U.S. ARMY

Technical Note 8-66

A RAPID TACTICAL MINE-PLANTING SYSTEM:

HOW FORCE LEVEL AFFECTS LEVER-THROWING TIME

George G. Gentry
R. Bradley Randall

September 1966

HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
MARYLAND

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DEPARTMENT OF THE ARMY
U. S. ARMY HUMAN ENGINEERING LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND 21005

AMXHE-SYS

17 MAR 1967

Eberhard K. H. Kroemer, Dr.-Ing.
Anthropology Branch
Human Engineering Division
Wright-Patterson Air Force Base, Ohio 45433

Dear Dr. Kroemer:

Thank you for your letter requesting additional information on the mine-planter investigation.

Mr. Gentry is no longer with us, but here is the information you desire.

The inclosed diagram gives the more important dimensions of the mine planter mockup. The lever was a flat steel bar topped with a smooth cylinder 9.5" x 1.5" for a handle. It moved through an arc of 33°. The throw was 30.14" measured at a point 4.25" down from the top of the handle. The only adjustment in the lever system was the throw distance. This distance remained constant, however, through all trials.

The pivot point of the lever was 5.25" below the platform on which the subject stood. A 2" x 8" board was placed on the forward edge of the platform. The subject could hook the heel of his left boot over this board to assist in pulling the lever back. The platform measured approximately 28" x 35.5", and except for the board, was covered with aluminum plate embossed with a non-skid pattern.

The braking force was applied to the 24" diameter disk brake by four hard-wood pucks, each measuring 2.25" in diameter. The total brake area was 15.95 square inches.

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Eberhard K. H. Kroemer, Dr.-Ing.

Before any subject's trials began, the system was calibrated. Initial break-away forces in either direction were ignored. The brake pad pressure was adjusted until a constant force application at the required level (60, 80, or 100 pounds) resulted through the entire 33° arc. The applied forces were recorded continuously throughout the trials.

The only anthropometric data Mr. Gentry recorded were the height and weight of the subjects. These data could be found for only 27 of the 31 subjects, and are inclosed.

The moment of inertia of the moving parts was not calculated.

If we can provide further assistance to you, please let us know.

Sincerely yours,

JOHN D. WEISZ
Technical Director

2 Incl
1. Mine Planter Mockup Dimensions
2. Anthropometric Data

ANTHROPOMETRIC DATA

60 Pound Group

S	Weight	Height	Age
M.D.	160	70"	19
R.L.	210	72"	24
B.H.	165	73"	20
R.P.	160	72"	23
L.S.	155	74"	26
D.B.	185	70"	20
J.B.	188	68.5"	19
T.S.	147	68"	21
Total	1370.0	567.5	
Mean	171.5	71.0	

n = 8

80 Pound Group

S	Weight	Height	Age
D.H.	172	67"	24
T.P.	180	72"	19
J.B.	153	69"	20
W.S.	162	71"	21
E.R.	150	71"	18
M.D.	150	71"	20
J.L.	175	72"	24
G.S.	178	72"	22
P.L.	164	69"	20
Total	1484	634.0	
Mean	165	70.5	

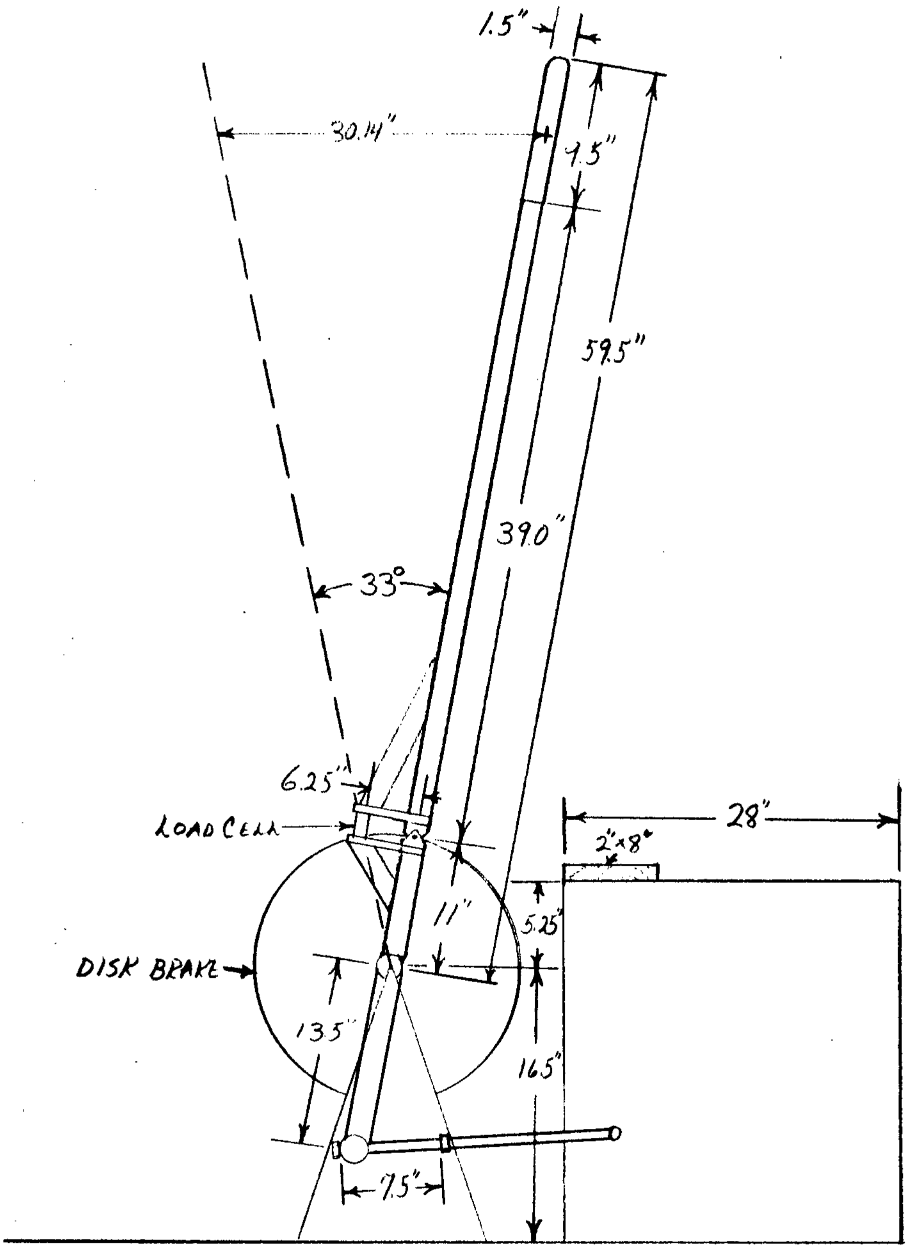
n = 9

100 Pound Group

S	Weight	Height	Age
R.W.	190	71"	23
C.L.	150	71"	20
H.A.	150	68"	20
A.A.	200	69"	21
B.E.	150	73.5"	18
C.S.	155	71"	24
C.H.	170	71"	19
R.P.	155	67"	20
H.G.	185	71"	26
P.L.	180	71"	23
Total	1685.0	703.5	
Mean	168.5	70.4	

n = 10

Incl 22



NOTE: NOT TO SCALE

MINE PLANTER MOCKUP DIMENSIONS

Incl 1

RBR

Technical Note 8-66

A RAPID TACTICAL MINE-PLANTING SYSTEM:

HOW FORCE LEVEL AFFECTS LEVER-THROWING TIME

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Technical Assistance

Mason C. Emery

September 1966

APPROVED: John D. Weisz
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U. S. ARMY HUMAN ENGINEERING LABORATORIES
Aberdeen Proving Ground, Maryland

ABSTRACT

This study investigated how well manpower normally available in the field could operate the control levers of a rapid tactical mine-planting system. The subjects, who were selected to represent a normal range of arm strength, operated a control lever at force levels of 60, 80, and 100 pounds while standing on a mock-up of the mine-planter's control lever platform.

The subjects were able to complete the lever push-pull cycle within a two-second time limit at force levels of 60 and 80 pounds. When the force was increased to 100 pounds, they took 3 1/2 seconds to complete the cycle. The time to complete a cycle at 100 pounds grew longer as the one-hour test period continued, but there was no such decrement at 60 and 80 pounds.

Arm strength in the seated position, as measured by a push-pull gauge, did not reliably predict performance at the lever-throwing task.

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A RAPID TACTICAL MINE-PLANTING SYSTEM:

HOW FORCE LEVEL AFFECTS LEVER-THROWING TIME

INTRODUCTION

Several designs have been proposed to satisfy the Army's requirements for a rapid tactical mine-planting system. One of the main considerations was the use of available (i.e., unselected) manpower wherever possible. A system presently under consideration requires a crew of three or four men -- one of whom manually operates draft levers to lower and raise the tools of the planter.

Two important factors influencing operator performance must be considered -- force and time. As a guide to permissible operating forces, the Association of American Railroads' standard for wheel brake mechanisms (1) says that an operator should not have to exert more than 125 pounds of push or pull on a control lever. However, unlike a railroad brakeman, the operator must operate his levers as much as 300 times per hour in order to dispense the mines as required. For a given spacing between adjacent mines, the dispensing rate is determined by the speed at which the mine planter is towed.

Using a human operator imposes certain limitations in this system. According to McCormick (4), humans have limited abilities to ". . . apply physical force with precision, especially when continuous application is required; perform highly repetitive activities reliably; perform work continuously over long periods or under adverse conditions (they are subject to fatigue or stress)."

Tests of strength show that the maximum force that humans can exert depends on the degree of elbow flexion and the direction of movement. A study by Hunsicker (2) measured the amount of force that an individual could exert with his arms when his elbows were fixed at 180°, 150°, 120°, 90°, and 60°. The movements made at each position and angle were pulling from and pushing to the front, lifting up and pushing down, pulling from the side (adduction), and pushing to the side (abduction). The maximum forces of arm movements depend on the elbow's position, as well as direction of movement. Hunsicker's data show that people can exert the most force when sitting and pushing with the arm straight (elbow at 180°).

Since the mine-planter operator works while standing, he uses rather gross, whole-body movements to develop the greatest possible force. The most convenient method for selecting subjects (Ss) seemed to be by testing their arm strength, which, along with arm endurance, work position (standing or sitting), elbow flexion, and direction of force (push or pull), is an important factor in human work capability. The test was given to the Ss while they were seated, so the data could be compared directly with Hunsicker's.

A literature search showed no studies of the relationship between arm strength and endurance. However, Tuttle et al. (6) did relate grip strength to endurance. Strength was defined as an amount of force exerted (for short times), as measured by a dynamometer (like the Chatillon push-pull gauge). Similarly, endurance was defined as the average amount of force exerted over a specified period of time. The correlations between strength and endurance were $r = .67$ for the right hand and $r = .66$ for the left hand. In other words, individuals with stronger grips tend to be able to work longer. These investigations indicated that correlating arm strength and arm endurance would probably give similar results.

Most studies placed Ss in the seated position, but Hunsicker used both the seated and prone positions. He found that strength was always greater in the sitting position -- perhaps because, as Simonson and Enzer (5) have pointed out, the oxidative recovery speed which influences performance depends on body position. Simonson and Enzer add that a person working in a standing position should rest sitting down.

The present study attempted to determine how the force level affects the enlisted man's ability to operate a lever in the rapid tactical mine-planting system. It was expected that force level, arm strength, direction of movement (push vs. pull), and practice would affect performance.

METHOD

Subjects

The Ss were 31 enlisted men stationed at Aberdeen Proving Ground, Md. These men were selected on the basis of an arm-strength test.

The selection test was given to each S in a special chair (Fig. 1) with the Chatillon push-pull gauge mounted on it. During the test, the S's arm was straight (elbow at 180°). Complete instructions to the Ss are given in the Appendix.

Apparatus

A special chair, with the Chatillon push-pull gauge mounted on it (Fig. 1), was built for the S selection test. The actual study was performed on a mock-up of the rapid tactical mine-planter operator's platform (Fig. 2). A comprehensive data-recording system (Figs. 3 and 4) was assembled to measure and record the S's performance during the test. An oscillographic recorder (CEC model 119 with CEC model 323 recording galvanometers) recorded signals from transducers mounted on the mine-planter mock-up. An electrical timer started the recorder, and a buzzer signalled the S that a trial was beginning. When the S had pushed the lever all the way forward, a contact closed on the forward stop, on the travel-limiting rod, and the S could then pull the lever back to the starting position. When the lever reached the rear travel-limiting rod stop, it closed another contact and stopped the recorder. Timing markers printed on the chart at .10-second intervals allowed accurate measurements of how long the S took to complete an entire forward-and-back cycle of the operating lever. The force level on the operating lever was produced by a large disk-brake on one end of the lever shaft. A linear potentiometer on the brake shaft produced a signal indicating the lever's range of motion. A load cell mounted on the lever gave an indication of the break-away force the S had to overcome as he initiated the lever movements.

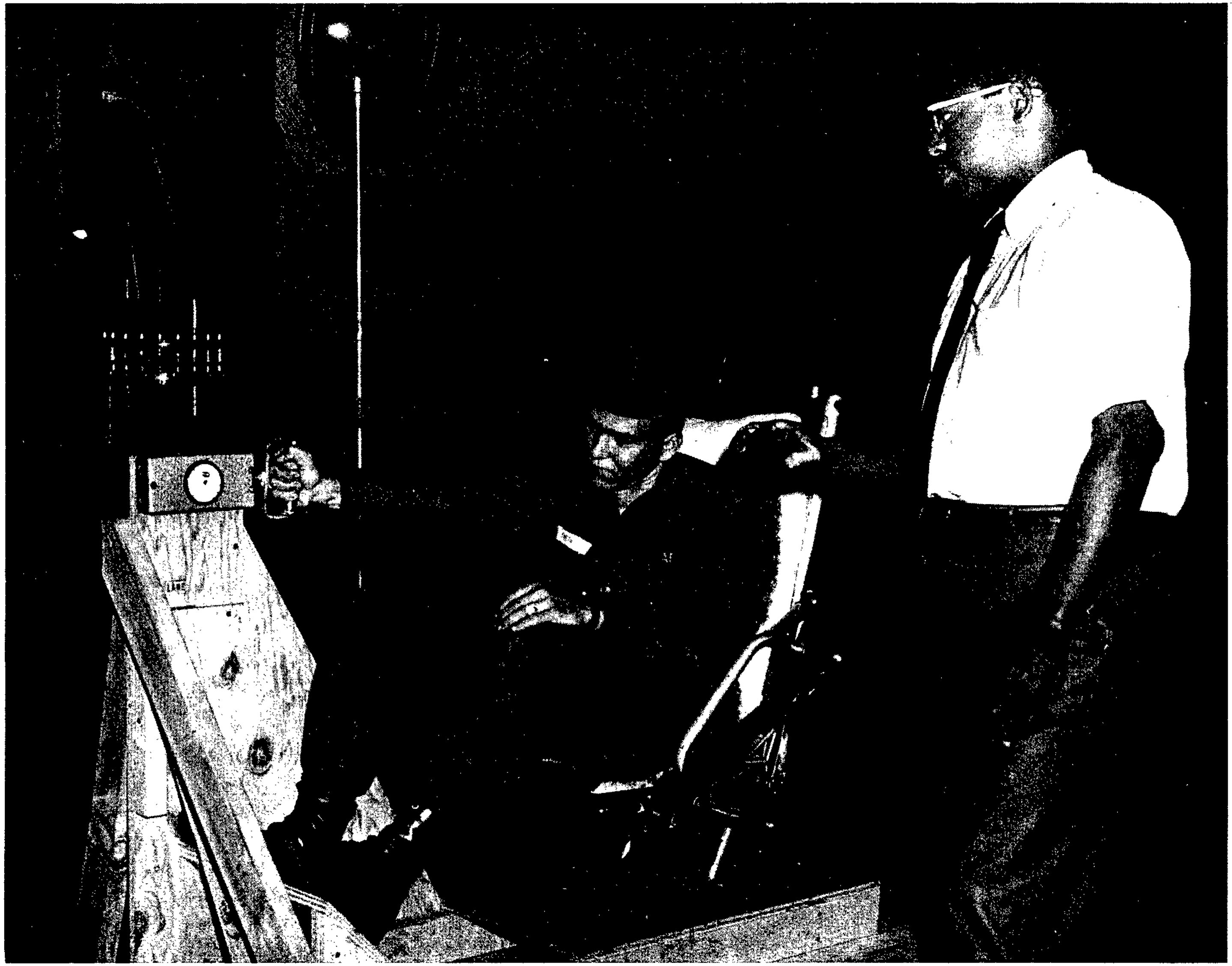
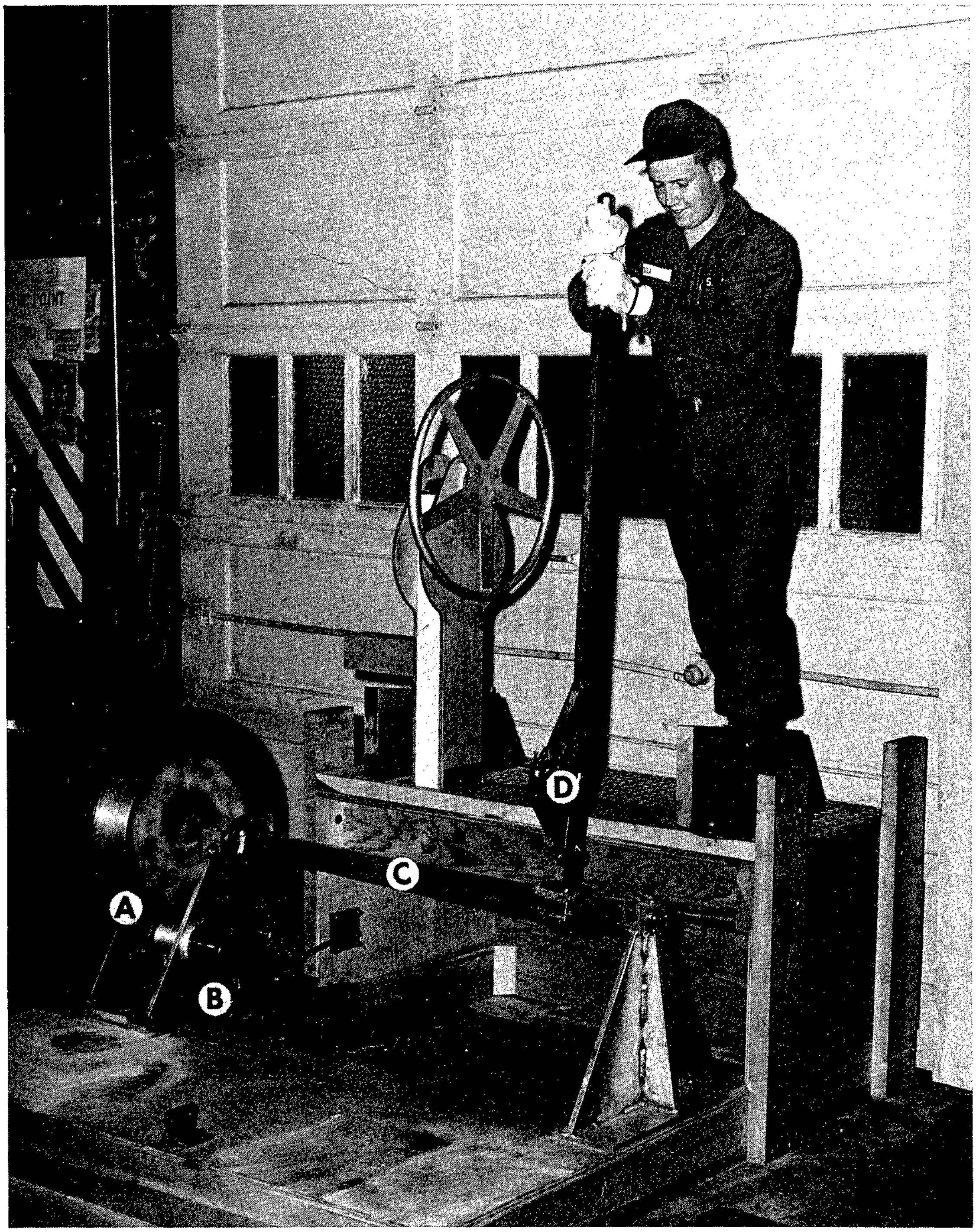


Fig. 1. SUBJECT-SELECTION CHAIR FOR MEASURING ARM STRENGTH



A -- Disk Brake

B -- Traveling-Limiting Rod

C -- Brake-Lever Shaft

D -- Load Cell

Fig. 2. MINE-PLANTER MOCK-UP

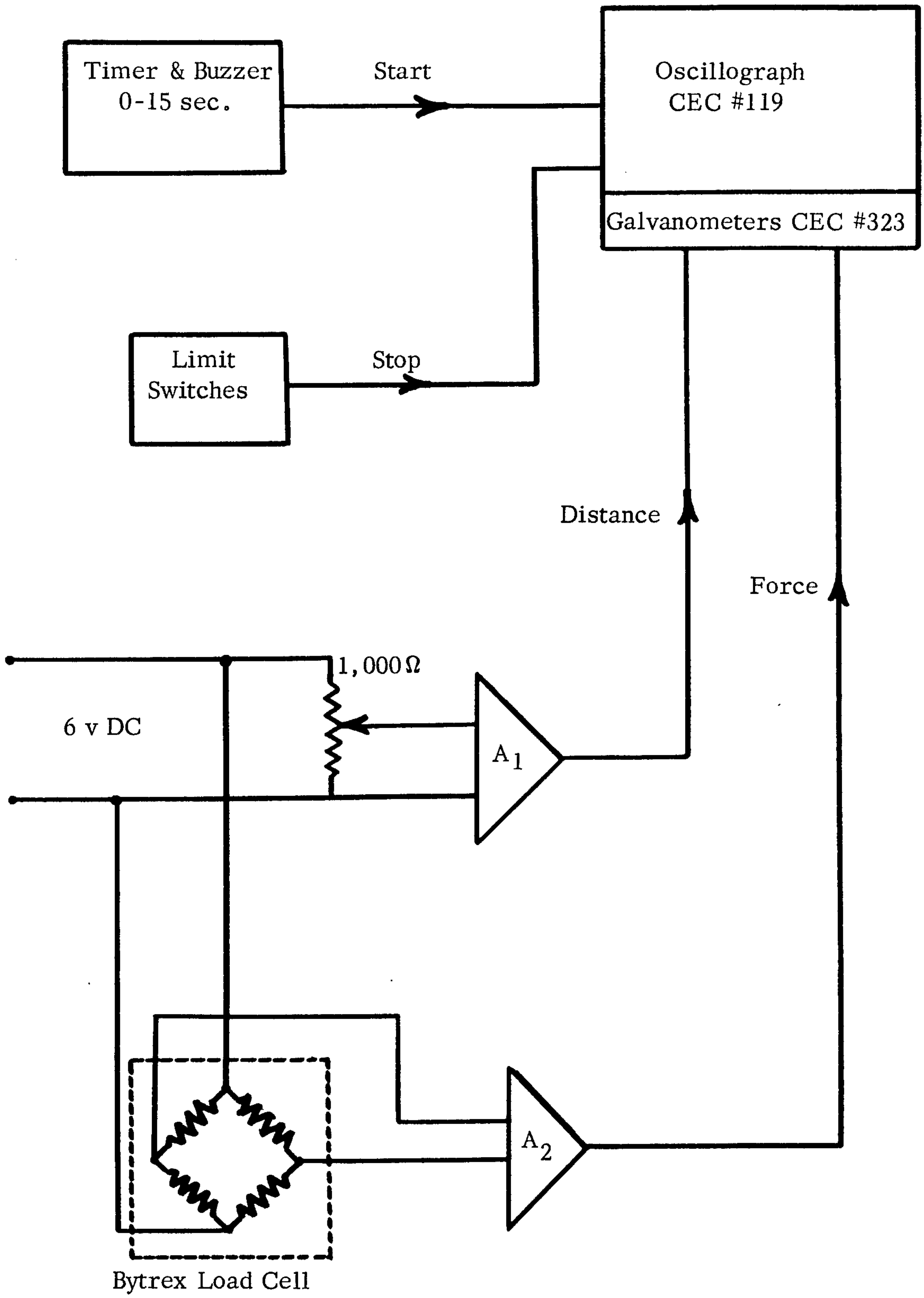


Fig. 3. BLOCK DIAGRAM OF RECORDING DEVICE

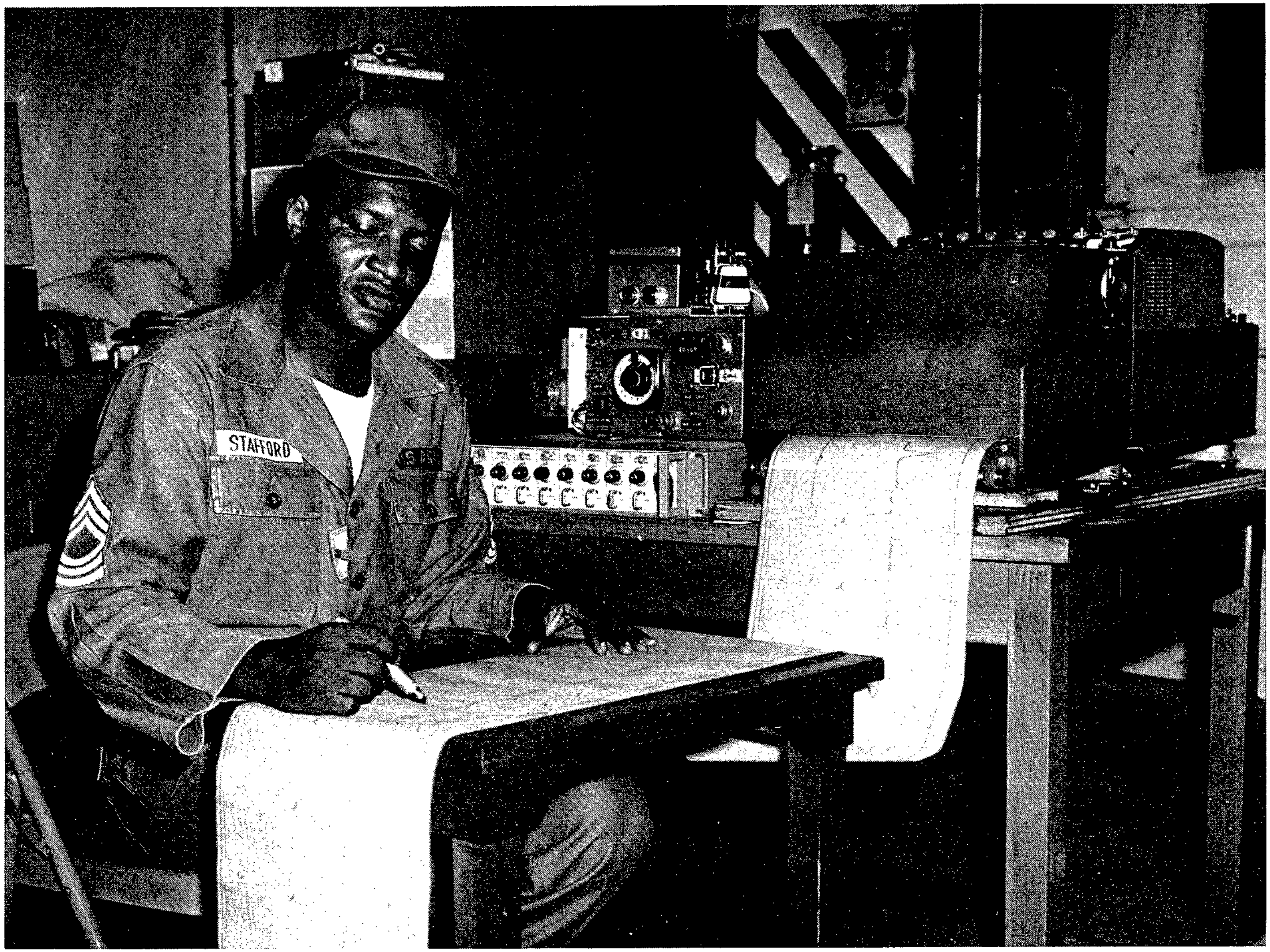


Fig. 4. OSCILLOGRAPH RECORDER (CEC MODEL 119)

Procedure

It was felt that men whose arm strength fell within the 20th - 80th percentile range, as specified by Hunsicker (2), would be most typical of men who would be chosen to operate the mine planter in the field. Thus the Ss used in the mine-planter experiment were selected on the basis of their performance with the Chatillon push-pull gauge mounted on the special chair. The men were tested in a seated position so that their arm strength could be compared with Hunsicker's data.

The 31 Ss who scored within the normal strength range of 80 to 184 pounds push (Hunsicker's 20th - 80th percentile) were randomly assigned to three force-level groups. There were 11 Ss in the 100-pound group, nine Ss in the 80-pound group, and 11 Ss in the 60-pound group.

Each S was given the instructions which appear in the Appendix, and was familiarized with the mine-planter mock-up. To be sure the instructions were understood, each S pushed and pulled the lever through five complete cycles before the experiment began.

To assess the possible effects of practice or fatigue on performance, Ss were required to complete 300 push-pull cycles within one hour, or one cycle every 12 seconds. This represents the amount of work that would be required in the field. One second was allowed for a push, one second for a pull, and ten seconds for rest before the next push.

In summary, the three different Groups (force levels of 60, 80, and 100 pounds) constituted a "between-subjects" variable, while Push-vs.-Pull and Practice constituted "within-subjects" variables.

RESULTS

The time taken to complete a push or a pull (response time), measured in hundredths of a second, served as the measure of performance. The shorter the response time, the better the performance.

To assess the effect of practice or fatigue, both a mean time to complete a push and a mean time to complete a pull were computed for each block of 15 trials. This resulted in a total of 40 scores for each S -- a mean push score and a mean pull score for each of the 20 blocks of 15 trials. A Lindquist (3) type VI analysis-of-variance design was used to evaluate these scores. The three different Groups (force levels of 60, 80, and 100 pounds) constituted the "between-subjects" effect, and Push-vs.-Pull and Practice were "within-subjects" effects. The results of the analysis of variance are summarized in Table 1.

All three main effects (Groups, Push-vs.-Pull, and Practice) reached statistical significance. The interaction of Groups x Practice was also significant.

Table 2 presents the mean response times for pushing and pulling the lever at each level of force. These values were derived by averaging means from 40 blocks of 15 trials.

Table 2 shows that the Ss performed better at 60- and 80-pound force levels than at the 100-pound level. The Ss also pulled better than they pushed at all force levels.

Figure 5 illustrates the Ss' performance across the blocks of 15 trials. Continued performance degraded the Ss' performance at the 100-pound force level.

TABLE 1

Analysis of Variance:

Push-Pull Scores by Groups (Force Levels), Push-vs.-Pull, and Practice

	df	Mean Square	F
Between Subjects	30	13.81	
Groups (60 x 80 x 100 pounds)	2	105.53	14.52***
Error	28	7.27	
Within Subjects	1209		
Push-vs.-Pull	1	10.17	18.21***
Practice	19	0.33	4.56***
Groups x Practice	38	0.17	2.39***
Push-vs.-Pull x Practice	19	0.03	1.07
Push-vs.-Pull x Groups	2	0.57	1.03
Groups x Push-vs.-Pull x Practice	38	0.02	0.93
$Error_1$	28	0.56	
$Error_2$	532	0.07	
$Error_3$	532	0.03	
Total	1239		

*** Significant beyond 0.001 level of confidence.

TABLE 2

Mean Response Times (Seconds) at Each Force Level

	Force Level		
	60 pounds	80 pounds	100 pounds
Push	0.987	0.970	1.785
Pull	0.734	0.786	1.677
Total	1.721	1.756	3.462
Mean	0.860	0.878	1.731

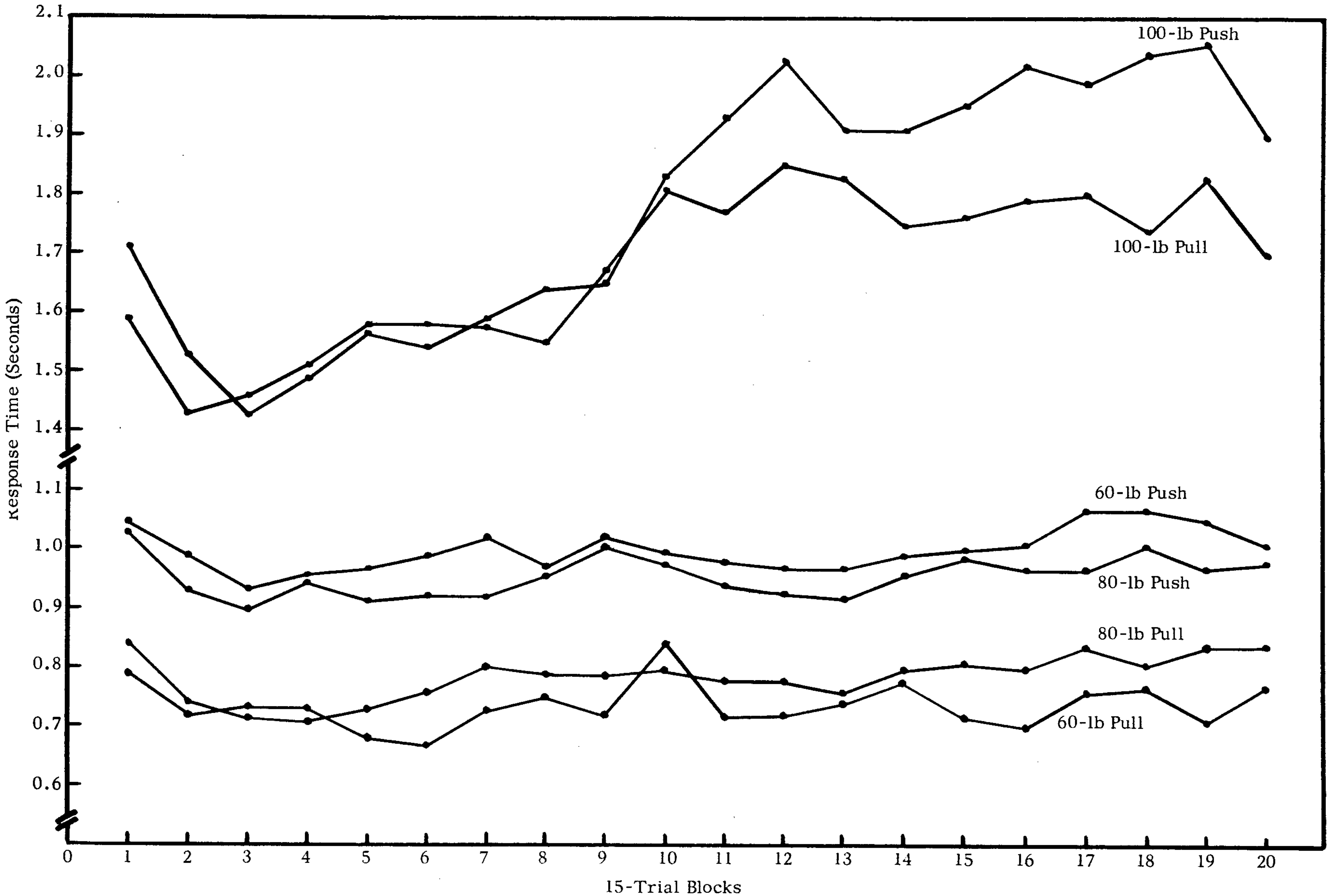


Fig. 5. MEAN PUSH AND PULL RESPONSE TIMES: TWENTY 15-TRIAL BLOCKS

DISCUSSION

The results show that enlisted men who can exert between 80 and 184 pounds of force on the Chatillon push-pull gauge can complete the push-pull cycle within two seconds when the lever force is 80 pounds or less. However, they take a second and a half longer -- or about 3 1/2 seconds -- when the lever force is increased to 100 pounds.

The significant interaction between Groups and Practice shows that groups differed more at the end of the hour than they did at the beginning. It is likely that the Ss working at a 100-pound force level became fatigued, since the Ss working at force levels of 60 and 80 pounds showed very little change in performance from start to finish (Fig. 5).

Although the literature states that men can push harder than they can pull (2), we found the opposite to be true. However, Hunsicker (2) measured his Ss in sitting and prone positions. Since our Ss were required to stand, they used different sets of muscles and their weight was distributed differently, which may account for this discrepancy. Nevertheless, these differences deserve further investigation.

Performance at the mine-planter task and performance on the push-pull gauge test were correlated with a Pearson product-moment coefficient, but the correlation was not statistically significant. This means that the Chatillon push-pull gauge did not predict performance at the mine-planter lever-throwing task reliably.

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APPENDIX

INSTRUCTIONS TO SUBJECTS

INSTRUCTIONS FOR SUBJECT-SELECTION TEST

This is a short test to measure your arm strength. Please adjust the seat so that your arm is straight as you grasp the handle. Place your feet on the foot rest. When I say "ready," you will grasp the handle. When I say "go," push the handle as hard as you can and hold it for five seconds. When I say "stop," you will place your arm at your side and rest for one minute. After resting you will hear the command "ready," and you will grasp the handle again. When I say "go," you will push the handle as hard as you can, and hold it for five seconds. When I say "stop," you will place your arm at your side and rest for one minute. This procedure will be repeated six times. Do your best and push the handle as hard as you can.

Relax now and wait until you are given the ready signal.

INSTRUCTIONS FOR RAPID TACTICAL MINE-PLANTER MOCK-UP

This is a study to investigate how well you can push and pull this control lever for an extended period of time. You will be required to push this lever to the stop point [demonstrate] and pull it back to the starting position. You must push this lever and pull it back as quickly as you can. First, you must place both hands on the lever handle and stand with your left foot forward [demonstrate]. A buzzer will sound every 12 seconds. When the buzzer sounds, you will push this lever to the stop point and pull it back to the starting position as quickly as you can [demonstrate].

You may now push the lever and pull it back five times to get the feel of it. Remember -- the lever must be pushed and pulled to both stop points in order that the push-pull cycle is completed. If you do not pull it back to the starting point, the experimenter will tell you to finish the pull. We need your full cooperation. But we do not want you to hurt yourself in any way. If you feel that you cannot go on, by all means let the experimenter know. This will be a test of your endurance and it will last for one hour. Your full effort will be deeply appreciated.

Relax now and wait for the buzzer to sound.

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13. ABSTRACT

This study investigated how well manpower normally available in the field could operate the control levers of a rapid tactical mine-planting system. The subjects, who were selected to represent a normal range of arm strength, operated a control lever at force levels of 60, 80, and 100 pounds while standing on a mock-up of the mine-planter's control lever platform.

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