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21 September 1967

Scientific and Technical Information Facility
Attention: NASA Representative
Post Office Box 5700
Bethesda, Maryland

Reference: (a) Contract NASW-1329

Gentlemen:

Enclosed are a reproducible original and one copy each of two final reports prepared under the reference (a) contract. The titles of these reports are:

"Development of an Improved Perceptual-Motor Performance Measurement System"

"Effect of Heat Stress and Prolonged Activity on Perceptual-Motor Performance"

Additional copies are being distributed as specified in the contract.

Sincerely,

William Paul Shanahan

William Paul Shanahan
Secretary-Treasurer

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Enclosure
Copy to: Code BCA

DEVELOPMENT OF AN IMPROVED PERCEPTUAL-MOTOR PERFORMANCE MEASUREMENT SYSTEM

By Raymond E. Reilly and James F. Parker, Jr.

August 1967

Prepared under Contract No. NASW-1329 by

BIOTECHNOLOGY, INC.
3219 Columbia Pike
Arlington, Virginia

for Headquarters

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report was prepared by BioTechnology, Inc., as one task under Contract No. NASW-1329 with the National Aeronautics and Space Administration. The work was performed under the direction of the Manned-Systems Integration Branch, Biotechnology and Human Research Division, of the Office of Advanced Research and Technology with Dr. Stanley Deutsch serving as the NASA Project Monitor. Dr. Deutsch was most helpful during the establishment of design objectives for the modification of the measurement consoles and during the review of the draft manuscript.

ABSTRACT

This report describes the development and fabrication of three units of a perceptual-motor performance measurement system. The measurement system, consisting of a subject console and an experimenter console, is designed to measure 18 basic dimensions of human perceptual-motor performance. The present system represents an improved version of an earlier measurement console built under a prior NASA contract. Improvements are primarily in the areas of (1) separation of the subject and experimenter functions, thereby making the device more useful as an item of research equipment, (2) increased reliability during sustained operations, and (3) better design for maintainability.

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Introduction

This report describes the development and fabrication of an integrated test battery designed to measure eighteen basic dimensions of human perceptual-motor performance. The system was conceived as an efficient means of assessing a broad range of primary performance abilities which appear to characterize both present and foreseen man-machine operations in the aerospace field.

Selection of the particular abilities to be tested was based on an extensive analysis of factor analytic and system-oriented studies of human perceptual-motor performance. The resulting test battery is intended to provide a profile of basic and relatively independent measures of component skills which underlie the execution of more complex man-machine interactions.

Development of an integrated perceptual-motor performance test battery is a logical consequence of research in the field of performance assessment coupled with the requirement for efficient measurement techniques within the aerospace environment.

In 1964 work was begun by BioTechnology, Inc., under the auspices of the National Aeronautics and Space Administration (Contract NAS9-2542) on the development of an integrated battery of tests to measure the primary dimensions of perceptual-motor performance. Following an extensive review and analysis of the technical literature on studies of perceptual-motor performance and a task analysis of astronaut performance requirements in the Gemini flights, eighteen basic measures were selected for inclusion in the battery. As represented in the form of standard tests, these measures presented a rather large array of materials ranging from simple paper-and-pencil tests to bulky electronic and electro-mechanical devices. The requirement at that point was to redesign the

tests, make them compatible with the space environment (e.g., weightlessness), and attempt to integrate all components into a reasonably compact and lightweight prototype testing device.

A test console was developed which demonstrated the feasibility of the "integrated battery" approach. The completed test console is shown in Figure 1. All electronic and electromechanical components are contained within this unit. A limited number of ancillary plug-in components, used to test abilities such as manual dexterity, are not shown in this view.

Upon completion of the console, the test battery was administered to a group of ten adult males. This permitted the refinement of test procedures and instructions and provided an estimate of administration time for each test. The results were used in the preparation of a manual of operating and test instructions.

At the conclusion of the program, the prototype console was delivered to the Manned Spacecraft Center. A NASA Contractor's Report (Parker, Reilly, Dillon, Andrews, & Fleishman, 1965) was prepared which presents the complete rationale for the development program and describes the console in detail.

After a brief period of use at the Manned Spacecraft Center, the console was transferred to the University of Houston for a more complete evaluation using a large number of subjects. The purpose was to validate the basic concepts and to pinpoint problems relating to the operating reliability and maintainability of the device.

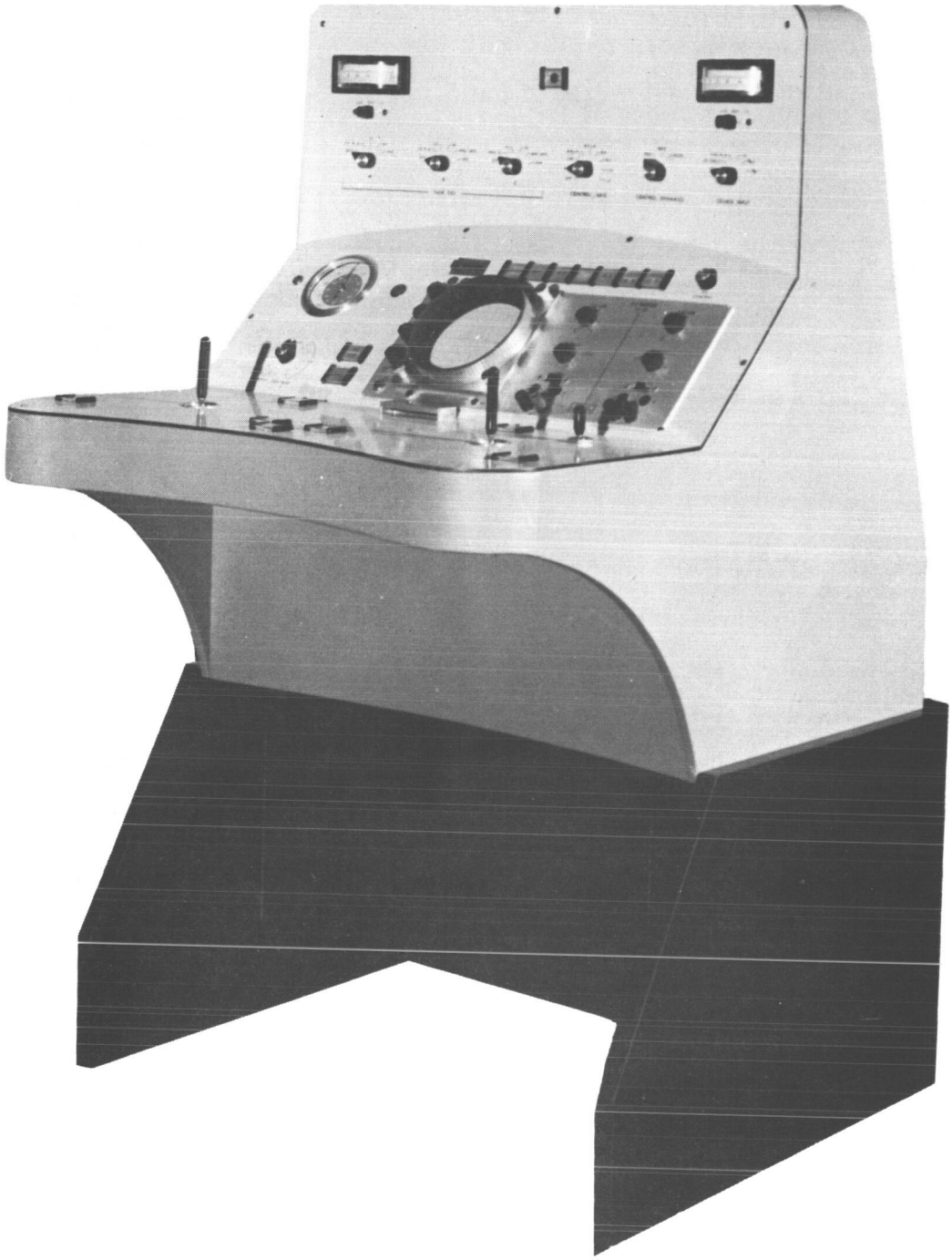

Figure 1. Prototype Perceptual-Motor Performance Measurement Console

Objectives of System Redesign

The objective of the present effort was to produce an improved version of the test console by capitalizing on the experience and information gained through development and use of the prototype model. In this regard, efforts were focused on three major requirements: (1) reconfiguration of the system to permit remote test administration, (2) improvement of the functional reliability of the system, (3) simplification of construction, calibration, and maintenance. The following sections describe the basic changes which were effected during the redesign. A more detailed list of console modifications is presented as Appendix C.

System Reconfiguration

The prototype model was built as a single unit encompassing all displays, controls, and components. While this design is appropriate for conditions in which a single individual in isolation could self-administer the tests, it was decided that the system would have greater utility for research purposes if the subject and experimenter functions were separated so that subjects could be tested within a particular environment while the experimenter operated from outside that environment. Accordingly, the system was redesigned as two units, one for the subject containing all test display and response elements, and an experimenter console through which all test setups, programming, and scoring are accomplished. The two consoles are connected by a single multiconductor cable approximately twenty feet in length.

Auxiliary output terminals were added to the experimenter's console so that, with appropriate ancillary equipment, he can monitor all subject display functions (e.g., oscilloscope activity) and record subject response times and errors automatically.

Functional Reliability

Inasmuch as the prototype was constructed to demonstrate the feasibility of packaging some eighteen different tests, little effort was directed toward providing durability and high mechanical reliability. Such considerations were properly reserved until the overall design could be finalized. To that extent, the prototype served its intended purpose.

In the present effort, all internal circuits and components of the system were reviewed carefully and redesigned to achieve a level of functional reliability and durability consistent with extensive use of the device.

Major changes in the internal design construction of the system involved (1) replacement of units found to have questionable reliability, such as the camswitch programmer, and the 28-volt power supply, with more expensive components of higher quality, (2) simplification of electronic circuits, and (3) substantial reduction of handwiring through the substitution of printed circuit cards. The internal construction of the system now bears little resemblance to that of the prototype. Subject display and control components and their spatial arrangement on the console, however, were not changed since these were established on the basis of original task definitions.

Calibration and Maintenance

To facilitate calibration and maintenance activities, the redesign effort was conducted with four objectives. These were:

1. Rapid disassembly and assembly of major components.
2. Easy access to circuitry and components for testing, repair, or replacement.

3. Easily traceable circuitry to simplify location and remedy of malfunctions.

4. Conveniently located and plainly marked test points.

Major improvements were effected through use of printed circuit cards, as noted earlier, which eliminated approximately 80 percent of what was originally point-to-point handwiring. All relays, operational amplifiers, and calibration potentiometers are affixed to the cards by plug-in connectors, and the cards, in turn, plug into the console. All amplifier outputs now are represented in a row of test terminals along the inside top of the experimenter console.

Access to components in the experimenter console may be gained through the hinged cabinet top or by removing the front or back panels held in place by a few screws. Both the horizontal and vertical front panels of the subject console are easily removed for troubleshooting and maintenance purposes.

End Products

Three improved perceptual-motor performance measurement systems were produced and delivered to the National Aeronautics and Space Administration in accordance with contract requirements. Included in this delivery were operating manuals, a 16mm color motion picture projector showing the device in operation, a set of 35mm color transparencies, and 8 x 10 inch color photographs of the device.

Upon completion of the first of the three test consoles, a research study was conducted using this device to assess the effect of high ambient temperature and prolonged activity on perceptual-motor performance. This experiment is described in a separate report (Reilly & Parker, 1967) submitted in fulfillment of the remaining major requirements of the contract.

REFERENCES

Parker, J. F., Jr., Reilly, R. E., Dillon, R. F., Andrews, T. G., & Fleishman, E. A. Development of tests for measurement of primary perceptual-motor performance. NASA CR-335, National Aeronautics and Space Administration, Washington, Dec. 1965.

Reilly, R. E., & Parker, J. F., Jr. Effect of heat stress and prolonged activity on perceptual-motor performance. BioTechnology, Inc., Tech. Rpt. prepared for Headquarters National Aeronautics and Space Administration, Washington, under contract NASW-1329.

APPENDIX A

Description and Operation of Test Battery

Tests included in the battery were designed to measure the basic perceptual-motor abilities listed in Table 1. A description of each test and details concerning its administration are presented following the discussion of the test consoles.

Test Consoles

The testing system is comprised of two main units, the subject console and the experimenter console (Figure 2) plus certain ancillary items used by the subject in conjunction with his console. The two units are connected by a cable. With the exception of a few adjustments of the subject's oscilloscope, all test setup, programming, and scoring is done through the experimenter console. Console dimensions, weight, and power requirements are shown in Table 2.

Table 1

Eighteen Basic Perceptual-Motor Abilities for Which Performance Measures are Obtained

Ability	Description of Behavior
Fine Manipulative Abilities	
Arm-Hand Steadiness	Hold arm and hand steady while fully extended.
Wrist-Finger Speed	Make rapid, repetitive, tapping movements.
Finger Dexterity	Manipulate small objects with fingers.
Manual Dexterity	Manipulate large objects with hands.

(Continued)

Table 1--Continued

Ability	Description of Behavior
Gross Positioning and Movement Abilities	
Position Estimation	Reach for specific locations without use of vision.
Response Orientation	Make appropriate directional response to nonspatial stimulus.
Control Precision	Make fine, controlled positioning movements.
Speed of Arm Movement	Make discrete, rapid arm movements.
Multilimb Coordination	Use hands and/or feet simultaneously.
Position Reproduction	Repeat discrete arm-hand movement without aid of vision.
System Equalization Abilities	
Movement Analysis	Differentiate target velocity and acceleration.
Movement Prediction	Integrate target motion components to estimate future target position.
Rate Control	Control vehicle having first-order system dynamics.
Acceleration Control	Control vehicle having second-order system dynamics.

(Continued)

Table 1--Continued

Ability	Description of Behavior
Perceptual-Cognitive Abilities	
Perceptual Speed	Make rapid visual comparison of display elements.
Time Sharing	Divide attention among several displays.
Reaction Time Ability	
Reaction Time	Respond as rapidly as possible to discrete signal.
Mirror Tracing Ability	
Mirror Tracing	Use mirror-image display to perform directional hand-arm movements.

Table 2

Descriptive Data Concerning
Perceptual-Motor Measurement System

	Experimenter Console	Subject Console
Dimensions (in.)	16.5 x 21 x 19.5	29.5 x 26 x 16.5
Weight (lbs.)	65	40
Operating Power	117 vac, 60 cycles @ less than 3 amps	all power supplied by experimenter console.

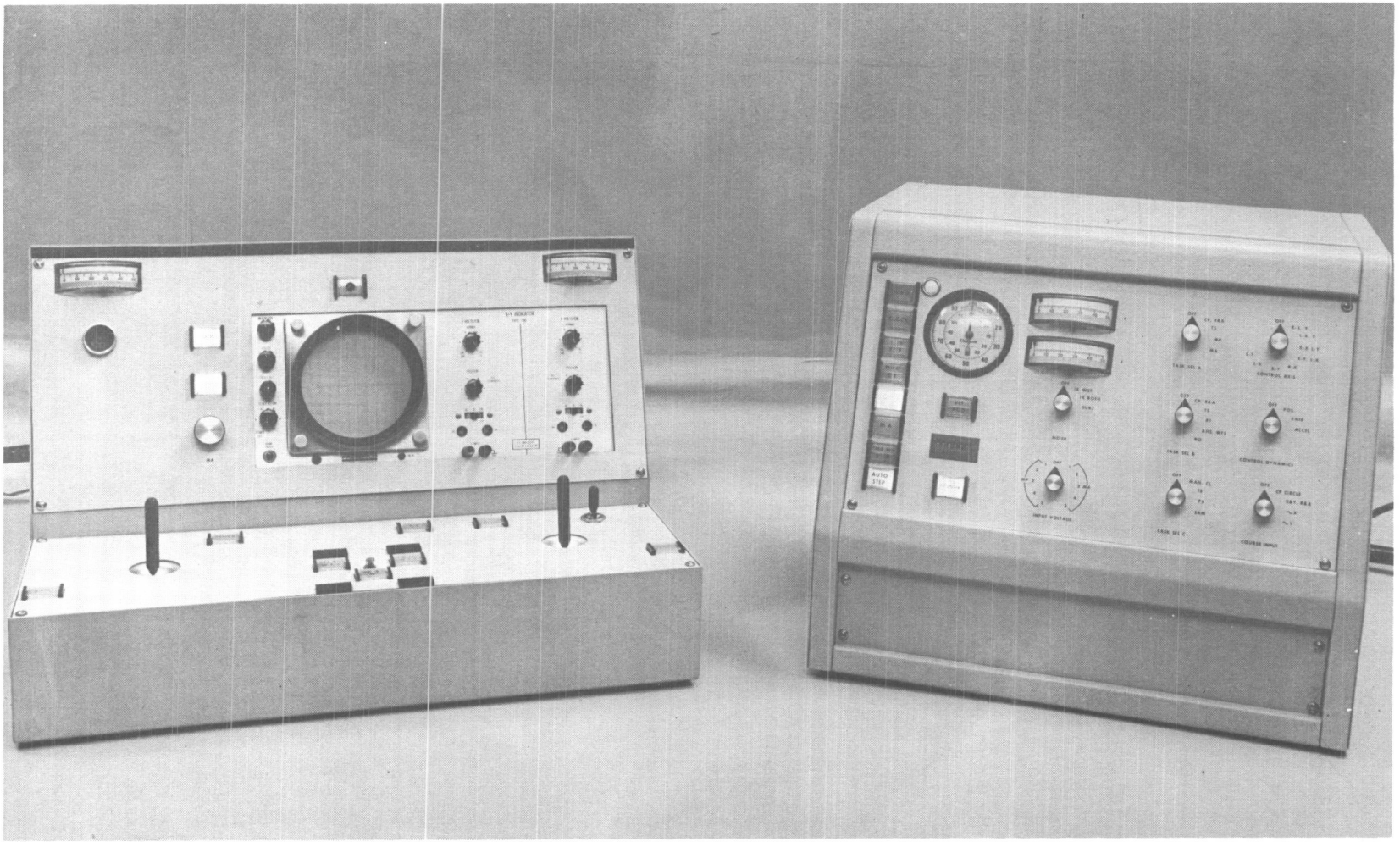

Figure 2. Improved Perceptual-Motor Performance Measurement System.

Subject Console and Equipment. Figure 3 shows the subject console. The function of each display and control is given in Table 3. Additional subject equipment is shown in Figure 4 and described in Table 4. (Note: Not shown are three, five inch diameter targets which are mounted to project above the subject console at the left, center, and right, during the tests of Position Estimation and Position Reproduction.)

Experimenter Console. Figure 5 shows the experimenter console which contains all test setup, programming, and scoring components. Output connectors are provided for use with auxiliary monitoring and data recording equipment. Functions of the experimenter console and displays are given in Table 5.

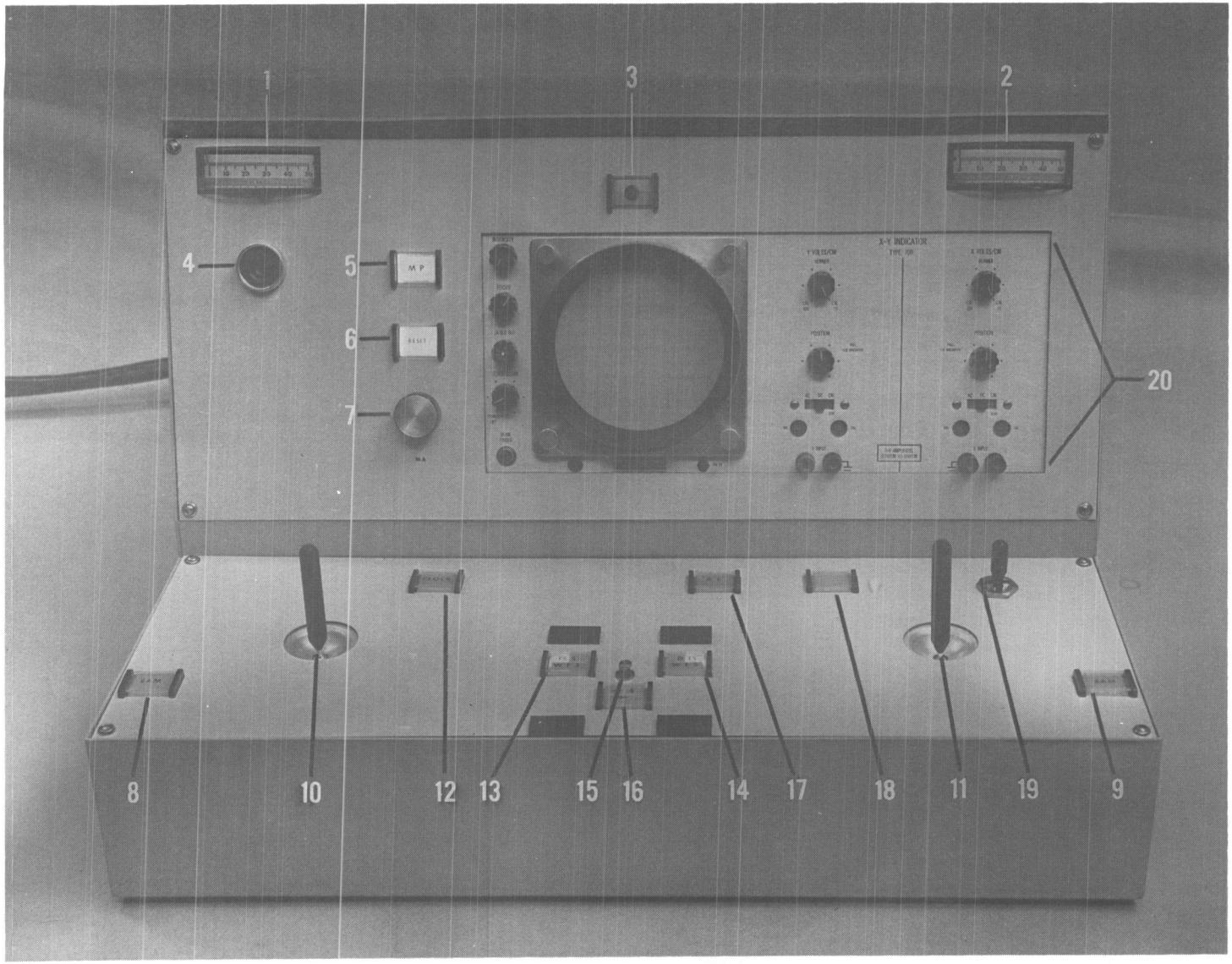

Figure 3. Subject Console

Table 3

Subject Console Display and Control Elements

Component	Reference No.	Function
Meter (left) Meter (right)	1 2	Stimulus displays for Time Sharing and Perceptual Speed.
Aperture/Lights	3	Contact aperture for Arm-Hand Steadiness; "warning" light (amber); "scoring" light (green).
Tone Generator	4	Produces auditory stimulus for Reaction Time. (Approximately 4800 cps.)
MP	5	Actuates Movement Prediction target dot on CRT.
RESET	6	Resets all computer integrators except sine-wave generator. (See Reference No. 5 on Experimenter Console.)
MA (knob)	7	Adjusts target dot acceleration in Movement Analysis.
SAM (left) SAM (right)	8 9	Speed of Arm Movement switch--left (8) starts clock; right (9) stops clock.
Left-hand control stick Right-hand control stick	10 11	Tracking controls.
CLOCK	12	Manual start and stop clock. (Functional when TASK SEL C is set to MAN CL.)
TS; S; WFS TS; D; WFS	13 14	Response keys for Time Sharing, Perceptual Speed and Wrist-Finger Speed.
Metal Contact	15	Electrical contact for Mirror Tracing maze. (Functional only with TASK SEL C set to MAN CL.)
Arrows	16	Direct subject to left, center, or right target. Arrows controlled by TARG ADV switch.

(Continued)

Table 3--Continued

Component	Reference No.	Function
RT	17	Reaction Time response key and stimulus light.
(Unmarked microswitch)	18	(a) Display module presents colored lights for Response Orientation test. (b) Switch module reverses y-axis polarity in tracking tasks.
Four-position lever switch	19	Subject response switch for Response Orientation test (used with 18 above).
CRT	20	Cathode ray tube X-Y indicator.

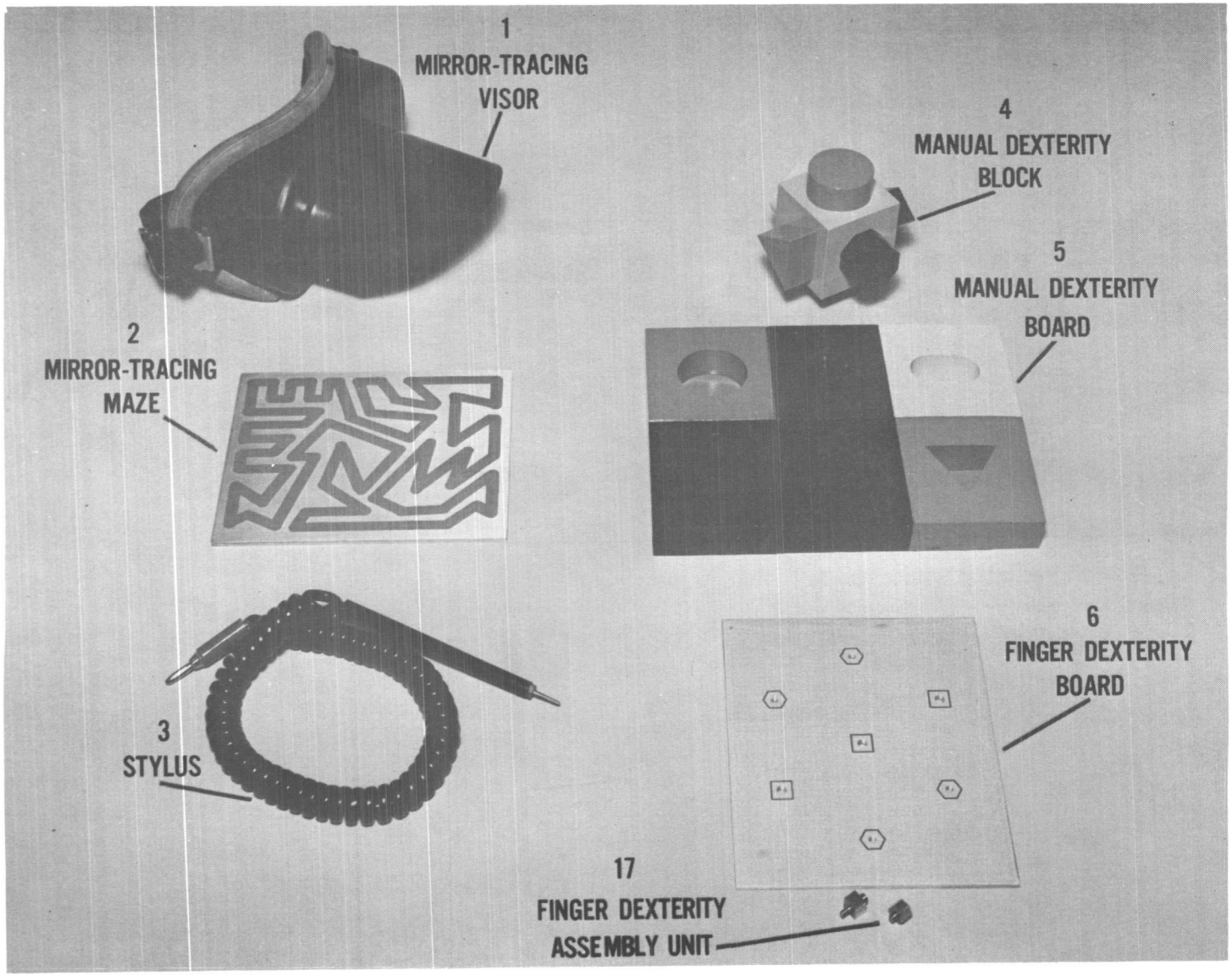

Figure 4. Test Items and Accessories Used With Subject Console.

Table 4

Listing of Extra-Console Test Equipment

Item	Figure 4--Reference No.
Mirror Tracing Visor (1 ea.)	1
Mirror Tracing Maze (1 ea.)	2
Stylus (1 ea.)	3
Manual Dexterity Test--Block (1 ea.)	4
Manual Dexterity Test--Board (1 ea.)	5
Finger Dexterity Test--Board (1 ea.)	6
Finger Dexterity Test--Assembly Unit (2 parts.)	7

Equipment Not Shown in Figure 3

Targets (3 ea.)

Cable (80-pin interconsole connector) (1 ea.)

Printed circuit extension card (1 ea.)

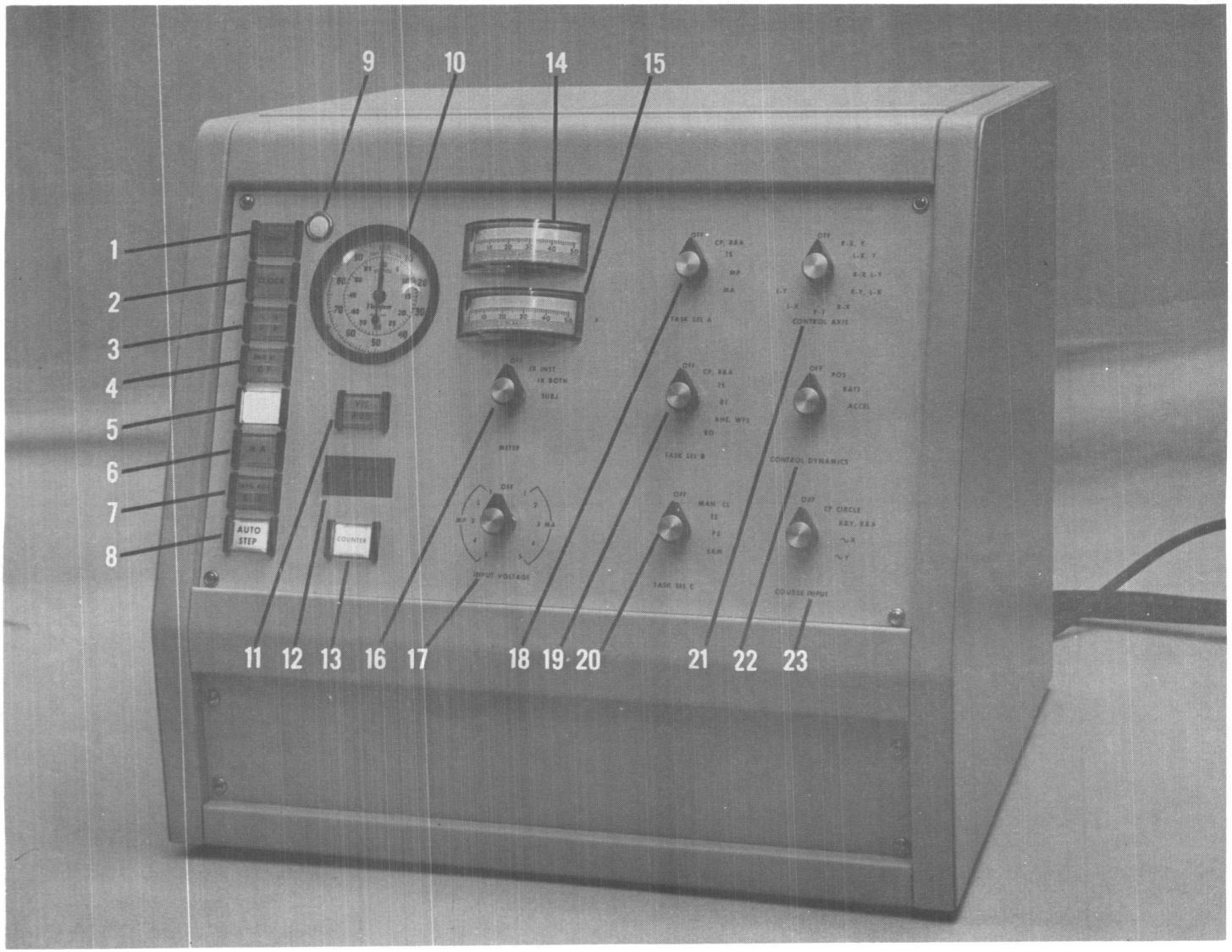

Figure 5. Experimenter Console

Table 5

Experimenter Console Display and Control Elements

Component	Reference No.	Function
POWER	1	Controls power to both consoles.
CLOCK	2	Manual start-stop clock.
1-2-3-R	3	Position Estimation and Postion Reproduction score display and reset switch. (Press to reset scoring circuit.)
PRO ST; C, T	4	Starts camswitch programmer, C-programmer runs continuously, T-automatic shutoff at end of test.
RESET	5	Resets all computer integrators except sin-wave (tracking course) generator.
MA	6	Controls input to Movement Analysis test circuitry. Functional when illuminated.
TARG ADV; S, F	7	Target Advance: manual control of stepping relay programmer. S=start position, F=finish position.
AUTO STEP	8	Advances stepping relay (7 above) to "F" (finish) from any position except "S" (start).
CLOCK RESET	9	Resets clock to zero
Clock	10	Accumulates time in seconds and 1/100 sec. to total of 60 seconds.
VIS-AUD	11	Selects visual (light) or auditory (tone) stimulus for Reaction Time test.
Counter	12	Registers contacts in scoring various tests. Note: Reset is on the face of the counter.

(Continued)

Table 5 --Continued

Component	Reference No.	Function
COUNTER	13	Manual operation of counter.
"Y" - Meter	14	Shows y-axis tracking error for all tracking tests and MA control position in scoring Movement Analysis.
"X" - Meter	15	Shows x-axis tracking error for all tracking tests and MP target dot position in scoring Movement Prediction.
Meter Selector Switch	16	Selects experimenter meters (1X INST) or subject meters (SUBJ). "1X BOTH" is not functional.
INPUT VOLTAGE	17	Selects input voltage for Movement Analysis and Movement Prediction tests.
TASK SEL A TASK SEL B TASK SEL C	18 19 20	Select circuitry and components for various tests.
CONTROL AXIS	21	Selects left (L), right (R), or both control sticks in horizontal (x) or vertical (y) axes.
CONTROL DYNAMICS	22	Selects zero (POS), first-(RATE), or second-(ACCEL) order tracking dynamics.
COURSE INPUT	23	Selects course for various tracking tasks; CP CIRCLE=Control Precision; X&Y, R&A=sine-wave forcing function to x- and y-axes during tests of Rate Control and Acceleration Control. X=sine-wave input to x only. Y=sine-wave input to y only. (For training purposes.)

APPENDIX B

Description of Individual Tests and Instructions to Subjects

Each of the eighteen tests is described below with reference to appropriate displays, controls and other materials. Instructions to the subject are included substantially as they appear in the Operating Manual to provide a more complete picture of the task requirements.

Fine Manipulative Abilities

Arm-Hand Steadiness (AHS)

This test measures the amount of tremor in a subject's hand and arm as he holds a stylus inside an aperture located at the top center of his console. Each trial is preceded by an amber light directly above the aperture which directs the subject to insert the tip of the stylus in preparation for scoring. A few seconds later a green light appears at the aperture, indicating that scoring is in progress. The subject keeps the tip of the stylus inside the aperture while the green light is on. Whenever the tip of the stylus contacts the rim of the aperture, it is registered on the counter on the experimenter console. A programmer (PRO ST) provides three 10-second trials equally spaced over a one-minute period.

Instructions: This test measures the amount of tremor in your arm and hand while held fully extended without locking your elbow. Plug the stylus into the blue terminal on the CRT. Hold the stylus as you would hold a pencil. Now extend your arm and insert the tip of the stylus into the aperture directly above the CRT. Do not lock your elbow. Do not jam the collar of the stylus against the rim of the aperture. Your task is to hold the tip of the stylus inside of the aperture without contacting

the rim. There will be three 10-second trials with about five seconds break between trials. When the amber warning light at the top of your console appears, insert the stylus. Within a few seconds the green light will appear indicating that you are being scored. Continue holding the stylus until the green light goes out, then rest your arm on the console until the next amber warning light appears.

Wrist-Finger Speed (WFS)

This test measures the speed at which a subject can tap back and forth between two switches using the first two fingers of his preferred hand. The two response switches are located at the center of the lower panel of the subject console. They are labeled WFS. Three equally spaced 10-second trials are programmed over a one-minute period. Immediately before each scoring period, an amber warning light at the top center of the subject console appears. At this time, the subject assumes the ready position by extending his fingers and holding his hand immediately above either one of the two response switches. Within a few seconds, the WFS sections are illuminated in green indicating that scoring is in progress. The subject taps rapidly back and forth between the two switches until the scoring lights are extinguished.

Each tap is registered on the counter on the experimenter console. The score is the number of taps accumulated over three 10-second trials.

Instructions: We are now going to measure the speed at which you can tap back and forth between two switches. The switches are those labeled W-F-S directly in front of you. Tapping will be done with the first two fingers of your right hand. There will be three 10-second scoring periods with about five seconds break between trials. Before each trial, an amber warning light will appear at the top center of your console which indicates that you are to take the ready position by holding

your fingers slightly above one of the switches. Begin tapping when the green W-F-S lights appear and continue tapping until these lights are extinguished. Remember, there will be three 10-second trials. I will tell you when the test is finished.

Finger Dexterity

This is a test of the subject's ability to manipulate small objects with the fingers of both hands. Test apparatus is the metal Finger Dexterity Board and Assembly Unit.

The subject is required to assemble and disassemble two small threaded units alternately screwing the units to the board separately or when joined together. The threads of these units are size-coded such that they may be assembled in only one way. There are essentially two steps to this test which are repeated to form the total sequence: The subject begins with the two threaded elements separated, holding one in each hand. He then assembles the unit and screws the entire assembly to the hexagon at the bottom of the test plate. He then retrieves the assembly, takes it apart, and screws the square portion of the assembly to the square on the left of the test plate, and the hexagon to the hex on the right of the test plate. He then retrieves both units, screws them together, and screws the assembly to the square at the center of the test plate, etc. As the final step, the two units are retrieved, assembled, and the assembly is screwed to the hexagon at the top of the test plate. As soon as the subject has attached the assembly to the hexagon at the top of the plate, he raises his hand indicating that the test is completed. The test is scored manually as the amount of time taken to complete the board one time.

Instructions: This is a test of your ability to manipulate small objects using the fingers of both of your hands. Take the aluminum

finger dexterity board containing the small hexagons and squares and set it on the console in front of you such that a single hexagon is located at the top and bottom of the board. Press down firmly on the board so that it will stay in place while you are performing the test. Pick up the small threaded assembly unit and separate it into two parts. Notice that one part is a hexagon and the other is a square and that these two units may be joined in only one way. I will take you through the procedure one time for practice.

1. Hold part of the assembly unit in each hand.
2. Screw the unit together.
3. Screw the entire assembly to the hex at the bottom of the board.
4. Retrieve the unit and disassemble.
5. Screw the square to the square on the left of the board and the hex to the hex on the right of the board. You may use either or both hands any way that you choose.
6. Retrieve and assemble the unit.
7. Screw the assembly to the square at the center of the board.
8. Retrieve and disassemble.
9. Screw the hex to the hex at the left and the square to the square at the right.
10. Retrieve and assemble.
11. Screw the assembly to the hex at the top of the board and raise your hand when you have finished.

Remove the assembly from the board and separate it into its parts. Hold one part in each hand. When I give the signal screw the assembly together and work your way up the board as you have just done.

Manual Dexterity

This test is performed with the plastic, color-coded Manual Dexterity Board and Block. The projections on the block and their colors correspond to the receptacles on the board.

The subject's task is to insert and retrieve the block, working his way twice around the board in a clockwise direction. There are certain restrictions regarding the manner in which the test block may be

manipulated: The board is oriented on the subject console so that the red square portion is in the upper right-hand corner. At the beginning of the test, the block is inserted into the red portion. The subject is required to pick up the block by grasping the projection corresponding to the receptacle next in the sequence. Thus, the first step would be to grasp the blue circular projection, rotate the block so as to grasp the opposite projection, namely the red square, and insert the block into the blue receptacle. The next receptacle is the yellow diamond. Therefore, the subject must retrieve the block by grasping the yellow projection, manipulate the block so as to grasp the gray oval and then insert the block into the yellow receptacle, etc. During retrieval or insertion, the gray portion of the block may not be touched. There are no restrictions during rotation (manipulation) of the block.

The test is scored manually as the amount of time taken to complete the board twice in succession.

Instructions: This is a test of your ability to manipulate an object using one hand. Set the colored plastic manual dexterity board on the console in front of you such that the red square is in the upper right-hand corner. Notice that the manual dexterity block has six projections on it, with each projection corresponding to a receptacle on the board. Each projection and its corresponding receptacle are the same color. Insert the block into the red square--that is the starting position. Your task is to pick up the block, rotate it in your hand, and insert it into each of the receptacles, working your way clockwise around the board. In performing this test, there are two rules which you must follow very carefully: you must pick up the block by the projection corresponding to the next receptacle in the sequence, rotate the block in your hand so as to grasp the projection opposite the one which you are going to insert, and then insert the block; when you are either picking up or inserting the

the block, you are not permitted to touch any of the gray portion of the block or any of the projections other than those two involved in that particular manipulation. You may touch any parts of the block as you rotate it in your hand.

Let's go through the procedure once, a step at a time, for practice.

1. Grasp the blue circle.
2. Rotate so as to hold red square.
3. Insert block into blue circle.
4. Pick up block by grasping yellow diamond.
5. Rotate so as to grasp gray oval.
6. Insert block into yellow diamond.
7. Pick up block by grasping gray oval.
8. Rotate so as to grasp black hexagon.
9. Insert into gray oval. (Instruct subject: "Try to think ahead. As you insert the block, think of the next movement.")
10. Pick up block by grasping green triangle.
11. Rotate so as to hold yellow diamond.
12. Insert into green triangle.
13. Pick up block by grasping black hexagon. (Pause to see if subject can continue without further instructions.)
14. Rotate so as to hold gray oval.
15. Insert into black hexagon.
16. Pick up by grasping red square.
17. Rotate so as to hold blue circle.
18. Insert into red square.

You have just worked your way around the board one time. In performing the test for score you will be required to work your way around the board twice in succession without stopping, ending at the starting position with the block inserted into the red square.

Gross Positioning and Movement Abilities

Position Estimation

This test measures the subject's ability to make "blind" positioning movements. The three targets projecting from the back of the subject console and the stylus are used.

At the center of the lower panel of the subject console immediately in front of the subject is a display module containing three arrows. The arrows tell the subject which target he is to attempt to contact with the stylus. The experimenter controls the arrow-indicator manually using the TARG ADV switch.

Each target contains three rings in the typical "bull's-eye" configuration. When the stylus contacts the target a score of 1, 2, or 3 points is registered on the experimenter console depending on the accuracy of the movement. A complete miss is recorded as zero. Score is total points for 10 trials.

Instructions: This test measures how well you can reach out and touch a target without looking at that target. Plug the stylus into the black terminal on the CRT. Directly in front of you on the lower portion of your console is a display containing three arrows. Each arrow corresponds to a target above your console. The targets are designated by the arrows as left, center, and right. On each trial you are to use the target designated by the illuminated arrow.

Now let's work through the procedure one step at a time. Hold the stylus as you would hold a pencil. Place the tip of the stylus directly above the arrow indicator. Keep your hand in this position and look up at the target indicated. Now, look back at the arrow. Keep your eyes on the arrow and reach up with the stylus; try to touch the center of the target. Speed of movement is not important. We are concerned only with accuracy. Make only one smooth movement in attempting to strike the target. When you contact the target, return your hand to the starting position at the arrow indicator. If you miss the target, do not grope for it. Simply return your hand to the starting point in preparation for the next trial.

Let's try one more for practice (experimenter changes arrow). Place the tip of the stylus above the arrow--look at the arrow--look up at the target--look back at the arrow and keep your gaze on it--reach up and attempt to contact the target. (Experimenter resets score after each contact.)

Response Orientation (RO)

This test measures a subject's ability to make directional control (switch) movements (left, right, forward, or back) in response to a nondirectional signal (colored light). The display and response elements for this test are located directly in back of the subject's right-hand tracking control stick: a black 4-position lever switch is operated in response to colored lights which appear in the display module immediately to the left of that switch.

Before beginning the test, the subject is instructed as to which switch position corresponds to which colored light. A series of 24 lights is presented to the subject automatically. When a stimulus light appears, the clock on the experimenter console starts. When the subject makes a correct directional response with the lever switch, the light is extinguished and the clock stops. The score is the total response time accumulated for the 24 events.

Instructions: This test measures your ability to make a directional control movement in response to a nondirectional signal. Your control is the black lever switch located in back of your right-hand control stick. Notice that it may be moved in four directions: left, right, forward, and back, and it returns to center when released. Just to the left of the lever switch is an unlabeled display module. During the test, this module will present a series of colored lights: green, red, white, and blue, in random order. Each color corresponds to a position on the switch.

When a light appears, you are to move the switch as quickly as you can to the appropriate position and extinguish the light. The relationships are as follows (Speak slowly. Give the subject time to think):

Green = Left
Red = Forward
White = Right
Blue = Back (toward subject)

Let's try this verbally for practice. I will say a color. You move the switch to its correct position. (Check subject's responses for accuracy.) Ready? -- Green. . .blue. . .white. . .green. . .red. . .white. . .blue . . .red.

When each light comes on, the clock starts running. When you make the correct response and extinguish the light, you also stop the clock. Your score is the total amount of time accumulated over the entire sequence. If your first response to a light is not correct, simply continue responding until you extinguish the light. Once the test has begun, do not assume it is finished for any reason until you are told to stop.

Control Precision (CP)

This test is an analog of the classical "pursuit-rotor" tracking task. The subject is presented with a target dot which moves in a clockwise course around the face of the CRT. The subject controls a second dot (shaped like a "checkmark" to allow discrimination between the two dots) which he attempts to keep superimposed upon the target dot. Performance is scored as the time integral of the absolute value of error voltage computed separately for the horizontal and vertical axes and shown on the experimenter x- (lower) and y- (upper) meters.

Instructions: This is a two-axis tracking task which measures your ability to make precise control movements. Notice that there are two dots on the scope. Move your right-hand control stick in a smooth clockwise circle. Notice that the checkmark on the scope follows in a clockwise circle. When the test begins, the other dot will move in a clockwise circle around the face of the scope. Your task is to keep your checkmark superimposed upon the target dot.

Speed of Arm Movement (SAM)

This test measures the speed at which a subject can move his arm between two designated points. The two points are the SAM switches located at the extreme left and right of the lower portion of the subject console. These switches are illuminated when the experimenter sets up the Speed of Arm Movement test.

The test involves a discreet arm movement made at the discretion of the subject. The task is simply to strike the left-hand SAM switch which starts the clock on the experimenter console. Then, as rapidly as possible move across and strike the right-hand SAM switch, which stops the clock. Score is taken as the time required to move from the left-hand switch to the right-hand switch.

Instructions: On the left and right sides of the lower portion of your console are two illuminated switches labeled S-A-M. We are going to measure the amount of time it takes you to move your arm from the switch on the left to the one on the right. When you touch the switch on the left, you start the clock; when you strike the switch on the right, the clock is stopped.

Let's try one trial for practice. Extend the fingers of your right hand and hold your hand slightly above the left-hand switch. Now, with

your hand in that position, look at the right-hand switch. You know where the left-hand switch is; it is important that you keep your eyes on the right-hand switch. When I say "go," strike the left-hand switch; then bring your arm across as quickly as possible and slap the right-hand switch: Ready. . .go!

Now we'll do five trials for score. I will not say "go" on each trial. You may start each trial at your own discretion; however, you must allow time after each trial for me to record your score from the clock and to reset the clock.

Multilimb Coordination

This a two-hand, two-axis compensatory tracking task using rate control system dynamics. The subject attempts to keep a target dot centered on the face of the CRT by using his right hand to control the horizontal (x) axis of motion and his left hand to control the vertical (y) axis of motion. Score is obtained separately for each axis as the time integral of the absolute value of error voltage shown on the experimenter x- and y-meters.

Instructions: This is a tracking task in which you will use both control sticks. Your task will be to keep the dot centered on the face of the CRT. (During the following steps, experimenter operates RESET to assist subject in maintaining control of the dot.) Move your right-hand control stick left and right; notice that the dot follows by moving left and right on the horizontal axis. Move your left-hand control stick forward and back; notice that moving this stick forward causes the dot to move downward, and, pulling the stick toward you causes the dot to move upward. Now use both of your control sticks to bring the dot to the center of the scope. (Experimenter starts test when dot is approximately centered.)

Position Reproduction

This test is approximately the same as Position Estimation. However, in the present test, the subject, in addition to being permitted to look up and view an indicated target, is also required at that time to reach up and touch the center of the target with the stylus. That is, when directed toward a particular target, the subject looks up at the target and touches the target with the stylus. Immediately thereafter, he keeps his gaze on the arrow-indicator and attempts to reproduce the movement just made.

Instructions: This test measures your ability to reproduce an arm-hand movement without the aid of vision having just performed that same movement with the aid of your vision. Plug the stylus into the black terminal on the CRT. Directly in front of you on the lower portion of your console is a display containing three arrows. These arrows correspond to the targets above your console. On each trial the arrow which is illuminated tells you which target to use.

Let's try this once for practice. Do the following steps as I give them to you: Hold the stylus as you would hold a pencil. Place the tip of the stylus above the arrow-indicator. Look up at the target indicated by the arrow and at the same time reach up and touch the center of the target with the stylus. Look back at the arrow indicator and return your hand to its starting position with the tip of the stylus above the arrow indicator. Now, without looking up, reach up and attempt to touch the target again. That is, try to reproduce the movement that you just made while you were looking at the target. When you reach for a target, use a smooth continuous motion. Speed is not important. We are concerned only with accuracy. If you miss the target do not grope for it. Simply return your hand to the starting position. Try it one more time. Hold the stylus above the arrow indicator--look up at the arrow indicated

and touch center of target with the stylus--look down at the arrow indicator and return your hand to starting position--without looking up, reach up and touch target by reproducing the movement just made.

System Equalization Abilities

Movement Analysis (MA)

In this test the subject views a target dot which accelerates across the face of the CRT. His task is to detect the acceleration component of motion (change in velocity) and null this acceleration by adjusting a potentiometer labeled MA which is located immediately to the left of the CRT. The subject is permitted to make adjustments until he is satisfied that the dot is moving at a constant velocity. The subject presses RESET after each adjustment. The procedure is repeated for a set of five initial velocities and accelerations selected on the experimenter console. (Input Voltage selector).

Position of the subject MA control knob is read on the y-meter of the experimenter console. The MA control position required to achieve constant target dot velocity for each condition is known from pretest calibration procedures. An error score is obtained by taking the absolute value of the difference between the value produced by the subject in attempting to achieve constant target dot velocity and the calibration value actually required for constant target dot velocity.

Instructions: In this test, you will see the target dot move across the scope at an increasing speed; that is, the dot will be accelerating. Your task is to adjust the system such that the dot travels at a constant velocity--so that it is neither accelerating nor decelerating. You will make your adjustments by using the large silver knob labeled MA just below your RESET switch. Here are the steps that you will follow in

performing this task. Perform each step as I give it to you: (Allow time for subject to respond to each step.)

(1) Press RESET. (2) Observe dot movement. (3) Turn MA knob "some amount" counterclockwise. (4) Press RESET and observe effect of adjustment. (5) Repeat the preceding steps until you are satisfied that the dot is moving at a constant speed. Do not try to judge the effect of your control adjustment while the dot is still moving! You must always press your RESET before the true effect of your adjustment appears. After you have made your final adjustment and you are satisfied that the dot is moving at a constant speed, do not touch your MA control knob until I instruct you to do so. At that time I will ask you to turn your MA control to its fully clockwise position in preparation for the next trial.

Movement Prediction (MP)

In this test, the subject views a target dot which travels at a constant velocity across the face of the CRT. When the dot reaches the center of the CRT it disappears as though it has moved behind a visual obstruction. The subject's task is to depress and hold his MP switch which initiates target dot movement and release the switch when he feels that the dot has arrived at the right-hand edge of the CRT grid.

Five target dot velocities are selected on the experimenter console (Input Voltage selector). The meter reading corresponding to exact alignment of the target dot and the right-hand edge of the CRT grid is obtained in pretest calibration. When, in the test, the subject responds by releasing his MP switch, the target dot reappears and holds its position. This position is given on the x-meter of the expermenter console. An error score is obtained by taking the absolute value of the difference between the meter indication produced by the subject and the calibration value.

Instructions: This is a test of your ability to judge the position of a moving target after it has disappeared from view. (Experimenter selects MP-1 on input voltage selector.) To the left of the scope is a switch labeled MP. Press this switch and continue to hold it down. Notice that the dot moves from left to right across the scope. When it reaches the center of the scope it disappears. Continue holding down your MP switch. The dot is moving across the scope but it is obscured from your view. Your task is to release your MP switch when you think the dot has arrived exactly behind the right-hand edge of the grid.

(Experimenter resets circuit.) Let's try it one time for practice. Press and hold your MP switch until you think the dot has arrived at the right-hand edge of grid and then release the switch. I will reset the dot after each trial. You may begin the next trial as soon as you see that the dot has been reset.

Rate Control (Rate; R)

This is a one-hand, two-axis compensatory tracking task using first order system dynamics. The subject's task is to keep a target dot centered on the face of the CRT by manipulating a control stick in two axes. Performance is scored as the time integral of the absolute value of error voltage computed separately for each axis and shown on the experimenter x- and y-meters.

Instructions: This is a two-axis tracking task. You will attempt to keep the dot centered on the scope by using your right-hand control stick. Take your right-hand control stick and see that you have control of the dot. Moving the stick forward should cause the dot to move downward; pulling back on the stick should cause the dot to move upward; moving the stick to the left causes the dot to move to the left, and moving the stick to the right causes the dot to move to the right. Now use your

control stick to move the dot onto the center of the scope. (Experimenter observes dot to be "under control" and approximately centered on CRT before beginning test.)

Acceleration Control (Accel; A)

This is a one-hand, two-axis compensatory tracking task using second-order system dynamics. The subject's task is to keep a target dot centered on the face of the CRT by manipulating a control stick in two axes. Performance is scored as the time integral of the absolute value of error voltage computed separately for each axis and shown on the experimenter x- and y-meters.

Instructions: This is a two-axis tracking task. You are to use your control stick to keep the dot centered on the CRT. In this test, when you move your control stick, you will cause the dot to accelerate. For example, if you move your control stick slightly to the right and leave it there, the dot will continue to accelerate toward the right and disappear from the CRT. (Experimenter depresses RESET--says "go ahead and try that"--releases RESET.) You can see that if you attempt to control the dot by making large control movements it will be difficult to keep the dot on the CRT. This test is similar to trying to keep a marble balanced on the center of a pieplate while someone else keeps tilting the plate. Try to make small control movements and return your control stick to center frequently.

Perceptual-Cognitive Abilities

Perceptual Speed (PS)

This test concerns the subject's ability to make rapid visual comparisons between two display elements. The displays are the two meters located at the top of the subject console.

The subject is presented with pairs of meter indications; his task is to determine whether or not the indication is the same on both meters or whether the meters are showing different values. The subject's response switches are located in the center of the lower portion of his console. The left-hand switch contains an illuminated "S"; the right-hand switch contains an illuminated "D." A correct response will advance the program and present the subject with a new pair of meter indications. An incorrect response will not advance the program, and an error will be recorded on the counter.

There are 24 pairs of meter indications to be processed by the subject. When the test is begun, the clock starts automatically and continues to run until the test sequence has been completed. Score is the total time to complete the test sequence and the number of incorrect responses made.

Instructions: This is a test of your ability to make rapid comparisons between two displays. The displays are the meters located at the top of your console. Notice that directly in front of you there are two switches--the switch on the left is labeled "S"; the switch on the right is labeled "D." Your task will be to compare the indications on your meters to determine whether they are the same or different. If both meters show the same value, press the switch labeled "S"; if the meter indications are different, press the switch labeled "D." If you make a correct response, that is, if you press "D" when the indications are different, the next pair of meter indications will appear. If you make an incorrect response the meters will not change and an error will be recorded on the counter. As soon as you realize that you have made an incorrect response, immediately press the other switch and continue with the test. Both speed and accuracy are important. Your score is the amount of time that you take to process the entire sequence of values and the number of errors made.

Time Sharing (TS)

This is a test of the ability to divide attention between display elements. Here, the subject's task is to monitor the meters at the top of his console in order to detect the onset of pointer movement. When this test is set up on the experimenter console, two response switches labeled "TS" directly in front of the subject will be illuminated. The left-hand switch corresponds to the left-hand meter; the right-hand switch to the right meter. When a subject detects movement of a pointer, he simply presses the appropriate switch. The clock runs whenever a pointer is moving. The subject's response stops the pointer and also stops the clock. Score is the accumulated response time for the detection of 24 events over a 4-minute test period. No error score is obtained.

Instructions: This test measures how well you can divide your attention between two displays to detect the occurrence of certain events. In this case you will be required to monitor the two meters at the top of your console in order to detect movement of either of the pointers. Directly in front of you are two switches labeled T-S: the switch on the left corresponds to the meter on the left; the switch on the right corresponds to the meter on the right.

When the test is started you are to scan back and forth between the two meters. As soon as you notice that a pointer has begun to move, press the appropriate switch as quickly as you can. Whenever a pointer begins to move, the clock starts; when you make the correct response, you will stop the pointer and the clock.

Reaction Time (RT) Ability

This is a test of simple reaction time. Either a light or a tone may be selected (VIS-AUD selector) as the stimulus by the experimenter. The

subject's response switch labeled "RT," is located at the back and to the right of center of the lower portion of his console. The stimulus light for visual reaction time is located within the subject's response switch. For auditory reaction time, the stimulus is a tone produced by the tone generator located directly beneath the subject's left-hand meter.

Four stimulus events are programmed automatically over a 1-minute test period. When the light or tone occurs, the clock starts. The clock is stopped when the subject presses his RT switch. Reaction time is measured as the duration between the onset of the stimulus and the occurrence of the subject's response.

Instructions--Visual Reaction Time. We are now going to measure your reaction time. Find the switch labeled RT at the back and just to the right of center on the lower portion of your console. This switch will light up as your signal to respond. Place your fingers very lightly on the switch. When the light appears, press the switch as rapidly as possible. There will be four trials with about ten seconds between signals.

Instructions--Auditory Reaction Time. We will now measure your auditory reaction time. The signal will be a tone which is produced by the small speaker located just beneath your left-hand meter. You will use the same response switch. There will be four trials. When you hear the tone, press your switch as rapidly as possible.

Mirror Tracing Ability

This is a test of the subject's ability to make directional arm-hand movements when visual information is inverted by a mirror. The metal maze is placed on the subject's console against the spring-loaded electrical contact. The subject's task is to trace the maze in a clockwise

direction using the stylus, while viewing the maze in the mirror contained in the visor. Time required to complete the maze one time is obtained manually. Contacts made with the metal portion of the maze when the stylus is moved off of the path, are recorded automatically on the counter. Score is the time required to complete the maze and the number of errors (contacts) made.

Instructions: Place the metal maze firmly on the console in front of you. Plug the stylus into the blue terminal on the CRT. Touch the silver portion of the maze with the tip of the stylus. (Experimenter checks counter operation.) Your task here is to trace once around the maze using the stylus. Now put on the visor and adjust it so that it is comfortable and so that you can see the maze clearly in the mirror without leaning or tilting your head. Place the tip of the stylus in the lower right-hand corner of the maze. When I say go, trace the maze in a clockwise direction (experimenter may need to orient subject by guiding his hand a short distance on the maze before beginning the test). Trace as rapidly as you can but try to avoid moving off the path. Both speed and accuracy are important. Your score is the time taken to go around the maze once, and the number of errors you make by straying off the path.

APPENDIX C

Comparison of Prototype and Modified Consoles

A comparison of the modified console with its predecessor is perhaps the simplest way to illustrate the major changes and improvements in this device. This appendix lists a number of items where design modifications were employed to increase console reliability, maintainability, and flexibility as a research tool. This list is not exhaustive. It does, however, point out the principal changes which were accomplished in an attempt to meet the objectives of the redesign effort.

Previous Console	Modified Console
1. Panel Design	
a. Single cabinet contains all electrical and electromechanical components, setup switches, response switches, and scoring units.	a. Console has been divided into two units: one for the subject, one for the experimenter.
b. Requires experimenter to sit next to subject to operate device and score tests.	b. Experimenter now may be located at a distance from the subject, or in another room. Since electrical components are housed in experimenter's console, subject's console may be placed in thermal chamber, etc. Extraneous cues or distractions due to operation of relays and experimenter activities have thus been eliminated.

(Continued)

Previous Console	Modified Console
c. Scoring meters must be turned off and on; clock must be covered and uncovered to prevent subject distraction and knowledge of results	c. Clock and scoring meters are out of subject's view. Experimenter can easily set up and score tasks without working around a subject seated at the console. Provision for intercom has been added.
2. Components	
a. Solid state operational amplifiers (1/2 x 3 x 2"); requires 17 amplifiers.	a. Solid state amplifiers (1 x 1 x 3/4") requires 15 amplifiers.
b. Stepping relay--controls stimulus sequence for four tests plus timing of events. Has no automatic reset; must be advanced manually one step at a time. Has two starting positions; some tests will not operate from both positions.	b. Controls four tests. Has automatic reset. Single starting position for all tests.
c. Camswitch programmer. Adequate, but difficult to build and adjust cams.	c. Miniature programmer--uses grooved cylinder with slide-on contact points. Simple to set up and adjust.
3. Component Mounting and Wiring	
All components hand wired; extensive interconnections; circuits difficult to trace; poor access to components; no test points provided.	All amplifiers and relays mounted on pull-out printed circuit cards (about 80% reduction in point-to-point wiring); components identified and important contacts labeled; immediate access to all components; test points for power sources and all operational amplifiers provided.

(Continued)

	Previous Console	Modified Console
4.	Circuit Redesign	
	a. Response Orientation-- Subject must hold response key until stepper advances to prevent clock from restarting.	a. Stepper advances as soon as subject responds; clock cannot accidentally restart.
	b. Reaction Time-- Subject must hold down response key until stimulus signal stops; otherwise clock will restart.	b. Subject simply presses and releases response key; clock will not accidentally restart.
	c. Time Sharing-- Subject must hold down response key until meter stops; otherwise clock will restart.	c. Subject simply presses and releases; clock will not accidentally restart.
	Pressing wrong response key will advance program causing test to be aborted; pressing either key between trials will advance program and abort test.	Pressing wrong key has no effect. Pressing either key between trials has no effect. Holding keys down to "cheat" starts alarm buzzer at experimenter's console.
	d. Control Precision-- Target dot difficult to tell apart from cursor dot.	d. Target dot is round; cursor is shaped like a tiny half-arrow or "check" (✓). Dots are easily discernible.
5.	Control-Display Relationships	
	a. Device cannot simulate aircraft radar tracking control-display relationships where pilot sees "pip" as fixed and flies scope grid onto target pip.	a. All combination of 2-axis control display relationships are provided; e.g., operator "controls grid" or "controls dot" as required.

(Continued)

Previous Console	Modified Console
b. Auxiliary Outputs-- No output terminals provided for monitoring CRT, scoring meters, or timer.	b. Terminals have been added to allow remote monitoring of CRT and recording of most scores.
c. Position-Estimation Targets-- Made of solid aluminum; no flexibility to absorb force when struck.	c. Targets are constructed of flexible, lightweight, printed-circuit board; will withstand considerable abuse.
6. Mechanical Reliability	
This console represents a first cut in redesign of many tests normally requiring extensive apparatus and operating space. Redesign of these tests (some of which were originally paper-and-pencil tests) and their integration into a unified console demonstrates the feasibility of this approach. This console is not a production item. It is a functioning prototype and not intended for use in extensive research programs requiring thousands of trials.	The only limitations in performance of the present console are inherent in the expected life span of its components. These components are all off-the-shelf items such as relays, amplifiers, and switches which are easily obtainable and can be replaced with minimum cost and labor. Proper operation of the device should result in extensive troublefree performance.
7. Maintainability	
This device is difficult to troubleshoot and maintain. In particular, amplifier and relay circuitry is not readily accessible; circuits are difficult to trace.	Every effort has been made to improve the accessibility of components and to increase the ease of circuit tracing. Maintenance procedures have been greatly simplified by use of removable circuit cards and components, color-coded wiring and test points.

(Continued)

Previous Console	Modified Console
	Comprehensive diagrams have been prepared which will greatly reduce difficulty in isolating a course of trouble if and when it occurs. It should be noted, however, that the device is complex and is still essentially the first of of its kind. Therefore, it is not possible to list anticipated maintenance problems and their remedies. In contrast to the earlier version, the present unit is several orders of magnitude superior in terms of maintainability.

8. Administration and Scoring

A primary source of difficulty with the earlier console was that on several tests subjects could make inadvertent responses which would abort a test run. (See Reaction Time, Time Sharing, Response Orientation.) Special instructions were required to prevent such events. These instructions required time and were not always effective. The extra trials also cost time. Through redesign of test circuitry, the possibility of these aborted trials has been eliminated.

With the previous console, a clock shield was used so that the clock did not serve as a cue; scoring meters had to be turned off during trials to prevent knowledge of results where this was a factor. Scoring units are now seen only by the experimenter.

The experimenter's task has been simplified since his console contains only those elements concerned with task setup and scoring. And, these functions have been reduced in complexity (e.g., single starting position for stepping switch and automatic reset capability).

On some tests, the experimenter may monitor performance and make corrections at a comfortable distance and without interfering with the subject. For example, subjects performing the tracking tasks

(Continued)

frequently lose the target (goes off CRT). When this occurs with the previous console, the "Reset" switch above the CRT must be pressed. Either the subject does this or the experimenter must reach in front of him to do it. With the present console, tracking performance may be monitored on an auxiliary CRT (or on the subject's CRT). The experimenter now has a separate switch which resets the system when a target is lost.

If automatic recording of performance scores is desired, appropriate equipment may be connected to the terminals provided for this purpose. Tracking scores and response times may be recorded directly in this manner.