of variance (ANOV) using the $\bar{X}_1$ values for the five subjects. First a summary ANOV was performed using a GDCA program written for the CDC 6400 computer. Any significant ($P < 0.05$) variances as to repetitions, rpm's, or interactions of those two variables were then specifically evaluated using a manual ANOV. Any significant variances demonstrated in this second analysis were then subjected to an analysis of means (ANOM), using Duncan's New Multiple Range Test[11], to isolate intra-variable differences of significance.

3.1 PERFORMANCE MEASUREMENTS

3.1.1 FLOOR ATAXIA TEST BATTERY (FATB). The FATB provided three performance measurements: Set Up Time (SUT), Walking with Eyes Closed (WEC), and Standing with Eyes Closed (SEC).

<u>FATB (SUT)</u>. This measurement was performed only during the second week of testing, in response to observations during the first week that subjects sometimes experienced greater difficulty in setting up for either WEC and/or SEC than in executing the tasks. It was surmised that a measurement of SUT might provide an additional index of postural equilibrium. Being measured only during the second week, no data are available from Subject B_1. The Set Up Time refers to the continuous period from the beginning of a subject's set up for either a WEC or SEC trial to the moment such trial is initiated. As the first step in setting up for either test is the assumption of the tandem heel-toe foot position, this is the point at which the setup time measurement is begun. The time measurement then continues — regardless of

delays, e.g., losing balance and having to reassume the heel-to-toe position — until the Walking with Eyes Closed or Standing with Eyes Closed trial begins.

The overall means ($\bar{\bar{X}}_2$'s) for each rpm are plotted as a function of test repetition (Rep.) in Figure 24. The format of the graph is representative of nearly all those presented in Section 3. The abscissa consists of the six repetitions of the test during the test day, the 'S' and 'R' denoting respectively Static and Rotating, the subscript 'h' indicating a demonstrated — by Sequential Head Turn Test and Sharpened OGY Test — state of complete canalicular habituation to 'S' or 'R' on the part of the subjects. The stippled area encloses 'R' data points only. As is true of most of the graphs included in this section, the calibration of the ordinate for the dependent variable (in this case, SUT) is in percent baseline (Rep. #1 being 100 percent). To provide an absolute comparison, the dimensional values for each rpm's Rep. #1 is tabulated to the right of the graph.

Figure 24 suggests a direct correlation between extended SUT (degraded function) and an unhabituated subject in either a static or rotating environment, the degradation increasing roughly with rpm. The SUT summary ANOV is presented in Table 3. Only the test repetitions are a source of significant variance. The results of an ANOV of the repetitions at each rpm, as shown in Table 4, indicate this same level of significance ($P < 0.01$) at 3, 4 and 5 rpm, but with the F-Ratios suggesting an inverse rpm-function within that range. The ANOM for the repetitions at each of the three rpm's are given in Tables 5 through 7. These ANOM results indicate that there is significant degradation in SUT in all unhabituated repetitions, and at 5 rpm even for 'R_h' and the second 'S_h' of the day. It should be noted that while the two unhabituated 'R' repetitions demonstrate some ambiguity as to the greater statistical decrement — varying with rpm —, the unhabituated 'S' repetition sustains the greatest decrement at all three rpm's.

FATB (WEC). The normalized WEC data — the raw data consist of the sum of steps for the two best trials — are plotted in Figure 25 and suggest that at 4 rpm and higher there is a marked decrement in that ability with only partial recovery with vestibular habituation. The WEC summary ANOV in Table 8 indicates a significant variation in performance as a function of repetitions, rpm's and their interaction, with an ANOV of the repetitions at each rpm (Table 9) demonstrating this occurs only at 4 and 5 rpm. The WEC ANOM for repetitions at 4 and 5 rpm are presented in Tables 10 and 11. These indicate that there is a significant reduction in WEC performance for all perrotational repetitions, habituated or nonhabituated, for both rpm's. There is significant decrement for 'S' only at 5 rpm.

FATB (SEC). The normalized SEC data — the raw data consist of the sum of balance time for the two best trials — are plotted in Figure 26. In contrast to the SUT and

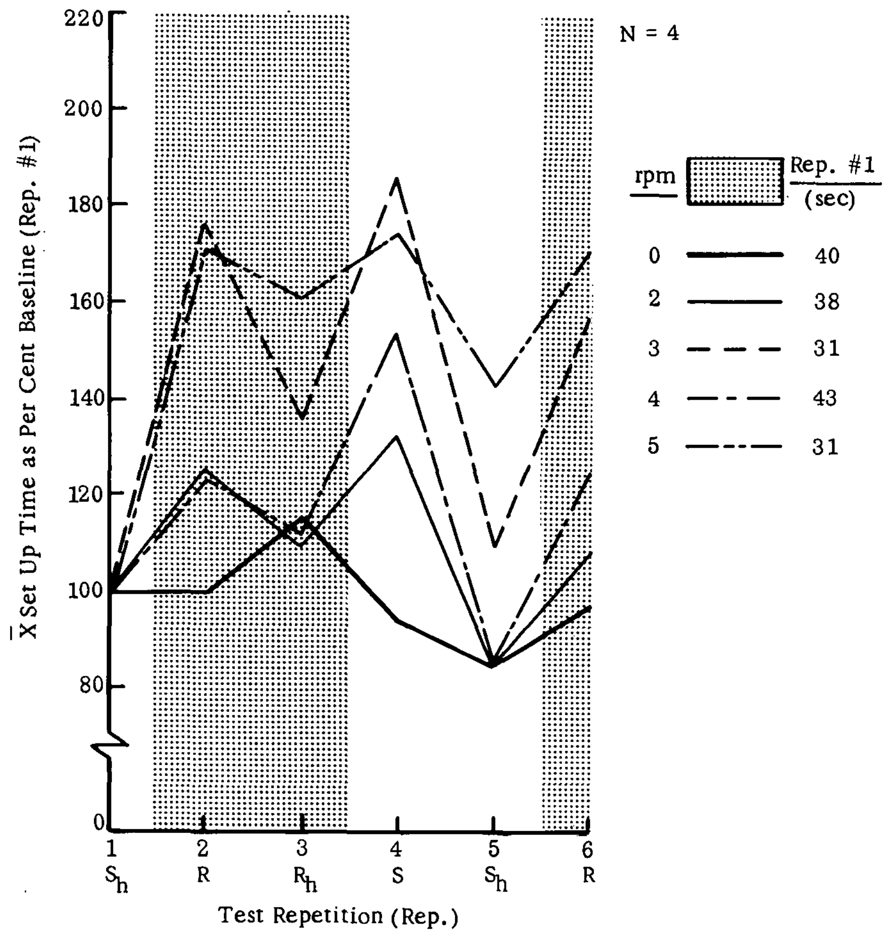

Figure 24. FATB (SUT) vs Rep. & rpm.

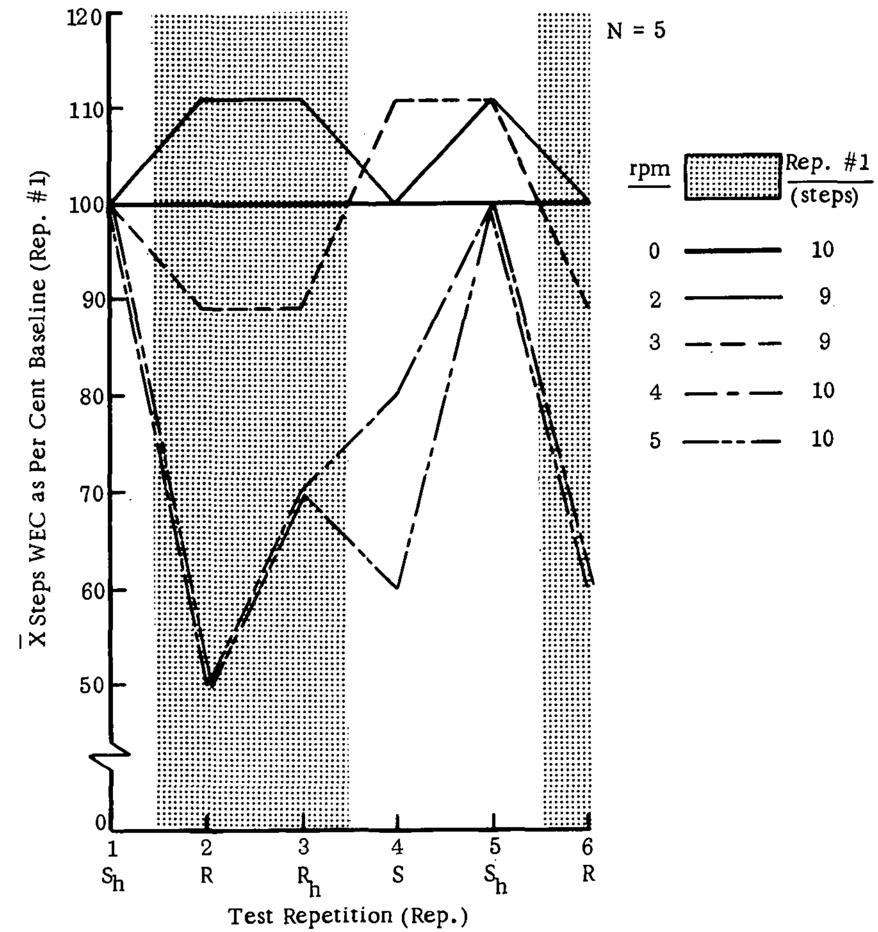

Figure 25. FATB (WEC) vs Rep. & rpm.

WEC functions, which sustained 50 percent and greater average decrements for some repetitions, the SEC performances — while affected by inertial changes — appear to be markedly less sensitive, with the maximal average decrement being 12 percent. The ANOV results given in Tables 12 and 13 indicate that, while there is a direct relationship between rpm and SEC dysfunction, it is not a significant one.

3.1.2 RATER TEST. The only RATER parameter plotted and subjected to statistical analysis was the total net score (total correct responses minus total errors) for the two 2-min. trials of each repetition, the primary performance criterion. The normalized data graphed in Figure 27 suggest no significant changes in performance, but the summary ANOV in Table 14 indicates a significant variation in performance as a function of rpm. As the ANOV of rpm's at each repetition (Table 15) indicated no significant variation per individual rpm, an ANOM of the inter-rpm variance was performed. This indicated (Table 16) that there was an overall degradation in RATER performance at each of the rpm's when compared with zero rpm. Although the summary ANOV (Table 14) showed no significant variation as a function of repetition, an ANOV of repetitions at each rpm (Table 17) was performed to determine if there was a direct-rpm trend. The results showed no correlation with rpm level among per-rotational runs.

3.1.3 LCC TEST. The only LCC parameter plotted and subjected to statistical analysis was the time required to complete the best (fastest) 50-problem trial during each repetition. Figure 28 is a graph of the overall LCC means per rpm as a function of repetition. The plot is similar to Figure 27 for RATER in that only a narrow range of mean variance occurred, with no apparent trend as to rpm or repetition. This is confirmed by the summary ANOV results in Table 18.

3.2 HABITUATION MEASUREMENTS

3.2.1 SEQUENTIAL HEADTURN TEST (SHTT). The SHTT plot (Figure 29) is one of two graphs — the other is the OGY Test — in which it was more meaningful to treat the data in its dimensional form. Figure 29 indicates a direct relationship between rpm and the number of headturns required to achieve complete vestibular habituation, and for each rpm a consistently fewer number of headturns is required for habituation to the static versus the rotating environment. The Table 19 summary ANOV indicates that both the rpm and repetition variances are significant. Table 20 indicates that although the repetition variance is significant for each rpm above zero, the magnitude of the difference is not a direct function of spin level.

3.2.2 SHARPENED OGY TEST. In Figure 30, as mentioned above, the ordinate is calibrated in the dimensions of the raw data, the duration of the OGY in seconds. The graph shows the illusory response to be nearly a direct function of the rpm, and to be somewhat greater during the initial 'R' repetitions than during the 'S' and

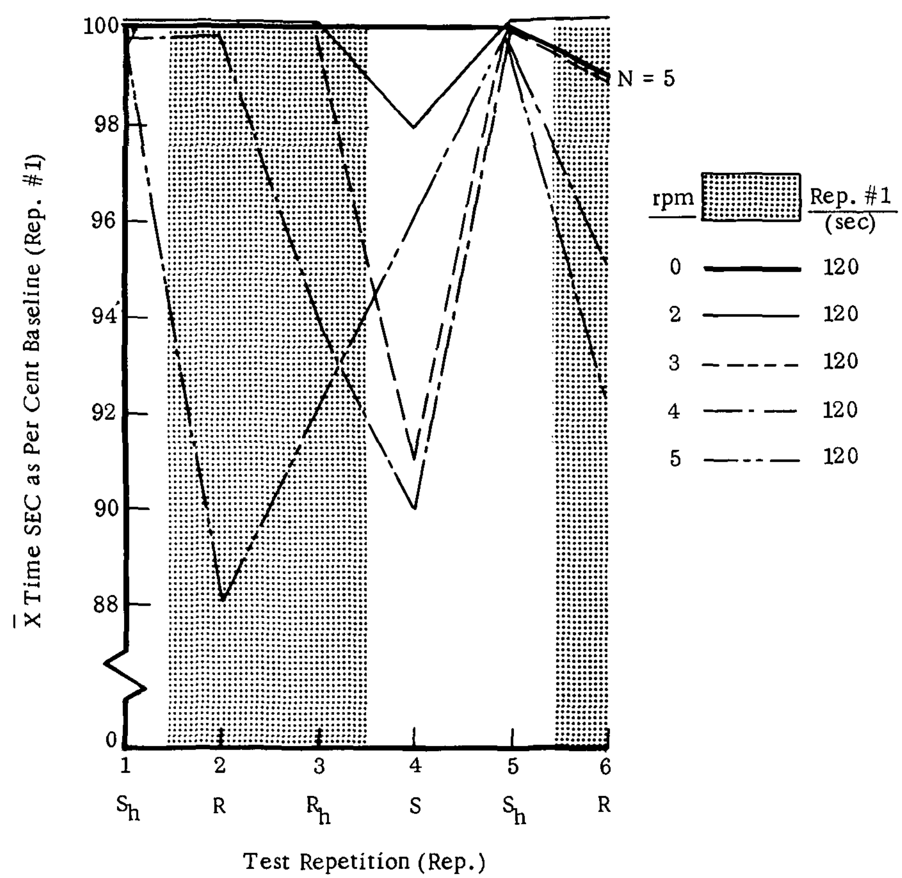

Figure 26. FATB (SEC) vs Rep. & rpm.

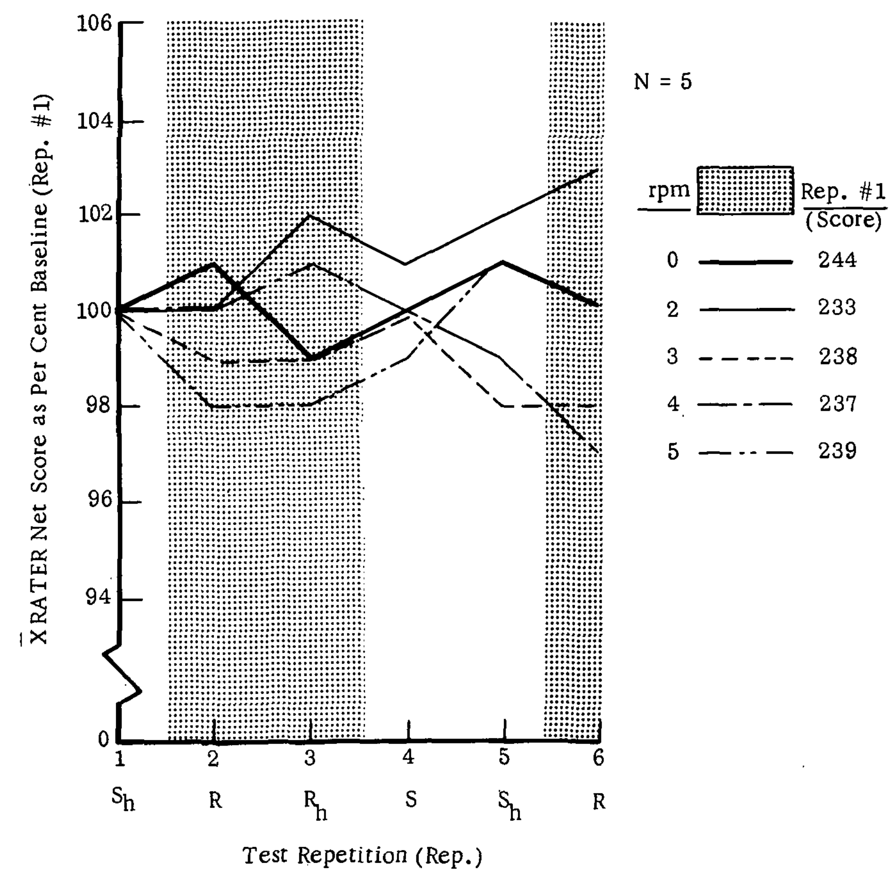

Figure 27. RATER Score vs Rep. & rpm.

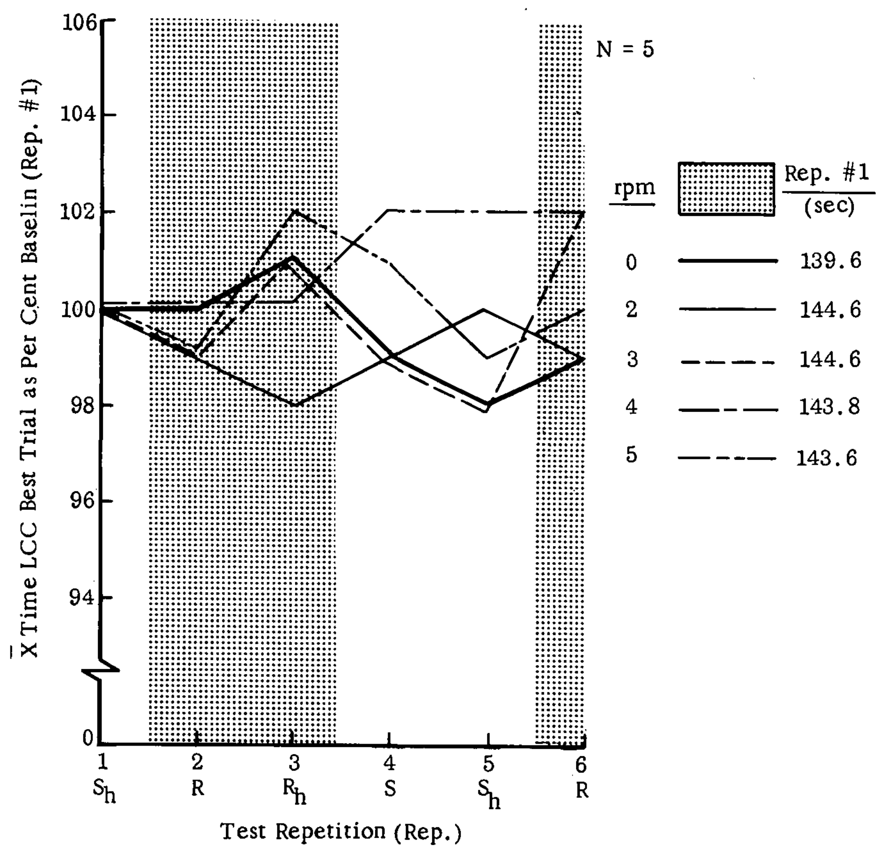

Figure 28. LCC Time vs Rep. & rpm.

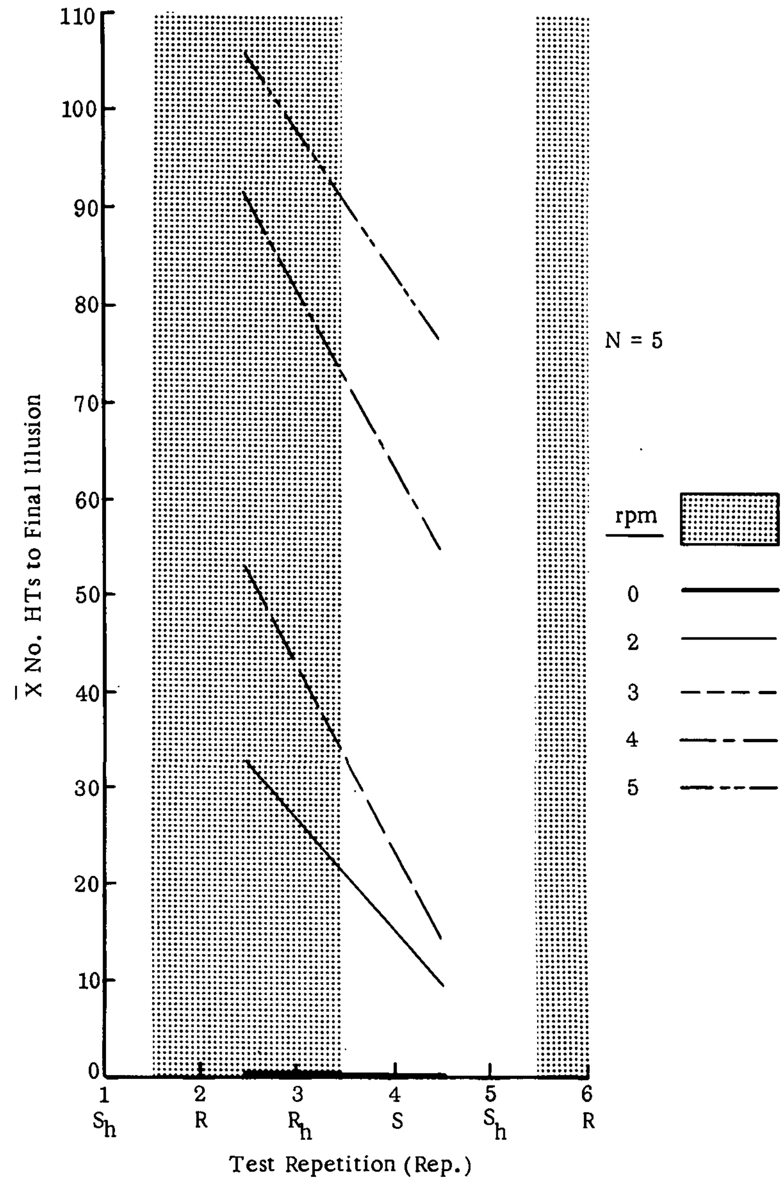

Figure 29. SHTT vs Rep. & rpm.

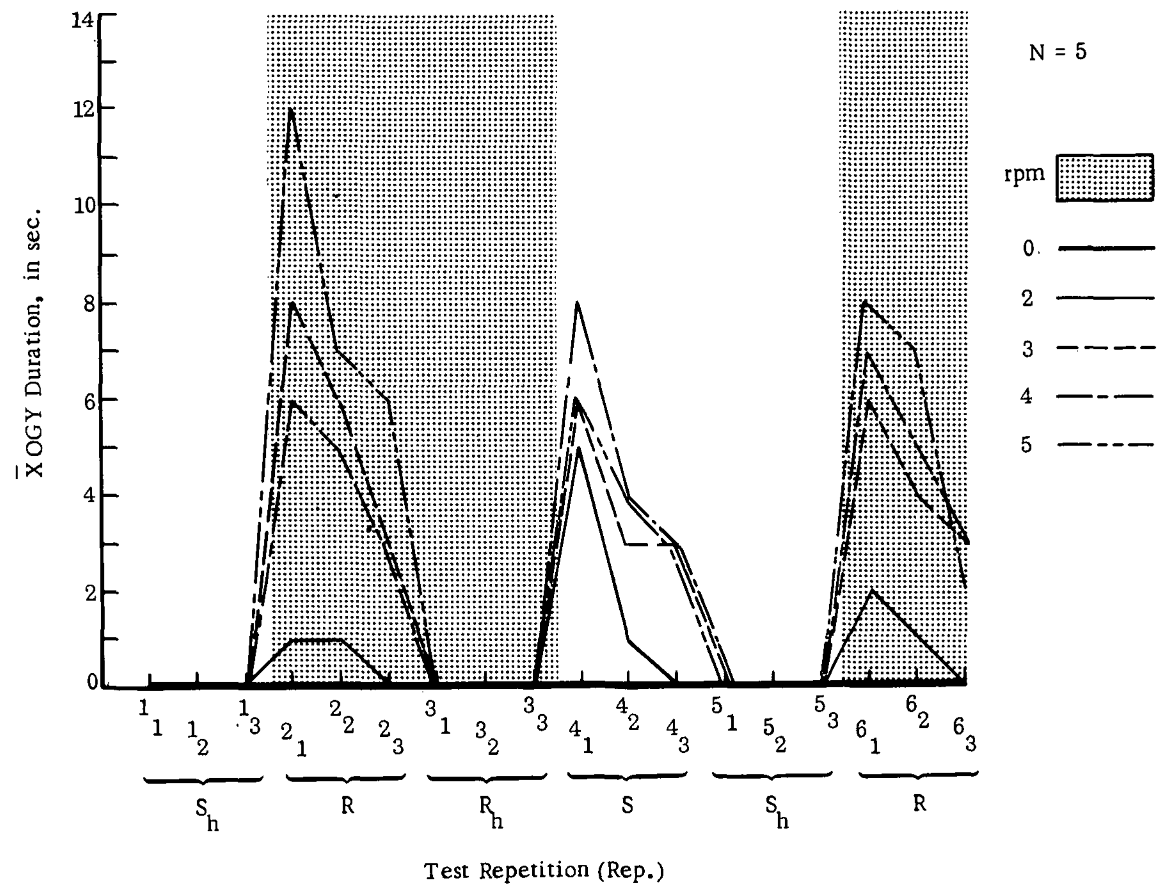

Figure 30. OGY Duration vs Rep. & rpm.

second 'R' repetitions. The graph also indicates that the SHTTs were able to produce complete vestibular habituation to both rotation and nonrotation. The Table 21 summary ANOV indicates significant variance as a function of repetition, rpm and interaction of those two factors. The ANOV then performed on the repetitions at each rpm (Table 22) indicates significant variances only at 4 and 5 rpm. Tables 23 and 24 are the OGY ANOM for the repetitions at these two spin rates. (Note: for typographical convenience, the subscripted subscript used in identifying each repetition was converted into a two digit subscript — e.g., subscript 3_2 to 32.) It is seen that at 4 rpm only the first 'S' repetition and the first repetition of the day's final 'R' exposure demonstrated OGY responses significantly greater than the null responses. At 5 rpm, the significant OGYs occurred during the first two 'R' repetitions and, again, during the first repetition of the day's last 'R' exposure.

3.3 PHYSIOLOGICAL MEASUREMENTS

3.3.1 HEART RATE. The Subject's ECGs recorded continuously on magnetic tape and intermittently on strip chart were evaluated post-test and overall heart rate (HR) averages were estimated for four subject conditions: (1) at rest, (2) while performing the FATB, (3) while performing the RATER, and (4) while performing the LCC. The resulting values, normalized to baseline, are plotted in Figures 31 through 34. Statistical results are given in Tables 25 through 32. While the configuration of the curves for the various tasks and rpm's vary, with the exception of the 4 rpm plots there appears to be a general tendency for the HRs to drop from the initial (baseline) level and then show at least a partial return with the second S_h of the day. The results of the statistical analyses for the four HR conditions followed similar patterns, with detailed tabulation of results presented for HR (FATB) and HR (RATER). For all four conditions, the summary ANOV demonstrated a significant variation in HR as a function of test repetition. As is seen in Tables 27 and 30, this variation is significant only at 2 rpm testing. The ANOM for HR (FATB) repetitions at 2 rpm (Table 28) indicates that the baseline repetition HR was significantly elevated relative to all other repetitions except the last 'R'. The ANOM for HR (RATER) repetitions at 2 rpm (Table 31) indicates that both 'S_h' HRs were elevated relative to the first 'R' and 'S' repetitions.

3.3.2 BLOOD PRESSURE. Systolic, diastolic and pulse pressures were determined, the measurements being taken immediately after the subject performed his last FATB trial (WEC) during each battery repetition. The plots of the normalized data are presented in Figures 35 through 37. Though variations are demonstrated, with the expanded scale of the ordinate the maximal range of the average systolic and diastolic pressures is only 12 percent. The pulse pressures demonstrate greater variation, covering a range of nearly 20 percent. The only trends suggested by the graphs are the decreases in systolic and diastolic pressures demonstrated by the second 'S_h' measurements of the day and the overall tendency (4 rpm data excepted) for a decrease in pulse pressure during the course of the day. The summary ANOVs presented in Tables 33 through 35 indicate that no significant variations in BP occurred.

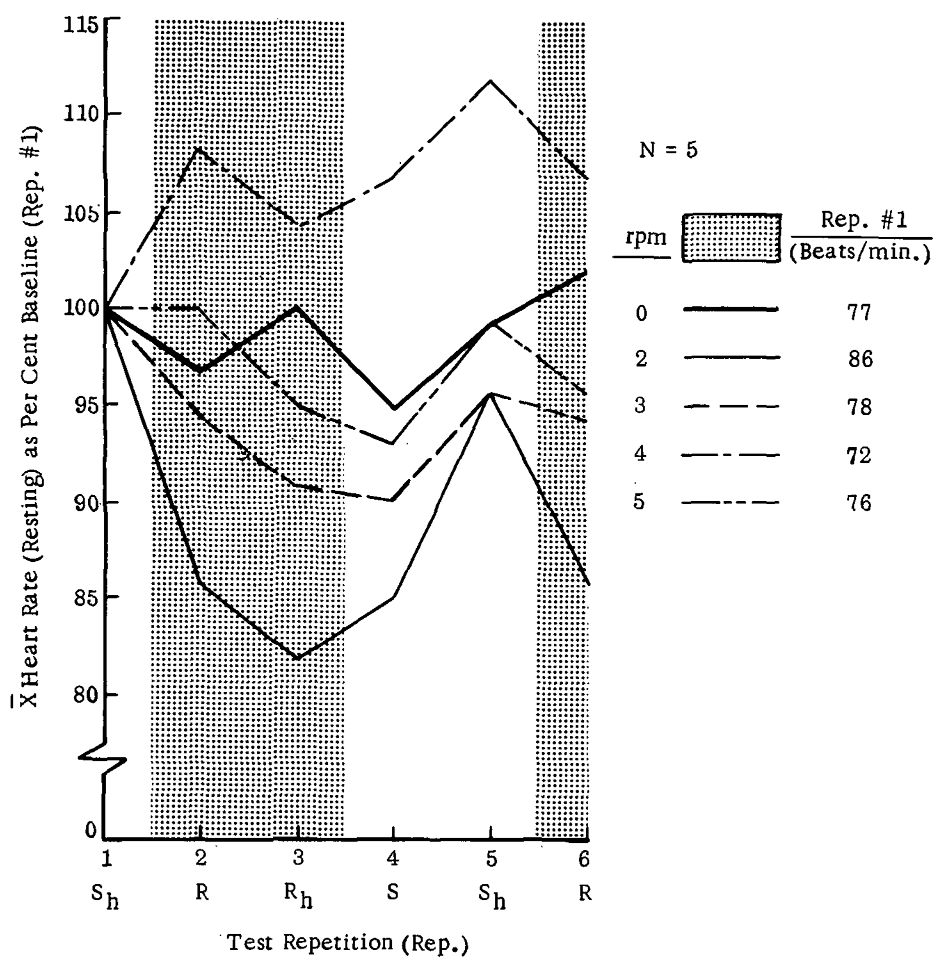

Figure 31. HR (Resting) vs Rep. & rpm.

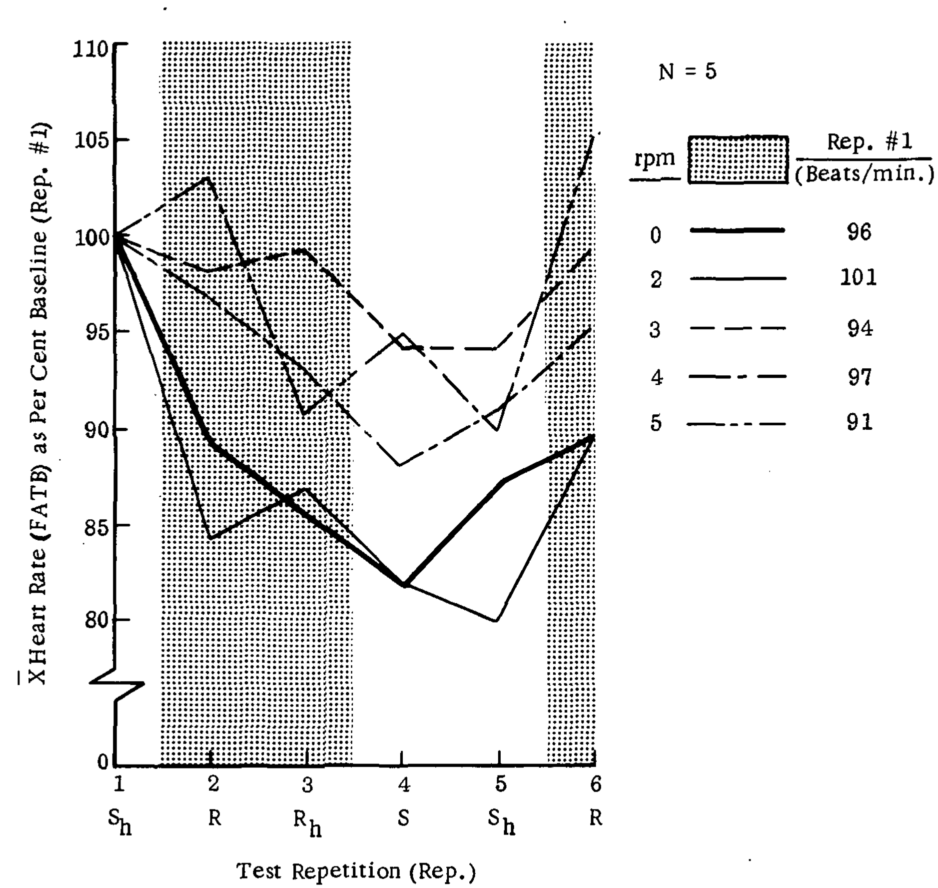

Figure 32. HR (FATB) vs Rep. & rpm.

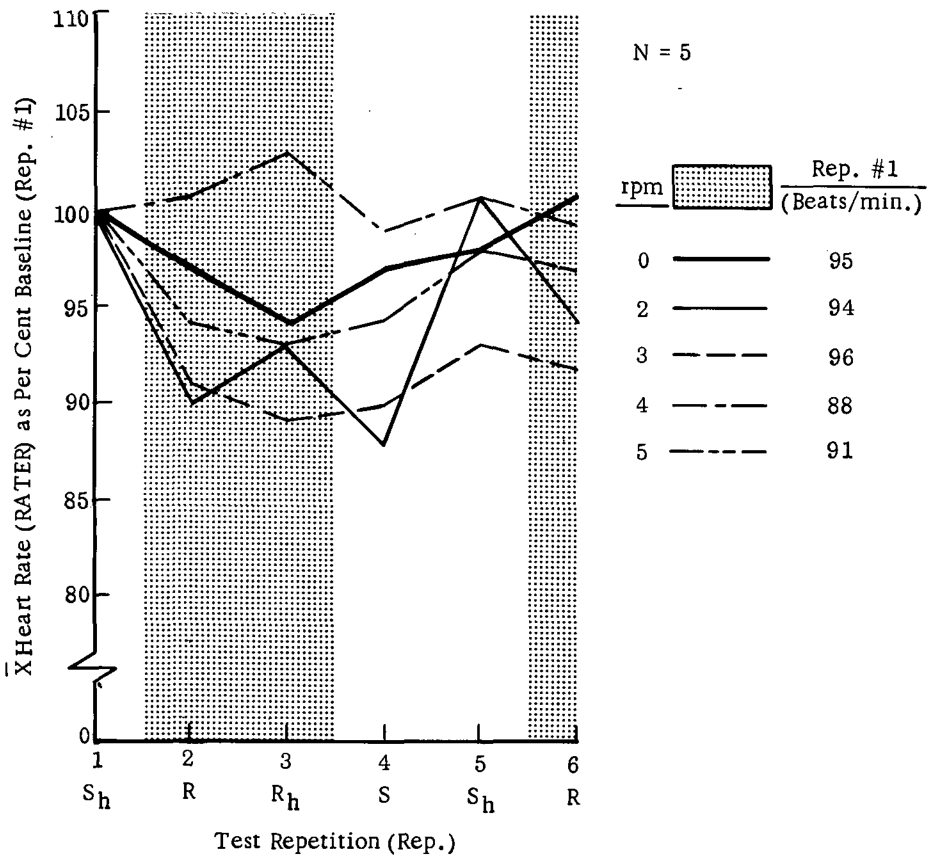

Figure 33. HR (RATER) vs Rep. & rpm.

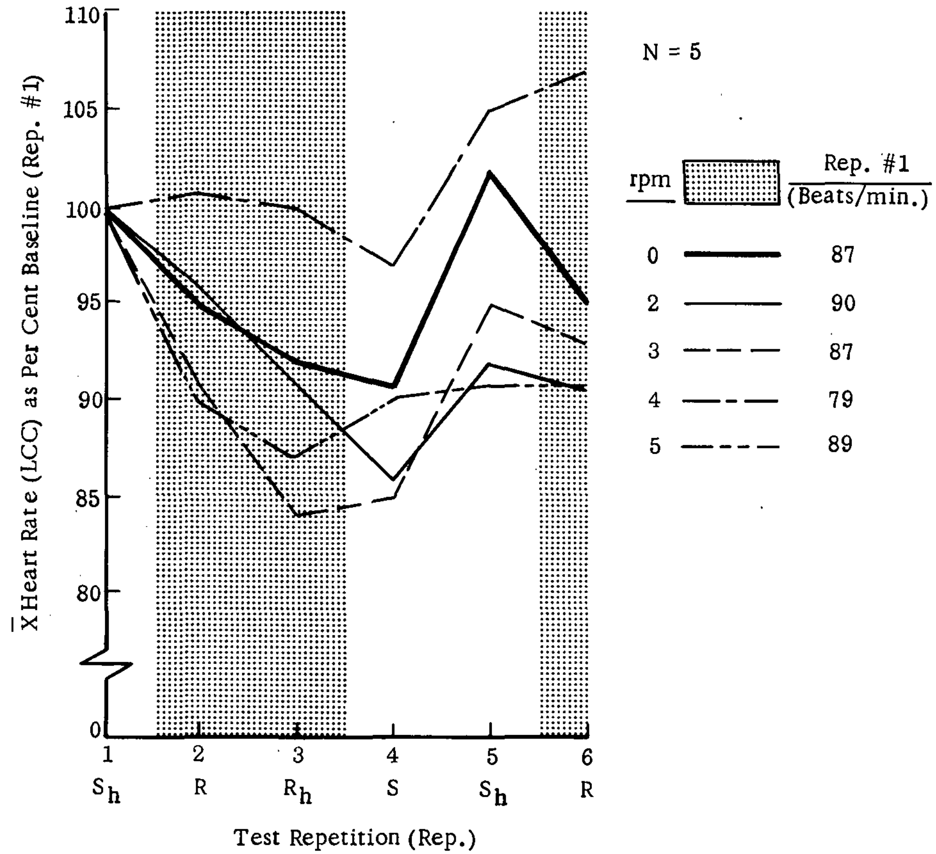

Figure 34. HR (LCC) vs Rep. & rpm.

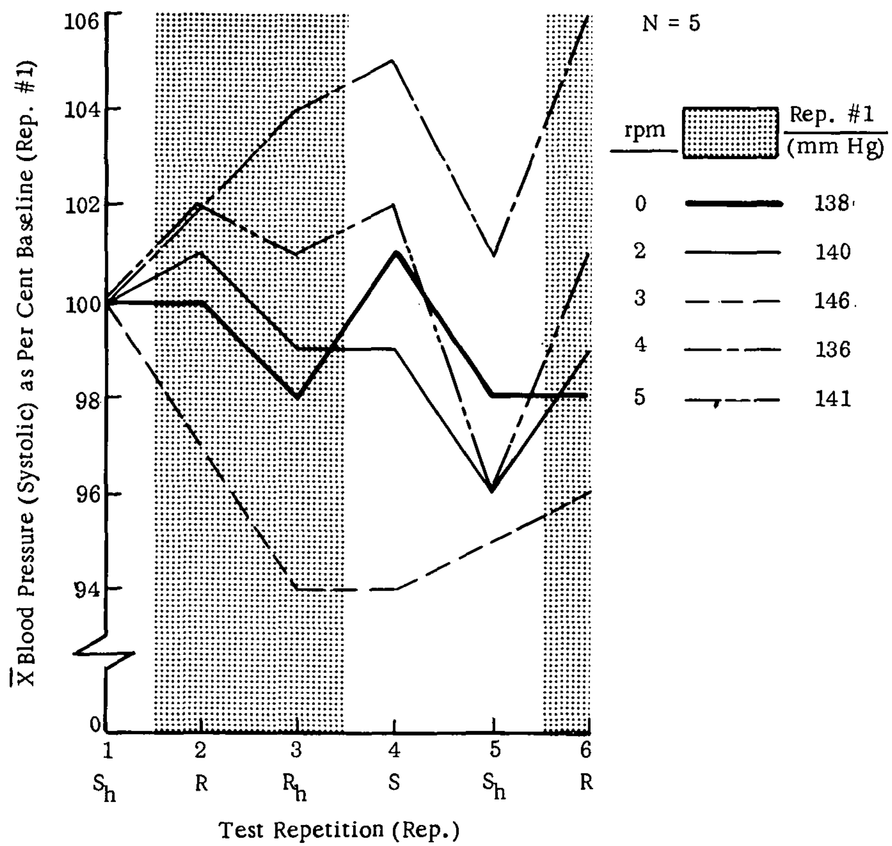

Figure 35. BP (Syst.) vs Rep. & rpm.

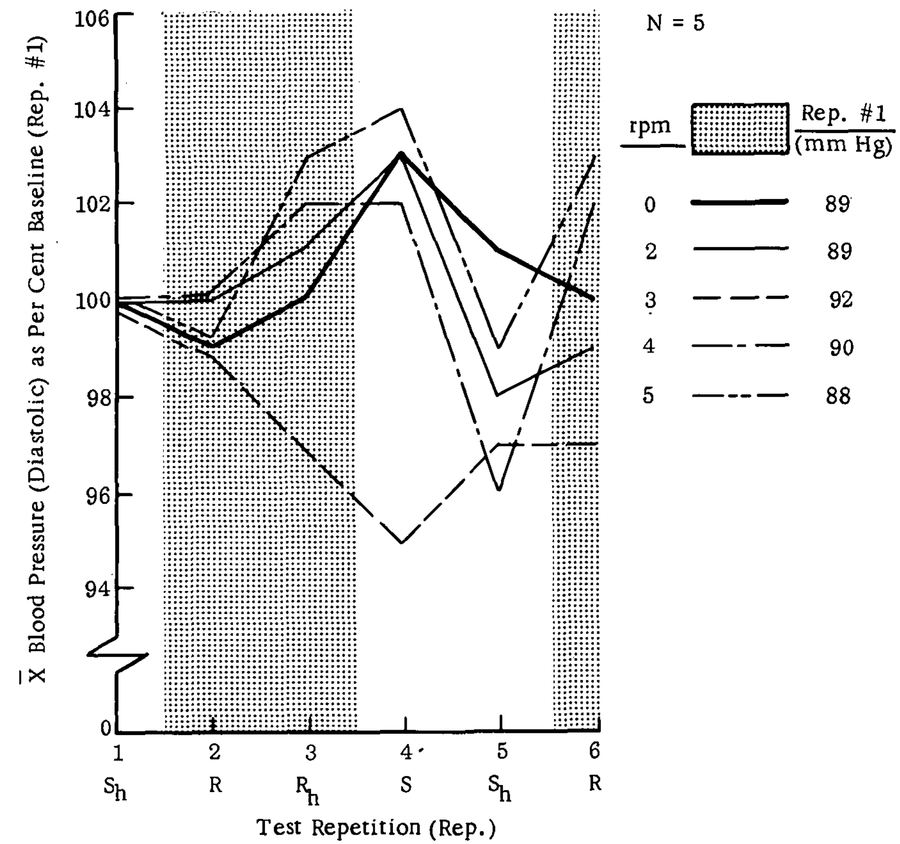

Figure 36. BP (Dias.) vs Rep. & rpm.

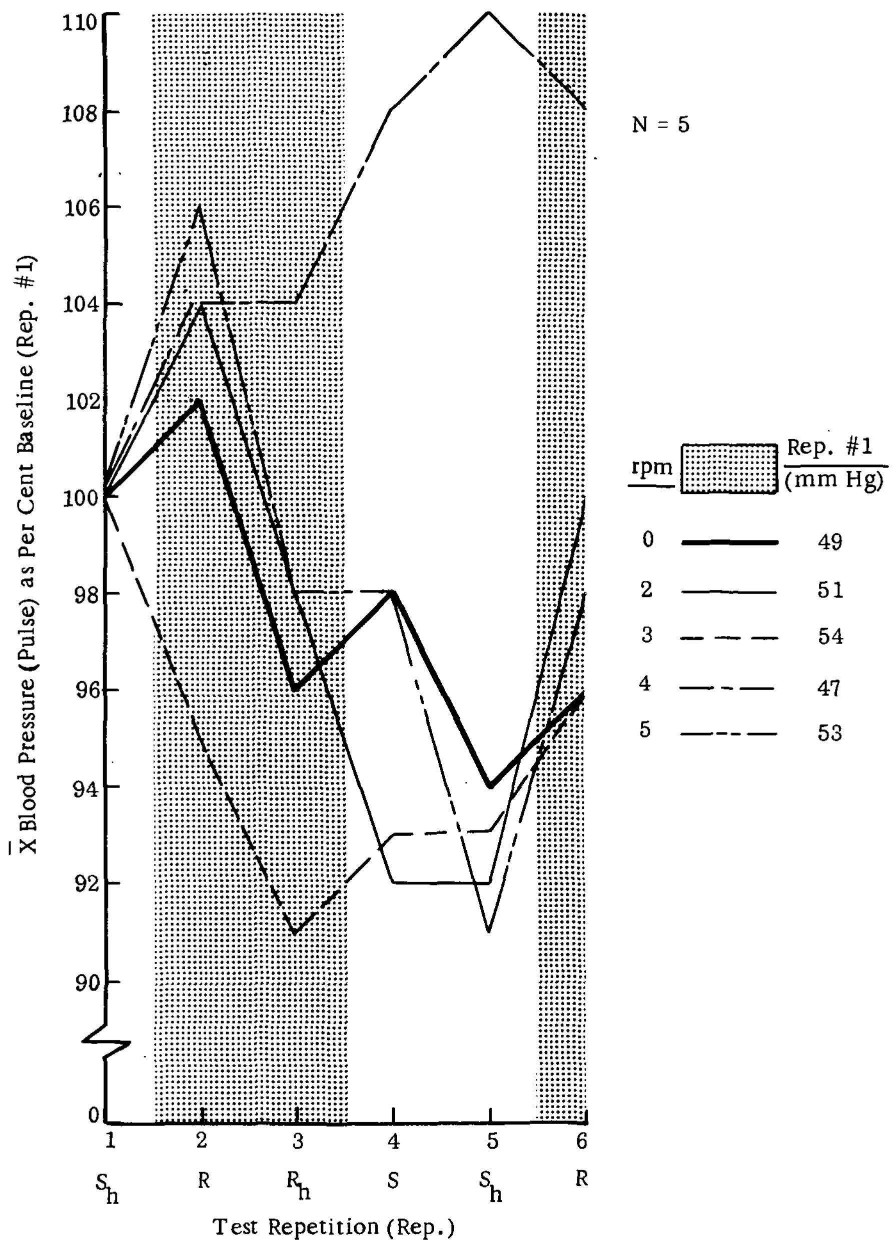

Figure 37. BP (Pulse) vs Rep. & rpm.

3.3.3 RESPIRATION RATE. This measurement was performed with the subject seated and relaxed. Figure 38, the graph of normalized RR values, suggests an rpm-related function in that at 3 rpm and higher there is a relative increase in RR with exposure to rotation. The summary ANOV (Table 36), however, indicates that no significant variations in RR occurred.

3.3.4 URINE SPECIFIC GRAVITY. The graph of normalized values (Figure 39) indicates a gradual decrease in urine concentration as the test day progresses. However, this dilution never exceeds 1.1 percent with the absolute sp. grav. remaining within the normal range. Table 37, the sp. grav. summary ANOV, demonstrates a significant variation as a function of repetitions and interaction of repetitions and rpm's. As an ANOV of the repetitions at each rpm (Table 38) failed to disclose the source of the variations, an ANOM of the repetitions for the combined rpm's was performed. This (Table 39) showed the baseline repetition's sp. grav. to be significantly elevated over all the succeeding samples of the day with the exception of the immediately following one ('R'), which itself was significantly higher than the final sample of the day.

3.3.5 URINE VOLUME. Qualitatively, the urine volume curves (Figure 40) suggest a reverse trend to that of the sp. grav. with the amounts voided tending to increase during the course of the day's testing. Table 40 (summary ANOV) indicates significant variation in volume as a function of repetitions and interaction of repetitions and rpm's. Subsequent statistical analyses showed no significant variance at a given rpm (Table 41), but a significant variation in repetition volumes as a function of the overall rpm's. The repetition ANOM indicated the baseline urine volume significantly smaller than those voided at succeeding repetitions.

3.3.6 ORAL TEMPERATURE. These measurements were taken with the subject seated and relaxed. The plot of the normalized data (Figure 41) suggests no significant changes with the entire range of variation for all rpm's not exceeding one percent. The summary ANOV (Table 42) corroborates this evaluation.

3.3.7 BODY WEIGHT. Comparing sample means as to weight loss per test day at each rpm, the range is seen to be very narrow — from 0.9 to 1.1 lbs, an essentially identical weight loss each day of testing whether rotating or not. This weight change was, of course, significant as shown by the summary ANOV (Table 43).

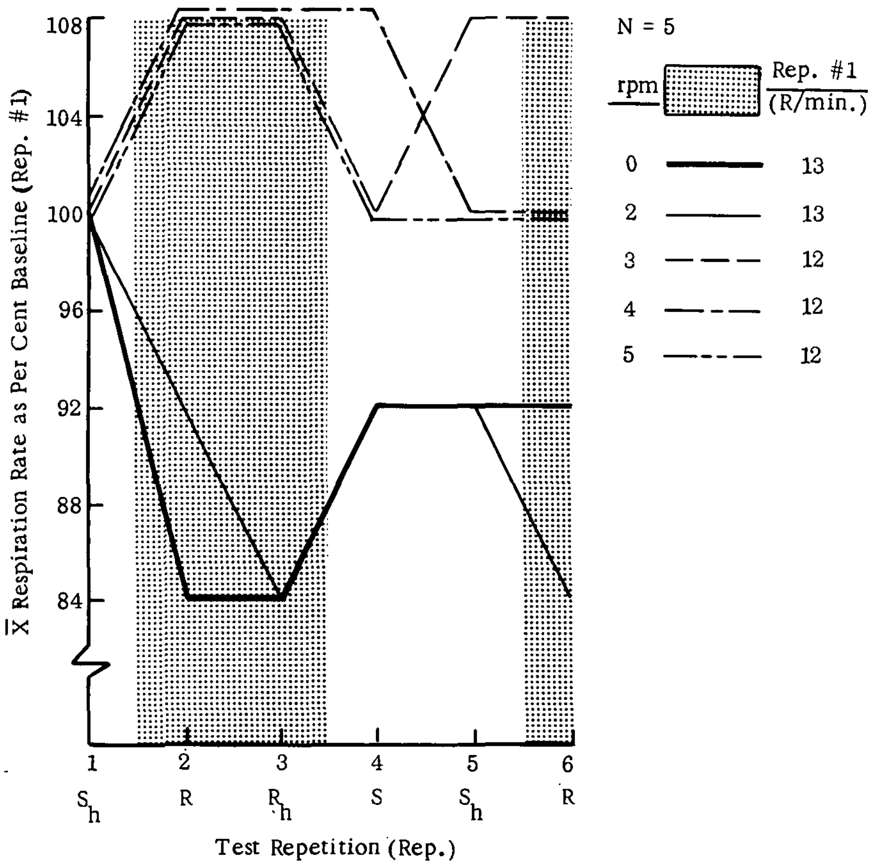

Figure 38. Respiration Rate vs Rep. & rpm.

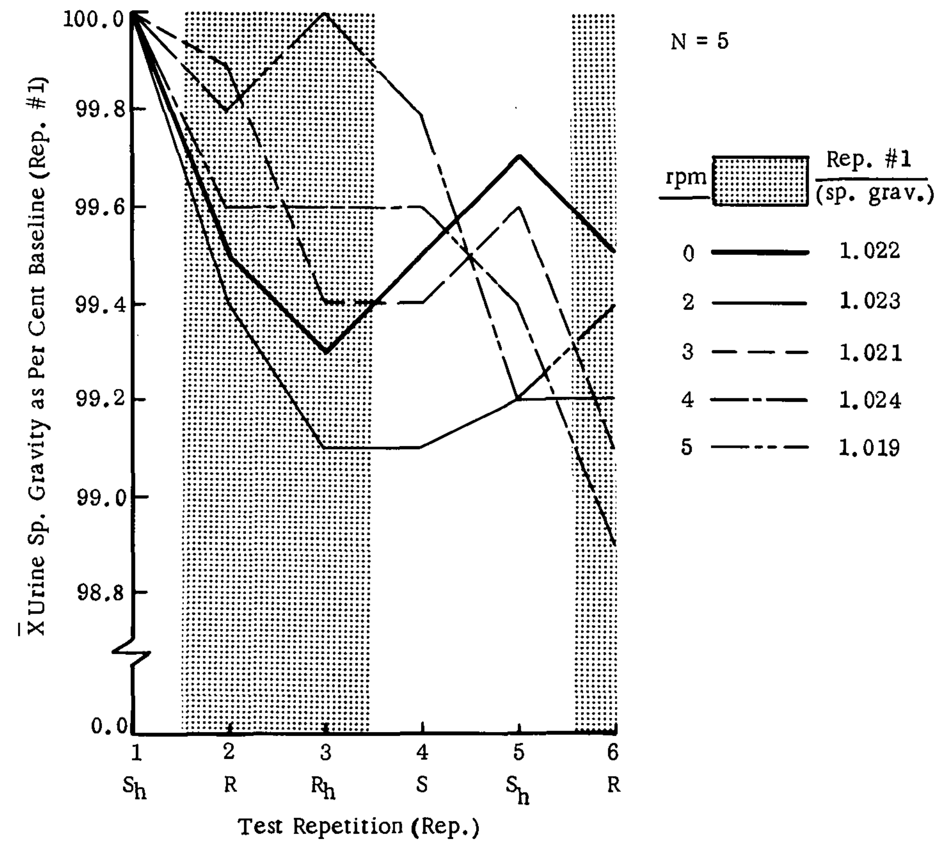

Figure 39. Urine Sp. Gravity vs Rep. & rpm.

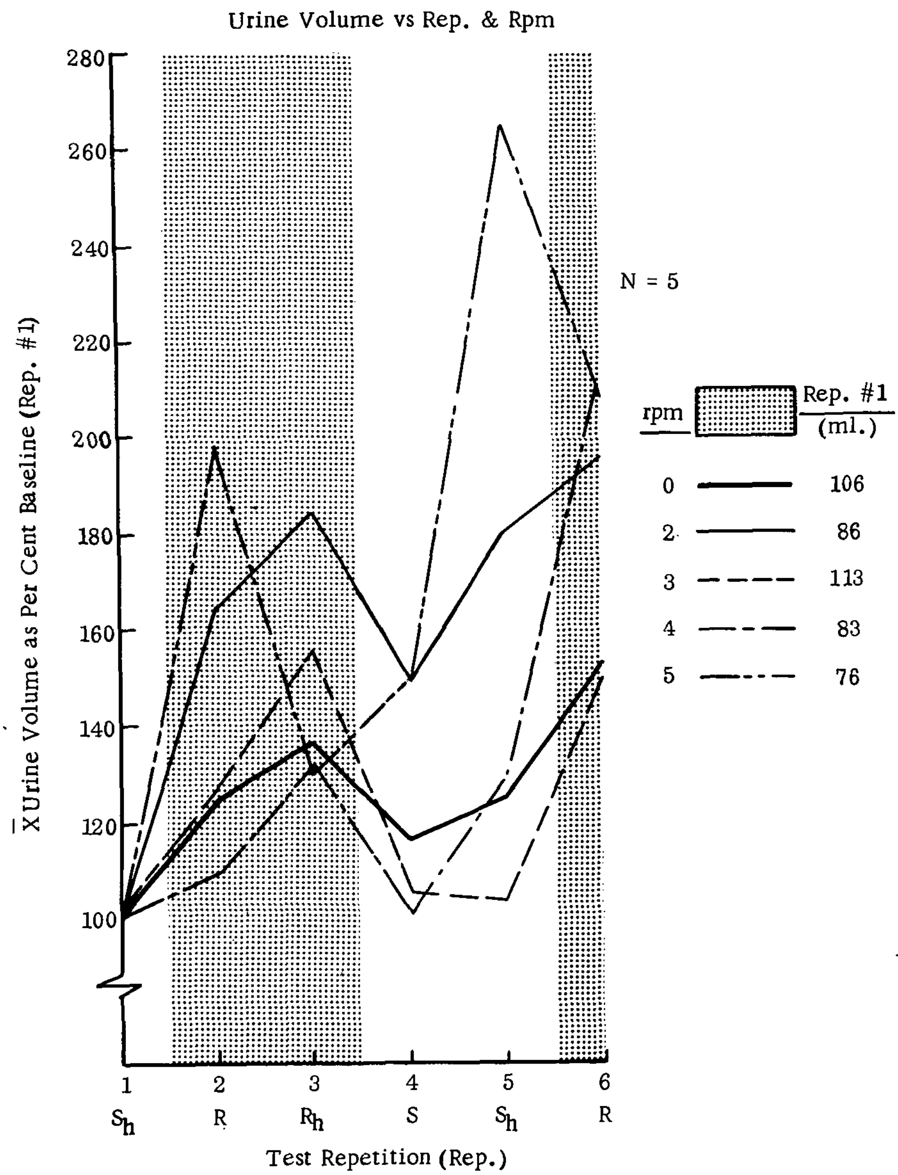

Figure 40. Urine Volume vs Rep. & rpm.

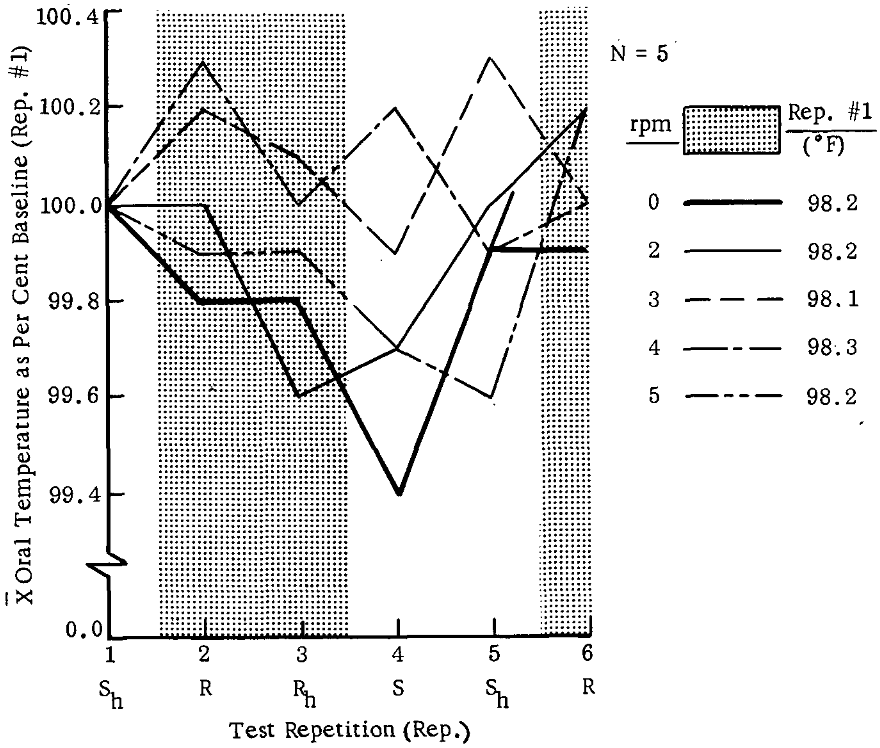

Figure 41. Oral Temp. vs Rep. & rpm.

TABLE 3. FATB (SUT) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	4641.16667	5	928.23333	14.57**
rpm's	1613.16667	4	403.29167	3.22
Reps x rpm's	2303.83333	20	115.19167	1.69

**P < 0.01

TABLE 4. FATB (SUT) ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	340.71	5	68.14	1.07
Reps @ 2 rpm	830.71	5	166.14	2.61
Reps @ 3 rpm	2226.87	5	445.37	6.91**
Reps @ 4 rpm	2090.37	5	418.07	6.56**
Reps @ 5 rpm	1456.33	5	291.27	4.57**

**P < 0.01

TABLE 5. FATB (SUT) ANOM: Reps at 3 rpm

	$\bar{X}_1$	$\bar{X}_5$	$\bar{X}_3$	$\bar{X}_6$	$\bar{X}_2$	$\bar{X}_4$
$\bar{X}_1$	--	6.50	11.00	17.00*	24.25**	27.50**
$\bar{X}_5$		--	4.50	10.50	17.75*	21.00**
$\bar{X}_3$			--	6.00	13.25*	16.50*
$\bar{X}_6$				--	7.25	10.50
$\bar{X}_2$					--	3.25
$\bar{X}_4$						--

*P < 0.05
**P < 0.01

TABLE 6. FATB (SUT) ANOM: Reps at 4 rpm

	$\bar{X}_5$	$\bar{X}_1$	$\bar{X}_3$	$\bar{X}_2$	$\bar{X}_6$	$\bar{X}_4$
$\bar{X}_5$	--	6.75	11.75	16.50*	26.75**	30.00**
$\bar{X}_1$		--	5.00	9.75	10.00	23.25**
$\bar{X}_3$			--		5.00	18.25**
$\bar{X}_2$				--		13.50*
$\bar{X}_6$					--	13.25*
$\bar{X}_4$						--

*P < 0.05
**P < 0.01

TABLE 7. FATB (SUT) ANOM: Reps at 5 rpm

	$\bar{X}_1$	$\bar{X}_5$	$\bar{X}_3$	$\bar{X}_6$	$\bar{X}_2$	$\bar{X}_4$
$\bar{X}_1$	--	12.50*	19.25**	**	**	**
$\bar{X}_5$		--	6.75	7.50	9.00	9.75
$\bar{X}_3$			--			
$\bar{X}_6$				--		
$\bar{X}_2$					--	
$\bar{X}_4$						--

*P < 0.05
**P < 0.01

TABLE 8. FATB (WEC) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	120.26833	5	24.05367	8.32**
rpms	160.67333	4	40.16833	10.20**
Reps x rpm	126.00667	20	6.30033	4.92**

**P < 0.01

TABLE 9. FATB (WEC) ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	0.67	5	0.13	0.04
Reps @ 2 rpm	5.57	5	1.11	0.38
Reps @ 3 rpm	24.80	5	4.96	1.72
Reps @ 4 rpm	100.27	5	20.05	6.94**
Reps @ 5 rpm	114.97	5	22.99	7.96**

**P < 0.01

TABLE 10. FATB (WEC) ANOM: Reps at 4 rpm

	$\bar{X}_2$	$\bar{X}_6$	$\bar{X}_3$	$\bar{X}_4$	$\bar{X}_1$	$\bar{X}_5$
$\bar{X}_2$	--	1.30	2.30	3.00*	5.00**	5.00**
$\bar{X}_6$		--	1.00	1.70	3.70**	3.70**
$\bar{X}_3$			--	0.70	2.70*	2.70*
$\bar{X}_4$				--	2.00	2.00
$\bar{X}_1$					--	0.00
$\bar{X}_5$						--

*P < 0.05
**P < 0.01

TABLE 11. FATB (WEC) ANOM: Reps at 5 rpm

	$\bar{X}_2$	$\bar{X}_6$	$\bar{X}_4$	$\bar{X}_3$	$\bar{X}_1$	$\bar{X}_5$
$\bar{X}_2$	--	0.50	1.00	1.70	4.60**	5.00**
$\bar{X}_6$		--	0.50	1.20	4.10**	4.50**
$\bar{X}_4$			--	0.70	3.60**	4.00**
$\bar{X}_3$				--	2.90*	3.30**
$\bar{X}_1$					--	0.40
$\bar{X}_5$						--

*P < 0.05
**P < 0.01

TABLE 12. FATB (SEC) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	566.93333	5	113.38667	1.73
rpm's	791.56000	4	197.89000	1.29
Reps x rpm's	1299.80000	20	64.99000	0.88

TABLE 13. FATB(SEC) ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	0.57	5	0.11	0.00
Reps @ 2 rpm	10.67	5	2.13	0.03
Reps @ 3 rpm	500.67	5	100.13	1.53
Reps @ 4 rpm	584.17	5	116.83	1.78
Reps @ 5 rpm	767.07	5	153.41	2.34

TABLE 14. RATER ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	72.11500	5	14.42300	0.55
rpm's	1801.47667	4	450.36917	3.66*
Reps x rpm's	874.04333	20	43.70217	1.45

*P < 0.05

TABLE 15. RATER ANOV: rpm's at Each Rep.

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
rpm's @ Rep.1	331.54	4	82.89	0.67
rpm's @ Rep.2	475.70	4	118.92	0.97
rpm's @ Rep.3	256.16	4	64.04	0.52
rpm's @ Rep.4	280.46	4	70.12	0.57
rpm's @ Rep.5	683.80	4	170.95	1.39
rpm's @ Rep.6	647.86	4	161.97	1.32

TABLE 16. RATER ANOM: Overall rpm's

	$\bar{X}_3$	$\bar{X}_4$	$\bar{X}_2$	$\bar{X}_5$	$\bar{X}_0$
$\bar{X}_3$	--	0.9	1.1	2.5	9.5**
$\bar{X}_4$		--	0.2	1.6	8.6*
$\bar{X}_2$			--	1.4	8.4*
$\bar{X}_5$				--	7.0*
$\bar{X}_0$					--

*P < 0.05
**P < 0.01

TABLE 17. RATER ANOV: Reps at Each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	68.67	5	13.73	0.52
Reps @ 2 rpm	261.17	5	52.23	1.98
Reps @ 3 rpm	128.94	5	25.79	0.98
Reps @ 4 rpm	288.44	5	57.69	2.19
Reps @ 5 rpm	198.94	5	39.79	1.51

TABLE 18. LCC ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREE OF FREEDOM	MEAN SQUARES	F RATIO
Reps	127.42000	5	25.48400	0.26
rpm's	1015.39333	4	253.84333	2.72
Reps x rpm's	585.04667	20	29.25233	0.86

TABLE 19. SHTT ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	7837.52000	1	7837.52000	45.57**
rpm's	55465.15000	4	13866.28750	36.49**
Reps x rpm's	2447.03000	4	611.75750	1.15

**P < 0.01

TABLE 20. SHTT ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	0.0	1	0.0	0.00
Reps @ 2 rpm	1428.02	1	1428.02	8.30*
Reps @ 3 rpm	3822.47	1	3822.47	22.22**
Reps @ 4 rpm	3496.90	1	3496.90	20.33**
Reps @ 5 rpm	1537.60	1	1537.60	8.94*

*P < 0.05
**P < 0.01

TABLE 21. OGY ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	1644.18500	17	96.71676	4.59**
rpm's	627.93667	4	156.98417	3.71*
Reps x rpm's	920.42333	68	13.53564	2.84*

*P < 0.05
**P < 0.01

TABLE 22. OGY ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	0.0	17	0.00	0.00
Reps @ 2 rpm	108.52	17	6.38	0.30
Reps @ 3 rpm	606.12	17	35.65	1.69
Reps @ 4 rpm	694.88	17	40.88	1.94*
Reps @ 5 rpm	1155.08	17	67.95	3.23**

*P < 0.05
**P < 0.01

TABLE 23. OGY ANOM: Reps at 4 rpm

	$\bar{X}_{11}$	$\bar{X}_{12}$	$\bar{X}_{13}$	$\bar{X}_{31}$	$\bar{X}_{32}$	$\bar{X}_{33}$	$\bar{X}_{51}$	$\bar{X}_{52}$	$\bar{X}_{53}$	$\bar{X}_{43}$	$\bar{X}_{23}$	$\bar{X}_{63}$	$\bar{X}_{42}$	$\bar{X}_{62}$	$\bar{X}_{22}$	$\bar{X}_{21}$	$\bar{X}_{61}$	$\bar{X}_{41}$
$\bar{X}_{11}$	-	0	0	0	0	0	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{12}$		-	0	0	0	0	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{13}$			-	0	0	0	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{31}$				-	0	0	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{32}$					-	0	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{33}$						-	0	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{51}$							-	0	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{52}$								-	0	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{53}$									-	2.9	3.0	3.0	4.5	4.7	4.8	6.2	7.4*	8.0*
$\bar{X}_{43}$										-	0.1	0.1	1.6	1.8	1.9	3.3	4.5	5.1
$\bar{X}_{23}$											-	0	1.5	1.7	1.8	3.2	4.4	5.0
$\bar{X}_{63}$												-	1.5	1.7	1.8	3.2	4.4	5.0
$\bar{X}_{42}$													-	0.2	0.3	1.7	2.9	3.5
$\bar{X}_{62}$														-	0.1			
$\bar{X}_{22}$															-			
$\bar{X}_{21}$																-		
$\bar{X}_{61}$																	-	
$\bar{X}_{41}$																		-

*$P < 0.05$
**$P < 0.01$

TABLE 24. OGY ANOM: Reps @ 5 rpm

	$\bar{X}_{11}$	$\bar{X}_{12}$	$\bar{X}_{13}$	$\bar{X}_{31}$	$\bar{X}_{32}$	$\bar{X}_{33}$	$\bar{X}_{51}$	$\bar{X}_{52}$	$\bar{X}_{53}$	$\bar{X}_{63}$	$\bar{X}_{43}$	$\bar{X}_{42}$	$\bar{X}_{41}$	$\bar{X}_{23}$	$\bar{X}_{62}$	$\bar{X}_{22}$	$\bar{X}_{61}$	$\bar{X}_{21}$
$\bar{X}_{11}$	-	0	0	0	0	0	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{12}$		-	0	0	0	0	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{13}$			-	0	0	0	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{31}$				-	0	0	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{32}$					-	0	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{33}$						-	0	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{51}$							-	0	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{52}$								-	0	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{53}$									-	2.2	3.7	4.5	5.5	5.6	6.9	7.1*	8.1*	11.7**
$\bar{X}_{63}$										-					4.7	4.9	5.9	9.5**
$\bar{X}_{43}$											-						4.4	8.8*
$\bar{X}_{42}$												-						7.2*
$\bar{X}_{41}$													-					6.2
$\bar{X}_{23}$														-				6.1
$\bar{X}_{62}$															-			4.8
$\bar{X}_{22}$																-		
$\bar{X}_{61}$																	-	
$\bar{X}_{21}$																		-

$^*P < 0.05$
$^{**}P < 0.01$

TABLE 25. HR (Resting) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	628.19500	5	125.63900	2.75*
rpm's	340.40000	4	85.10000	1.04
Reps x rpm's	901.38000	20	45.06900	1.14

*P < 0.05

TABLE 26. HR(FATB) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	2399.63333	5	479.92667	6.85**
rpm's	790.08333	4	197.52083	1.56
Reps x rpm's	1138.61667	20	56.93083	1.89

**P < 0.01

TABLE 27. HR(FATB) ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	803.90	5	160.78	2.29
Reps @ 2 rpm	1231.57	5	246.31	3.51*
Reps @ 3 rpm	182.67	5	36.53	0.52
Reps @ 4 rpm	392.77	5	78.55	1.12
Reps @ 5 rpm	898.94	5	179.79	2.56

*P < 0.05

TABLE 28. HR (FATB) ANOM: Reps at 2 rpm

	$\bar{X}_5$	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_3$	$\bar{X}_6$	$\bar{X}_1$
$\bar{X}_5$	--	1.9	4.4	6.8	8.8	19.7**
$\bar{X}_4$		--	2.5	4.9	6.9	17.8**
$\bar{X}_2$			--	2.4	4.4	15.3*
$\bar{X}_3$				--	2.0	12.9*
$\bar{X}_6$					--	10.9
$\bar{X}_1$						--

*P < 0.05
**P < 0.01

TABLE 29. HR (RATER) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	747.02833	5	149.40567	3.64*
rpm's	481.44000	4	120.36000	2.96
Reps x rpm's	631.48000	20	31.57400	1.57

*P < 0.05

TABLE 30. HR(RATER) ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	196.67	5	39.33	0.96
Reps @ 2 rpm	610.27	5	122.05	2.98*
Reps @ 3 rpm	375.67	5	75.13	1.83
Reps @ 4 rpm	63.37	5	12.67	0.31
Reps @ 5 rpm	129.77	5	25.95	0.63

*P < 0.05

TABLE 31. HR (RATER) ANOM: Reps at 2 rpm

	$\bar{X}_4$	$\bar{X}_2$	$\bar{X}_3$	$\bar{X}_6$	$\bar{X}_1$	$\bar{X}_5$
$\bar{X}_4$	--	2.0	4.4	5.6	11.6*	12.0*
$\bar{X}_2$		--	2.4	3.6	9.6*	10.0*
$\bar{X}_3$			--	1.2	7.2	7.6
$\bar{X}_6$				--	6.0	6.4
$\bar{X}_1$					--	0.4
$\bar{X}_5$						--

*P < 0.05
**P < 0.01

TABLE 32. HR(LCC) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	1401.63333	5	280.32667	8.45**
rpm's	410.05667	4	102.51417	1.12
Reps x rpm's	740.58333	20	37.02917	1.06

**P < 0.01

TABLE 33. BP(Syst.) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	316.46000	5	63.29200	2.49
rpm's	354.40000	4	88.60000	1.05
Reps x rpm's	657.04000	20	32.85200	1.43

TABLE 34. BP(Dias.) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	149.07333	5	29.81467	1.37
rpm's	25.42667	4	6.35667	0.56
Reps x rpm's	298.89333	20	14.94467	1.26

TABLE 35. BP (Pulse) ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	167.09333	5	33.41867	1.06
rpm's	319.29333	4	79.82333	1.41
Reps x rpm's	393.90667	20	19.69533	0.86

TABLE 36. Resp. Rate ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	2.96833	5	.59367	0.42
rpm's	20.84333	4	5.21083	2.59
Reps x rpm's	26.85667	20	1.34283	0.88

TABLE 37. Urine Sp. Grav. ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	.00082	5	.00016	5.33**
rpm's	.00020	4	.00005	0.63
Reps x rpm's	.00048	20	.00002	2.00*

* P < 0.05
** P < 0.01

TABLE 38. Urine Sp. Grav. ANOV: Reps at Each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	.000143	5	.000029	0.97
Reps @ 2 rpm	.000350	5	.000070	2.33
Reps @ 3 rpm	.000236	5	.000047	1.57
Reps @ 4 rpm	.000298	5	.000060	2.00
Reps @ 5 rpm	.000271	5	.000054	1.80

TABLE 39. Urine Sp. Grav. ANOM: Reps Overall rpm's

	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$
$\bar{X}_6$	-	.002	.003	.003	.004*	.007**
$\bar{X}_5$		-	.001	.001	.002	.005**
$\bar{X}_4$			-	.000	.001	.004*
$\bar{X}_3$				-	.001	.004*
$\bar{X}_2$					-	.003
$\bar{X}_1$						-

*P < 0.05
**P < 0.01

TABLE 40. Urine Volume ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	80898.36000	5	16179.67200	2.14*
rpm's	17609.36000	4	4402.34000	0.63
Reps x rpm's	51778.84000	20	2588.94200	1.75*

*P < 0.05

TABLE 41. Urine Volume ANOV: Reps at each rpm

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps @ 0 rpm	8,834.64	5	1,767	0.23
Reps @ 2 rpm	21,948.57	5	4,390	0.58
Reps @ 3 rpm	19,897.74	5	3,980	0.53
Reps @ 4 rpm	30,108.07	5	6,022	0.80
Reps @ 5 rpm	51,888.17	5	10,378	1.37

TABLE 42. Oral Temp. ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	1.63793	5	.32750	1.87
rpm's	2.14127	4	.53532	2.70
Reps x rpm's	2.92973	20	.14649	1.52

TABLE 43. Body Weight ANOV: Summary

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Reps	11.47205	1	11.47205	18.50*
rpm's	4.46170	4	1.11543	1.05
Reps x rpm's	.01770	4	.00443	0.03

*P < 0.01

SECTION 4

DISCUSSION AND CONCLUSIONS

This study was conducted to determine the major physiological and behavioral effects on habituated subjects of their abrupt active transfer — in either direction — across a rotating/non-rotating interface. As such, the study was essentially unprecedented, the only precursive investigations using a similar inertial profile being the previously mentioned GDCA pilot study and one aspect of a recent NR/SD study[12], both studies being restricted as to the rpm's explored and psychophysiological parameters measured The GDCA pilot study, restricted to 2 rpm, did provide results indicating that abrupt transfers might be associated with functional problems, particularly in the area of postural stability. The NR/SD study examined only one ability as a function of abrupt transfer, and unidirectionally from a condition of perrotational habituation into non-rotation. The present GDCA study explored the full range of rpm's (two through five) that would probably be considered in designing an artificial-gravity space vehicle. It employed procedures (the Sequential Head Turn Test and the Sharpened Oculogyral Test) to effect and demonstrate complete canalicular habituation to the pre-transfer inertial mode. It employed performance and physiological measurements that were reasonably inclusive in scope and pertinent to the crew functions that would be required immediately following inertial transition in an operational environment. Finally, postural stability tests were employed which were sensitive indications of the subjects' response to inertial changes in this test environment but which have limited relevance to actual performance requirements in space.

4.1 PERFORMANCE MEASUREMENTS

4.1.1 FLOOR ATAXIA TEST BATTERY. The three postural stability tests — Set Up Time (SUT), Walking with Eyes Closed (WEC), and Standing with Eyes Closed (SEC) — demonstrated decrements following abrupt inertial transfers that were in direct proportion to the head movement required for their individual execution. The SUTs required were nearly doubled relative to baseline when the subjects were unhabituated to the inertial environment, sustaining only nonsignificant decrement — with the exception of 5 rpm — when performing following vestibular habituation. That the canalicular receptors — and the associated spurious coriolis signals — are implicated reasonably follows in that the subject is actively moving his head while attempting to set up for WEC and SEC tests.

The SUT as a postural stability test is an intriguing one in that the subject's eyes are open and he is attempting to spatially orient himself for a task, as would be required operationally; yet it appears to be more inertially sensitive than the severely restrictive tasks of WEC and SEC which require blind performance. The SUT is further of interest in that it was the only measurement taken during the study that demonstrated decrement in accord with the subjects' anecdotal evaluations of environmental stress. The consensus of the subjects — supported, incidentally, by the personal observations of the onboard Test Conductor — was that they were functionally perturbed to the greatest extent while non-habituated to the stationary environment (S). Only the Set Up Time test results, Figure 24 and Tables 3 through 7, support this impression. The tables indicate that SUT scores while non-habituated to the stationary environment (S or $\bar{X}_4$) did indeed show the largest decrement from the baseline (S_h or $\bar{X}_1$) repetition, significant at the .01 level at 3, 4 and 5 rpm. While unsupported statistically, the other subjective rankings of the environments, in order of decreasing stress, initial 'R', second 'R', 'R_h', and second 'S_h', tend to be supported by the data trends illustrated in Figure 24. The lack of correlation of most test results with this subjective impression is analogous to what was found in the NR/SD test: that the subjects "felt" they had performed worse at the non-rotating hub station than they had at the rotating stations from which they had abruptly transferred whereas they had actually performed better[13].

The Walking with Eyes Closed test — requiring some, but not as much, head movement as the Set Up Time test — demonstrated significant decrement only at 4 and 5 rpm (SUT was degraded even at 3 rpm) with the 'S' performance degraded significantly only at 5 rpm. The maximum WEC decrement of 50 percent does not exceed that experienced in other studies performed at GDCA using, e.g., 5 min.[14] and 6 hr.[15] passive inertial transfers from the static condition.

The Standing with Eyes Closed test, which involves minimal head movement, demonstrated only nonsignificant decrement (the maximal average reduction being 12 percent), a reduction in performance ability dramatically smaller than was recorded in the study using the 6 hr. transfer[15].

4.1.2 RATER TEST. The only significant variation for this test was that, when comparing total test-day performance on an inter-rpm basis, performance involving rotation was degraded relative to context involving no rotation. This is not initially apparent in Figure 27, the plot of Response Analysis Tester (RATER) performance, as the data normalization obviates the inter-rpm baseline score differences (e.g., 0 rpm being 5 percent higher than 2 rpm and 2 percent higher than 5 rpm). Of direct importance to the objectives of this study, of course, is the failure to demonstrate inter-repetition decrements at any of the spin levels indicating that abrupt inertial transitions in either direction do not affect one's ability to perform a control/display task requiring random, large-excursion, multi-planar head and arm movements and visuo-motor acuity.

4.1.3 LANGLEY COMPLEX COORDINATOR TEST. As with the RATER task, the LCC performance was not affected by abrupt inertial transitions. The LCC Complex Mixed (M II) Program used throughout the training for, and conduct of, the formal test is patently demanding and sensitive to subject perturbations[16]. (Note: the best time of two juxtaposed trials was used as the performance index due to the rapid decay of a subject's ability when not utilized.) Therefore, the results for this task indicate that abrupt inertial transitions are not detrimental to psychomotor tasks requiring cognitive decisions and fine multi-limb coordination. The failure of as challenging a task as the LCC to sustain performance decrement under the conditions of this test provides a graphic example of the adaptive potential of elite subjects as considered at length in a previous report[17].

4.2 HABITUATION MEASUREMENTS

4.2.1 SEQUENTIAL HEADTURN TEST (SHTT). This five-minute, 120-headturn procedure was successful at all rpm's in accomplishing its purpose of producing complete canalicular habituation in all subjects. Predictably, the higher the day's rpm level, the greater were the number of headturns required to effect habituation whether in 'R' or 'S' modes. In no instance, however, was the full number of 120 headturns required, indicating that if hypogravitation in space does not alter the ground-based responsivity of the vestibulogenic reflexes this five-minute exercise would be sufficient to prepare crew members to each mode alternation in a zero-g/artificial-g vehicle. The consistently fewer number of headturns required for 'S' habituation relative to 'R' habituation at a given rpm level logically relates to one or both of two factors: a greater ease of re-establishing conditioned response due to the background of chronic habituation to non-rotation, or an incompleteness of perrotational habituation that was undetectable using even the OGY test. It needs to be emphasized that at even the highest rpm no subject had to interrupt his performance of the SHTT due to incipient motion sickness.

4.2.2 OCULOGYRAL (OGY) TEST. The results of this test demonstrated, as stated above, the essential completeness of canalicular habituation effected by the SHTT. No subjects experienced detectable OGYs in a particular inertial mode following performance of the SHTT. Also, the OGY responses were not significantly greater than those reported by a comparable sample of four subjects following a 6-hr. passive change in angular velocity of similar magnitude[15]. Finally, in accord with what has been reported in the literature concerning their relative thresholds[18], the postural illusions experienced during the pitch-up of the head (the first maneuver of the OGY test) were always smaller in number and magnitude than the OGYs experienced during the pitch-down head movement.

4.3 PHYSIOLOGICAL MEASUREMENTS

4.3.1 HEART RATES. The results of the heart rate measurements for the four conditions considered (resting, Floor Ataxia Test Battery, RATER, and Langley Complex Coordinator) are unremarkable. The absolute rates tend to increase in the order resting, LCC, RATER, and FATB, consistent with the level of physical exertion required in each condition. For a given condition, HRs tend to be higher for the first repetition (baseline) than for succeeding measurements, significantly so for 2 rpm testing. The relatively higher rates for baseline testing are logically attributable to anxiousness on the part of the subjects as to that day's testing. Considering that at submaximal levels of exertion the heart rate tends to overestimate energy costs[19], the moderate rates recorded during this study demonstrate — coupled with the nonsignificance of the variations — the minimal physiological stress associated with abrupt transfers even at the highest rpm.

4.3.2 BLOOD PRESSURES. The variations in systolic, diastolic and pulse pressures were well within nominal ranges and nonsignificant as to rpm and repetition. This reflects the minimal physiological stress associated with the abrupt transfers and is consistent with absence of the autonomic activity that would have accompanied any pronounced kinetosis.

4.3.3 URINALYSIS. All urine samples were normal as to pH, protein, and glucose. The tendency to a more copious, more dilute urine with inertial changes relative to baseline is antithetical to the responses demonstrated in previous studies involving perrotational stress. As the required fluid intake in this study was regulated to the nominal volume of 100 ml/hour and the urinary secretion was normal, further evidence is provided that the various spin levels and inertial changes were not stressful to the subjects. Coinciding with this is the observation that the only urine specimens that manifested a phosphate-rich ppt. following overnight refrigeration — a urinary characteristic associated with stress — were the baseline (Repetition #1) samples. This last observation is consistent with the moderately elevated heart rates also occurring during baseline testing.

4.3.4 OTHER PHYSIOLOGICAL PARAMETERS. Respiration rates and oral temperatures were not significantly changed from control values. The consistency in loss in body weight per test day — range of means being 0.9 to 1.1 lb — documents the stringency of the activity schedule and the absence of variations in energy cost due to rpm level. In view of the demanding schedule, the mean energy expenditure of approximately 1100 Btu/hr per man is not excessive. No level of acute motion sickness greater than MI (slight malaise)[20] was experienced by any subject during the entire testing program, testimony to the efficacy of the SHTT for effecting rapid habituation without undue stress.

4.4 CONCLUSIONS

There is no indication — on the basis of comparison with the results of previous studies — that abrupt inertial transfers within this rpm range are more degrading to physiology and performance than are gradual transfers of short (minutes) duration. And there is no indication from the results of this study that abrupt active transfers of habituated personnel in either direction across the inertial interface of operational systems using spin rates as high as 5 rpm would not be acceptable if one assumes that a subject's response to a given acceleration or Coriolis force, when superimposed upon a background of zero g in space, is quantitatively and qualitatively the same as the subject's response to these same forces superimposed upon the background of one g in an earth-based environment. A battery of ground-based tests of crew responses in simulated artificial gravity, if repeated in a real artificial-gravity environment in space, would determine the extent to which ground artificial-g test data can be confidently applied to space planning.

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