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A STUDY OF MUSCLE FORCES AND FATIGUE

PAUL A. HUNSICKER

UNIVERSITY OF MICHIGAN

FC

DECEMBER 1957

AERO MEDICAL LABORATORY

CONTRACT No. AF 33(616)-3461

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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WADC TECHNICAL REPORT 57-586 ✓

ASTIA DOCUMENT No. AD 131 089⁷

A STUDY OF MUSCLE FORCES AND FATIGUE

PAUL A. HUNSICKER

UNIVERSITY OF MICHIGAN

DECEMBER 1957

AERO MEDICAL LABORATORY
CONTRACT No. AF 33(616)-3461
PROJECT 7214
TASK 71727

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

The research project was conducted at the University of Michigan under the authority of Contract No. AF 33(616)-3461 with Paul A. Hunsicker as the Principal Investigator. The Kinematic Muscle Study machine used in conducting these tests was developed in the Anthropology Section of the Aero Medical Laboratory. The Kellogg Universal Dynamometer used for a few of the strength tests belongs to the Physical Education Research Laboratory at the University of Michigan. Mr. H. T. E. Hertzberg served as Project Engineer for the Aero Medical Laboratory.

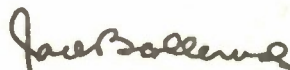
ABSTRACT

The first phase of the research deals with the strength test results taken on 30 subjects covering 120 strength tests. The subjects were seated in a simulated pilot-seat and six movements were tested. The results are presented in percentile tables and graphic form. The next part of the study involves data on 25 subjects who were tested to determine the amount of strength possible in wrist pronation and wrist supination. The final phase of the research gives information on the strength-decrement over a 42-hour period in which the subjects were tested hourly. Several recommendations are offered.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:



JACK BOLLERUD

Colonel, USAF (MC)

Chief, Aero Medical Laboratory
Directorate of Laboratories

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SECTION I

INTRODUCTION

The idea of determining the strength which an individual could exert while seated in a simulated pilot-seat was suggested several years ago by Mr. Hertzberg, Chief of the Anthropology Section, Biophysics Branch, Aero Medical Laboratory, Wright Air Development Center. Discussions between Mr. Hertzberg and the author resulted in the planning of several research projects.

An earlier investigation by the author (7)* was concerned with:

1. A survey of the literature dealing with the measurement of human strength.
2. Experimenting with the Kinematic Muscle Study machine to make it functional.
3. Testing an adequate sample of men to determine how much arm strength they could exert with the body and arms in selected positions.

To continue the exploration in the field of human strength, the present research will be divided into the following parts:

1. Testing an adequate sample of men with the Kinematic Muscle Study machine to determine the strength which they can exert with the arms and hands in selected positions.
2. Testing an adequate sample of men to determine the strength which they can exert in wrist pronation and wrist supination.
3. Testing a small sample of men hourly for 42 test periods to determine the strength-decrement during this period.

SECTION II

STRENGTH IN SITTING POSITION, ARMS VERTICALLY DOWN

Although the Kinematic Muscle Study machine was in good working order at the conclusion of the previous study, the

*Numbers in parentheses refer to the Bibliography

dynamometers, supporting structure, electrical system and recording camera were all rechecked. The dynamometers were recalibrated and the new readings appear in Appendices A through F.

Description of Tests

The test battery used in this phase of the research was divided into two parts; namely, tests in the sitting position with the hands pronated and tests in the sitting position with the hands supinated. Except in rare instances these were given on separate days and within a week of each other. The subject was oriented with the apparatus by running some trial tests. None of the testees had any difficulty comprehending the verbal instructions which were given at the first period of testing. The tests were administered in the following manner:

1. Sitting position, arms extended vertically down, elbows at 180° , wrists pronated and in a perpendicular line with the external canthus, hands grasping dynamometers (Fig. 1). With the subject in this position, a series of six strength tests was made on each hand. Each test lasted five seconds, and one minute rest was allowed between tests. The following sequence was adhered to:

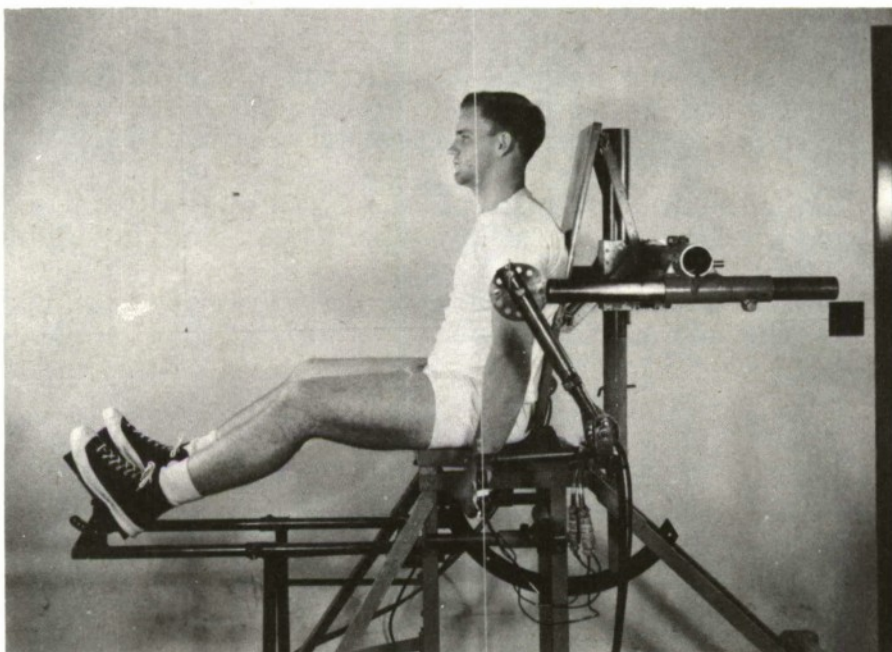


Fig. 1. Wrists Pronated, Elbows 180°

- (a) On a signal "go" from the examiner the subject pushed forward with the right hand as hard as possible for five seconds. The examiner did the timing and told the subject to stop at the end of five seconds. During the test the examiner took three single-frame exposures of the trial. These were usually taken at the two-second, three-second, and four-second intervals. Since the examiner was able to watch the indicators during the test it was possible to record the maximum effort in all instances.
- (b) The second test was to pull back on the right dynamometer with the right hand. The same procedure as in (a) was repeated for timing and recording the test result.
- (c) The third test consisted of pulling up on the dynamometer.
- (d) The subject pushed forward on the left hand dynamometer in a manner similar to (a).
- (e) In the next test the subject pulled back on the left dynamometer with the left hand.
- (f) The subject pulled up on the left hand dynamometer.
- (g) The subject pushed down on the right hand dynamometer.
- (h) The subject abducted the right arm, or pulled away from the mid-line.
- (i) The subject adducted the right arm, or pulled toward the mid-line.
- (j) The testee pushed down on the left hand dynamometer.
- (k) The testee abducted the left arm, or pulled away from the mid-line.
- (l) The subject adducted the left arm, or pulled toward the mid-line.

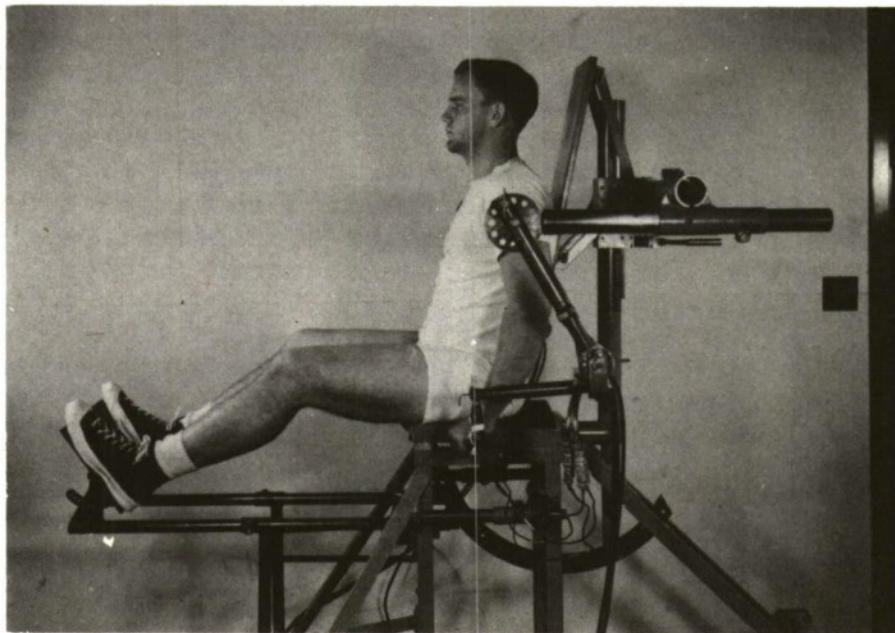


Fig. 2. Wrists Pronated, Elbows 150°

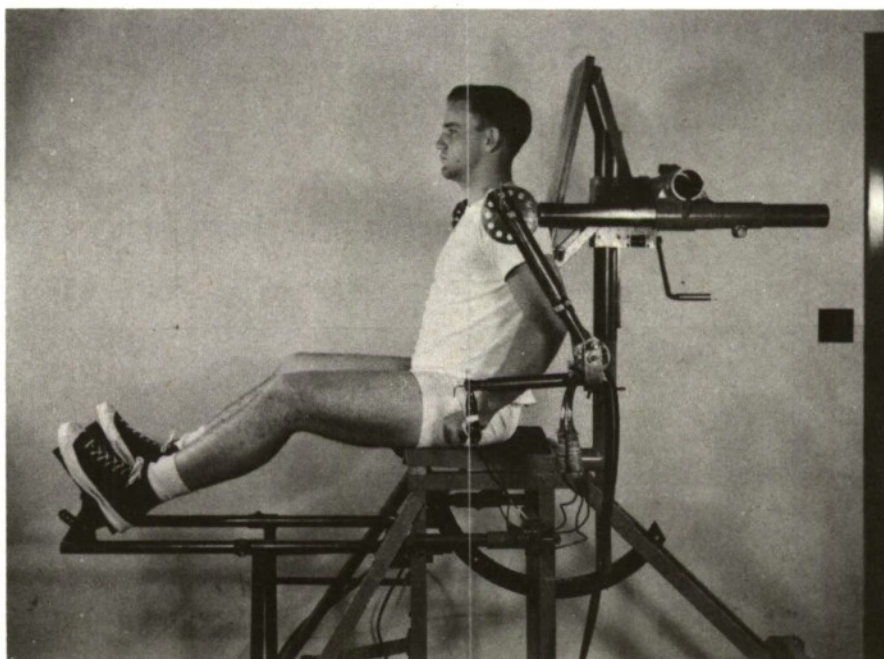


Fig. 3. Wrists Pronated, Elbows 120°

2. After tests (1a) through (1l) were given, the Kinematic Muscle Study machine was adjusted so as to fix the subject's elbows at 150° of flexion (Fig. 2). The same 12 tests were then administered at the new position.
3. The machine was adjusted and the 12 tests given with the subject's elbows at 120° (Fig. 3).
4. The machine was changed so the subject's elbows were at 90° , and the tests were given (Fig. 4).
5. The machine was adjusted so the subject's elbows were at 60° , and the tests administered (Fig. 5).

The sixty tests with the subject's wrists pronated were given in one test session. A second test period was required to administer the tests with the wrists supinated. The same procedure and test sequence was used with the wrists supinated as in the pronated position.

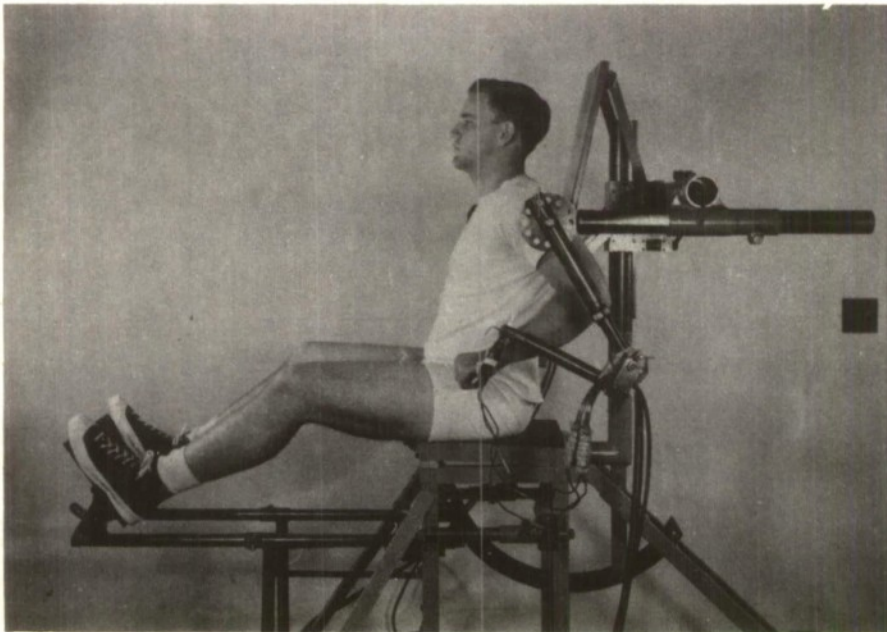


Fig. 4. Wrists Pronated, Elbows 90°

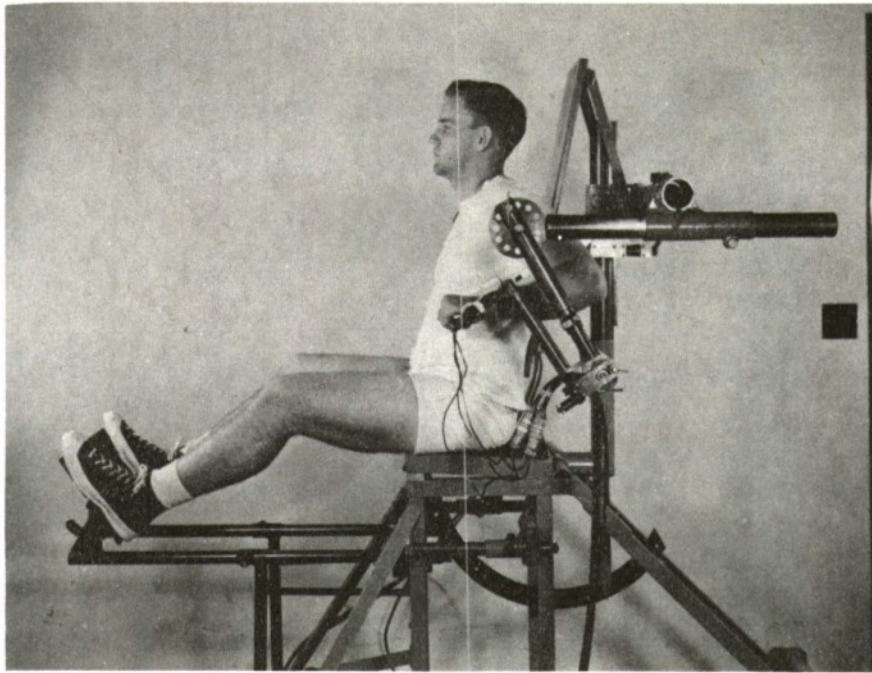


Fig. 5. Wrists Pronated, Elbows 60°

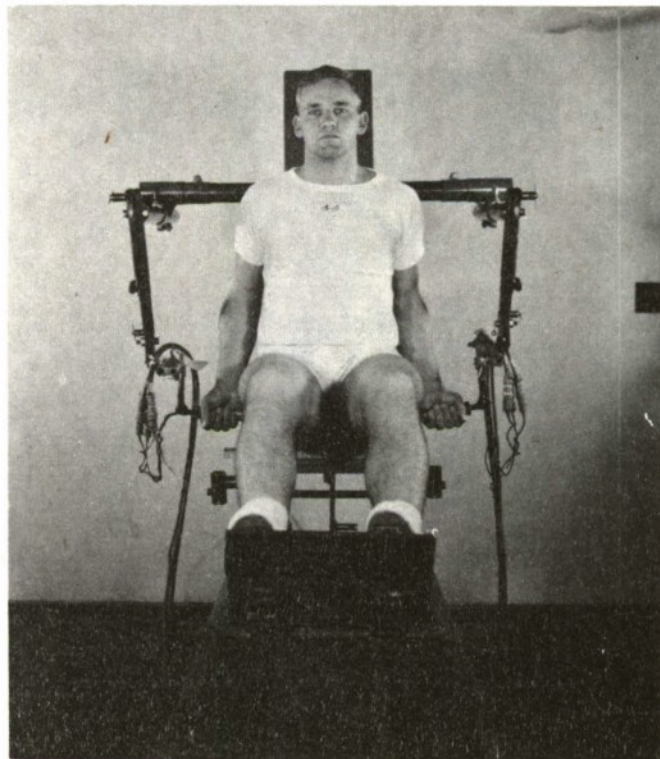


Fig. 6. Front View, Wrists Supinated

Subjects Tested

The subjects tested in this phase of the research were all students at the University of Michigan ranging in age from 18 to 27 years, or comparable to the age-span of a pilot trainee group. In selecting the sample an attempt was made to span the physical characteristics as outlined in the Hertzberg, Daniels and Churchill report Anthropometry of Flying Personnel-1950 (6).

An examination of Table 1 reveals that the anthropometric measurements of the testees were well within the range of the limits found in flying personnel. The subjects were selected with the thought of spanning the range of physical characteristics as it was desirable to determine the range of human strength.

All subjects were paid volunteers and the examiners felt that the testees were exerting maximum efforts during the test periods. The group was equally cooperative in keeping appointments at the scheduled times.

TABLE 1

PHYSICAL CHARACTERISTICS OF SUBJECTS

	Low Score	High Score	Mean	Sigma
Age (years)	18	27	22.8	2.9
Weight (lbs.)	126	206	156.5	17.3
Height (ins.)	64	74.5	69.2	3.5
Chest Cir. relaxed	32	41.2	36.6	2.2
Chest Cir. expanded	33.1	42.7	38.7	2.6
Waist Cir.	27.6	38.0	31.1	5.0
Biceps flexed	10.5	15.2	12.6	0.7
Lower Arm Cir. flexed	9.8	12.5	11.2	1.2
Wrist Cir.	6.1	7.6	6.8	0.8
Wrist to Knuckle	2.3	3.1	2.8	0.3
Shoulder Breadth (Biacromial)	14.5	17.4	16.2	.01

SECTION III

STRENGTH TEST RESULTS

In the analysis of the results three strength scores were available for each test. Since the dynamometers gave readings in three axes, a resultant force had to be calculated and the highest resultant was selected for describing the data. All tables and figures in this section are based on the highest of the three resultants for any given test.

Wrists Pronated, Forward Push (Table 2, Fig. 7)

In this action, the greatest strength was exerted with the elbows at 60° (right and left arms). Strength was progressively less in both arms with the elbows at 90, 120, 150 and 180° and the graphs ran parallel. The lowest score for the best position with the right arm was 30 pounds, and for the left arm, 32 pounds. Approximately two-thirds of the cases pulled between 58 and 130 pounds (right) and 51 and 121 (left). The weakest pull with the elbows at 60° was 17 percent (right) and 18 percent (left) as strong as the strongest.

Wrists Pronated, Pull Back (Table 3, Fig. 8)

The strength developed in this action was relatively small with the greatest amount when the elbows were at 60°. Approximately two-thirds of the sample pulled between 21 and 53 pounds (right) and 21 and 57 pounds (left). The range of 11 to 107 pounds (right) and 19 to 100 pounds (left) made it apparent that there are tremendous individual differences. The degree of elbow flexion did not have a marked effect on these scores. The curves for the right and left arms ran fairly parallel.

Wrists Pronated, Pull Up (Table 4, Fig. 9)

Unlike the previous tests, the greatest force could be exerted in this action with the elbows at 150°. In general the strength decreased as the degrees of elbow flexion approached 60. The scores ranged from 35 to 185 pounds (right) and from 56 to 179 pounds (left). The lowest mean values were 50 percent (right) and 57 percent of the maximum values (left). The middle two-thirds of the distribution ranged between 62 and 138 pounds for the right arm and between 69 and 131 pounds for the left arm.

Wrists Pronated, Push Down (Table 5, Fig. 10)

Although the degrees of elbow flexion did not seem to affect this action to a great extent there were minor differences. In the case of the right arm the maximum effort was achieved with the elbow flexed to 120°. With the left arm the high value was attained with 150° of flexion. The lowest mean value, 81 pounds at 60° was 88 percent of the maximum of 92 pounds at 120°. The variance was even less with the left arm, where the minimum of 74 pounds at 60° was 94 percent of the 79 pound maximum at 150°. The curve for the left arm comes fairly close to approximating a straight line.

Fig. 7. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: FORWARD

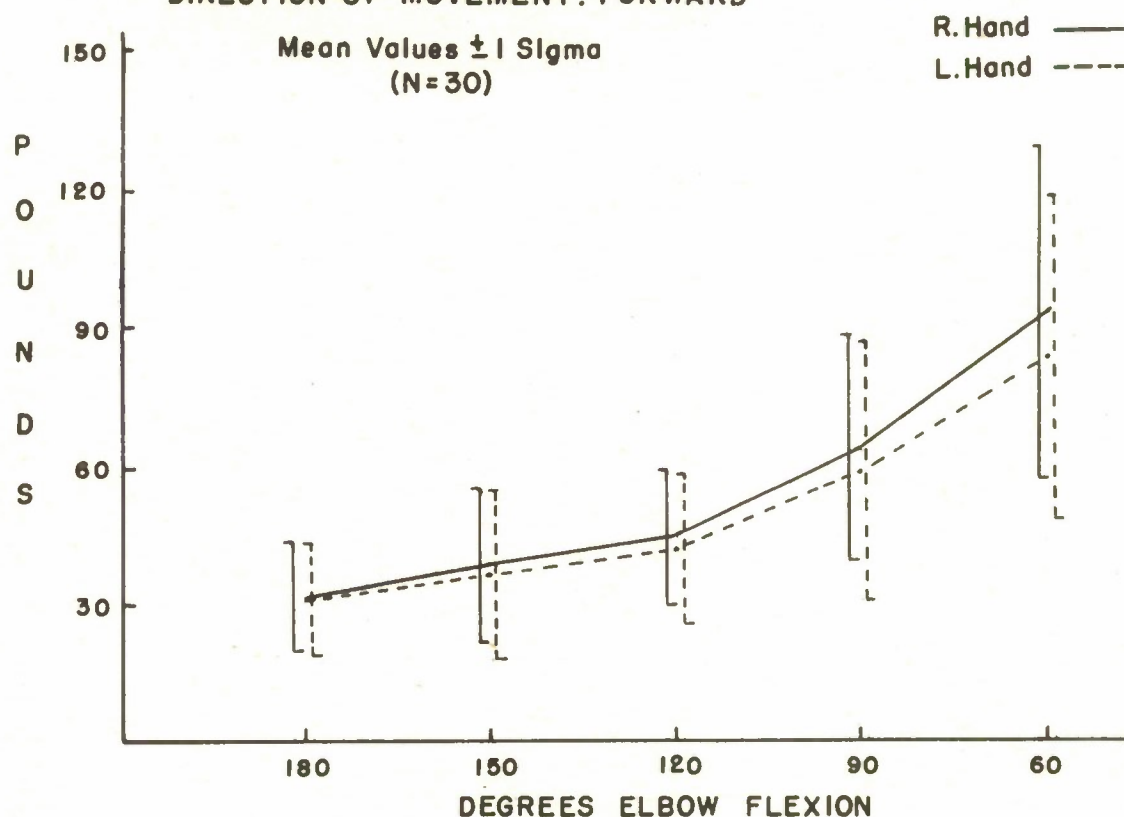


TABLE 2

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: FORWARD

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	17	18	23	25	40	12	15	17	27	33
10	19	21	27	34	52	16	17	21	29	40
20	23	26	30	45	57	19	20	25	36	49
30	24	29	33	48	70	22	24	29	43	62
40	26	31	42	58	78	24	29	32	49	72
50	27	33	45	64	83	28	30	42	52	80
60	29	41	47	70	93	34	33	45	54	85
70	33	44	52	79	111	37	40	48	71	95
80	42	49	60	82	127	38	57	58	81	113
90	49	59	63	99	140	55	65	69	91	135
95	59	66	70	100	156	59	69	71	93	138
Low Score	15	15	20	22	30	9	13	16	26	32
High Score	60	92	92	106	172	62	82	86	167	183
Number	30	30	30	30	30	30	30	30	30	30
Mean	32	40	46	65	94	32	37	43	60	86
Std. Dev.	12	18	15	24	36	13	18	17	28	35

Fig. 8. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: BACK

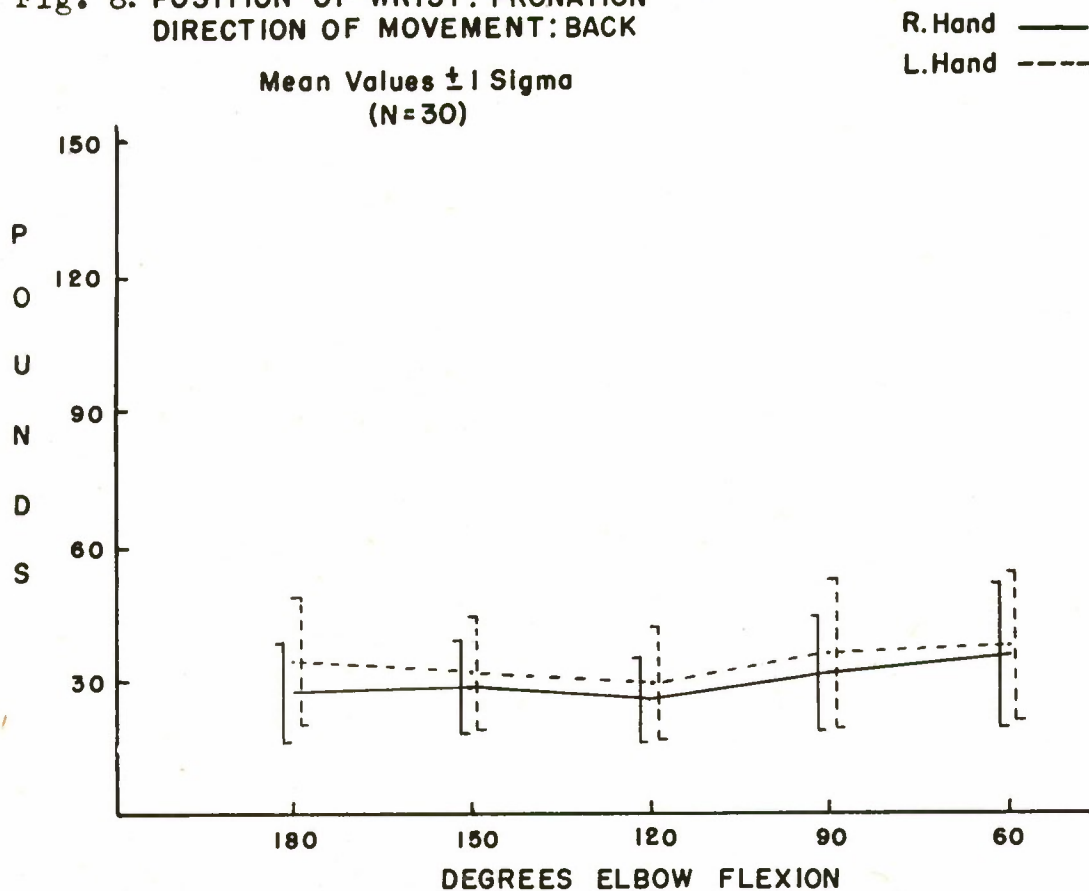


TABLE 3

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: BACK

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	11	12	13	14	13	16	15	12	17	20
10	14	15	17	18	16	20	20	15	20	22
20	17	18	19	22	24	22	21	20	22	23
30	19	20	20	25	29	25	23	23	25	27
40	22	22	22	27	31	29	26	25	28	32
50	25	28	24	32	37	29	31	27	32	35
60	31	30	29	35	39	32	34	29	36	40
70	35	34	29	36	42	38	37	36	40	45
80	39	40	34	40	45	43	41	40	45	52
90	45	41	36	46	49	52	47	48	55	55
95	48	48	43	54	50	61	52	56	65	64
Low Score	11	8	9	13	11	12	12	9	14	19
High Score	53	56	48	67	107	71	72	61	105	100
Number	30	30	30	30	30	30	30	30	30	30
Mean	28	29	26	32	37	34	32	30	37	39
Std. Dev.	12	10	10	13	16	15	13	14	18	18

Fig. 9. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: UP

R.Hand ———
L.Hand - - - -

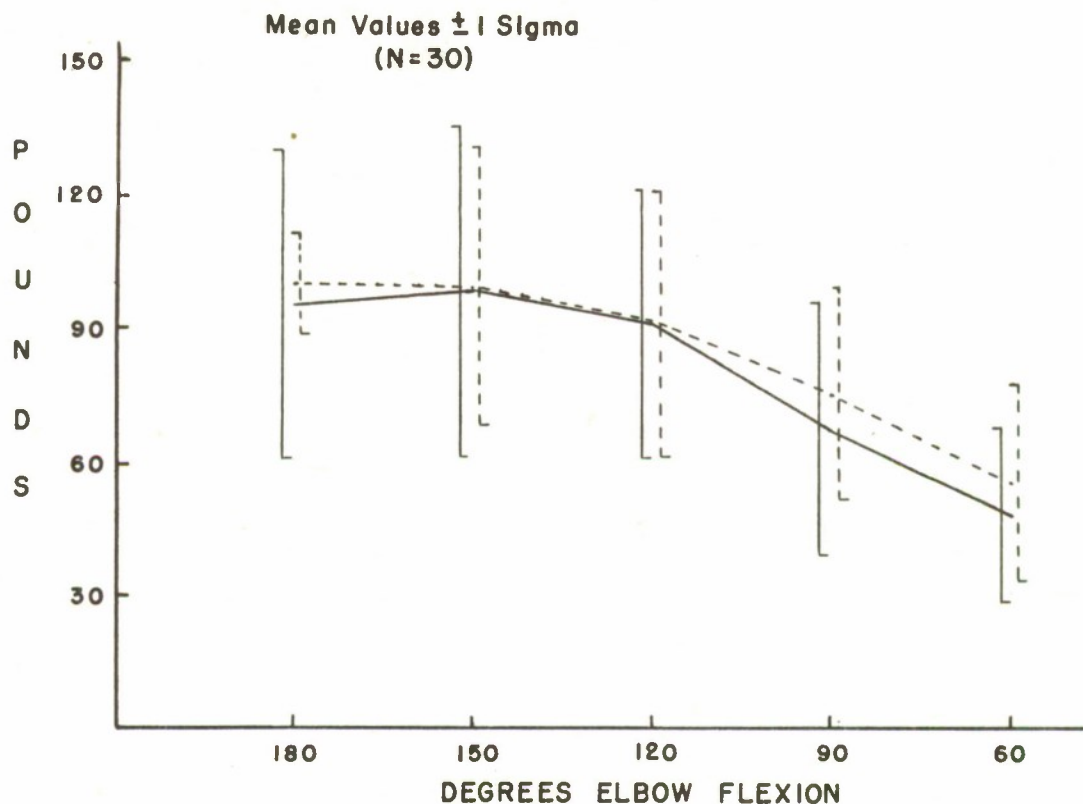


TABLE 4

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: UP

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	35	43	41	28	23	47	58	45	37	22
10	42	57	45	30	25	57	60	57	45	26
20	66	64	65	45	31	66	73	68	54	39
30	71	77	75	53	35	85	79	75	61	42
40	77	80	85	58	42	89	85	80	68	50
50	91	83	88	69	44	92	89	83	76	53
60	99	105	96	71	50	106	95	90	79	56
70	109	118	101	81	59	113	111	99	85	67
80	122	132	115	92	71	118	128	114	90	72
90	139	129	127	97	76	138	139	140	110	83
95	156	165	138	112	79	171	159	145	123	100
Low Score	29	35	39	28	22	38	56	39	30	21
High Score	167	185	159	126	83	178	179	149	131	114
Number	30	30	30	30	30	30	30	30	30	30
Mean	95	99	91	69	49	101	100	91	77	57
Std. Dev.	35	38	30	29	20	11	32	30	24	22

Fig. 10. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: DOWN

R. Hand ———
L. Hand - - - -

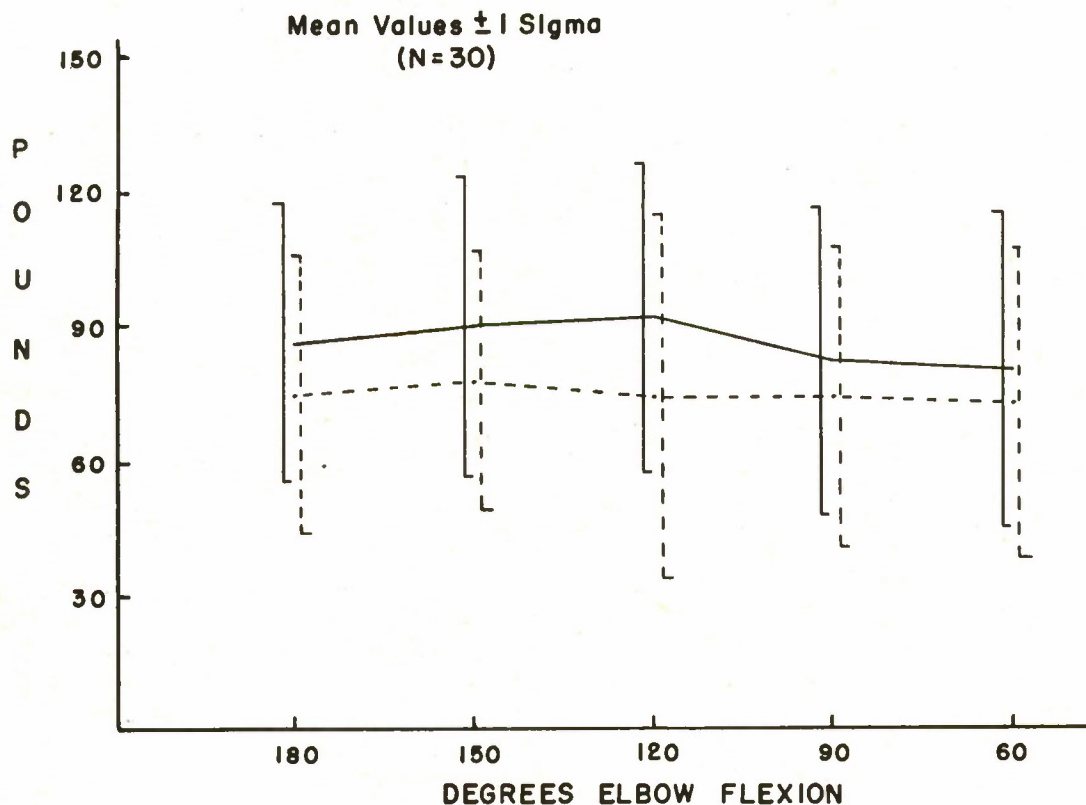


TABLE 5

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: DOWN

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	41	40	37	22	23	34	39	29	23	18
10	43	47	58	37	47	36	43	35	30	26
20	52	58	65	55	53	45	48	42	48	46
30	59	69	70	65	61	51	56	53	65	60
40	77	75	78	75	67	63	68	64	67	66
50	87	81	83	79	70	69	76	72	73	71
60	93	93	90	90	79	77	79	78	82	76
70	97	101	95	94	91	85	91	82	86	84
80	107	111	108	97	105	97	104	92	89	91
90	136	140	146	127	115	114	112	122	93	106
95	143	154	161	142	158	138	136	148	136	139
Low Score	41	37	34	20	23	33	35	25	19	15
High Score	160	161	179	165	173	142	153	159	174	175
Number	30	30	30	30	30	30	30	30	30	30
Mean	87	90	92	83	81	76	79	75	75	74
Std. Dev.	31	34	35	35	35	31	29	40	34	35

Wrists Pronated, Abduction (Table 6, Fig. 11)

It was quite difficult for the subjects to exert very much strength in this movement. The right arm scores ranged from a high mean value of 41 pounds at 60° to a low of 19 pounds at 180°. The plot for the left arm was quite similar with a high of 36 pounds at 60° and a low of 20 pounds at 180°. The low mean values were approximately 46 (right) and 56 (left) percent of the maximum values. The middle two-thirds of the distribution at 60° elbow flexion, ranged between 22 and 60 pounds for the right arm and between 21 and 51 pounds for the left arm.

Wrists Pronated, Adduction (Table 7, Fig. 12)

Although this action was somewhat stronger than abduction, it was one of the weaker movements. As in abduction, the strongest force was exerted with the elbows at 60°. Both the right arm and left arm forces increased as the elbow flexion changed from 180 to 60°. The scores, with the elbows at 60°, ranged from 15 to 84 pounds (right) and 17 to 72 pounds (left). The one sigma range for the right arm was 30 to 66 pounds and for the left arm 28 to 56 pounds. The minimum mean values were 63 and 67 percent of the maximum means.

Wrists Supinated, Forward Push (Table 8, Fig. 13)

The strength exerted in this movement varied considerably with the degrees of elbow flexion. At 180° the force was only 33 percent of the maximum at 60° flexion. The curves for both arms ran fairly parallel with increases in mean values as the elbow flexion ranged from 180 to 60°. Of the six movements done with the wrists supinated, this action yielded the second highest strength values. The scores ranged from 29 to 188 pounds with the right arm and from 26 to 195 pounds with the left arm. The middle two-thirds of the distribution varied between 57 and 135 pounds (right) and 47 to 131 pounds (left).

Wrists Supinated, Pull Back (Table 9, Fig. 14)

The degree of elbow flexion did not have a marked influence on the amount of strength that was possible in this action. In the case of the left arm the scores at 180, 150 and 120° were identical and 74 percent of the maximum, 54 pounds at 60°. The graph for the right arm was somewhat similar with a maximum at 60°. As in the Forward Push, the maximum was possible at the same degree of elbow flexion but the force was less than 60 percent of the value. The one sigma range from the mean extended from 27 to 75 pounds (right) and 31 to 77 pounds (left).

Fig. 11. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ABDUCTION

R.Hand ———
L.Hand - - - -

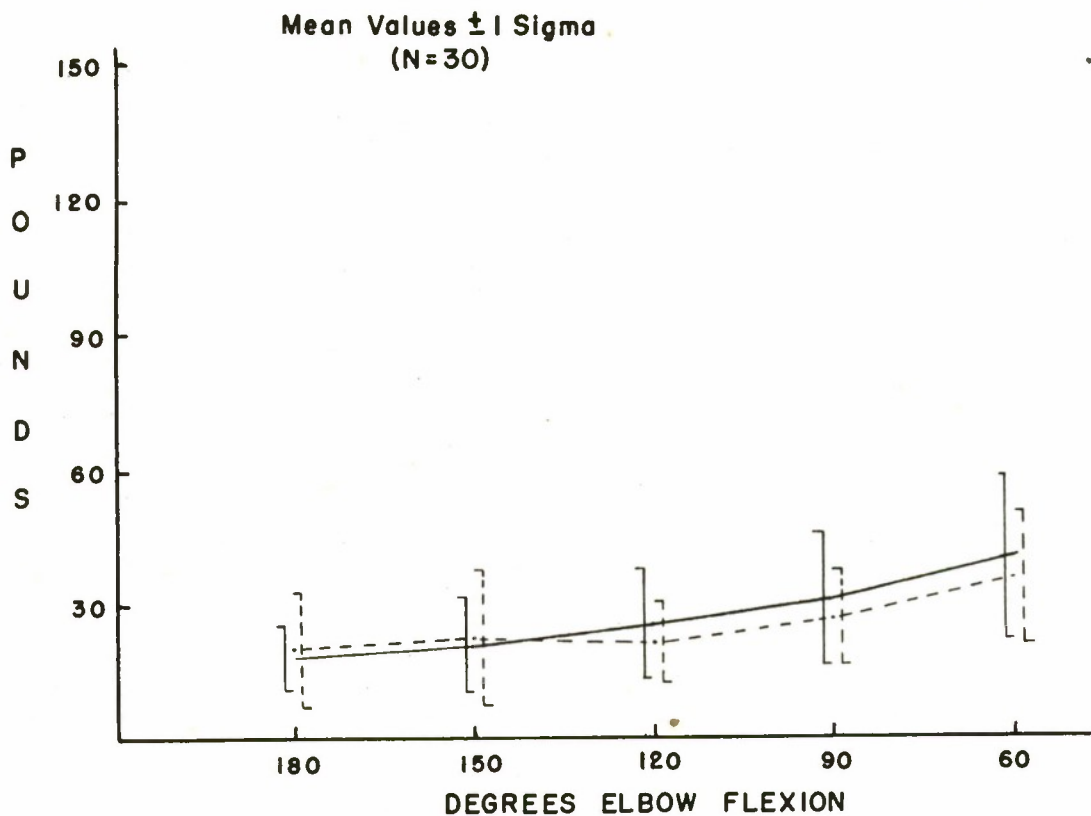


TABLE 6

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ABDUCTION

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	10	9	9	12	19	10	9	10	11	18
10	11	11	15	14	21	11	13	13	16	21
20	12	12	16	16	26	13	14	15	18	22
30	14	14	16	19	30	14	15	16	19	26
40	16	17	17	25	33	15	17	18	21	28
50	18	19	23	26	35	16	18	19	25	29
60	19	19	25	31	41	18	21	23	26	38
70	19	21	26	35	47	19	24	23	27	42
80	21	23	35	40	58	22	26	26	32	46
90	27	27	39	61	64	29	30	35	42	48
95	34	39	53	64	72	49	53	39	54	51
Low Score	9	8	7	11	18	8	8	7	8	15
High Score	44	71	67	67	87	64	83	46	58	100
Number	30	30	30	30	30	30	30	30	30	30
Mean	19	21	26	31	41	20	23	22	27	36
Std. Dev.	7	11	13	15	19	13	16	10	11	15

Fig. 12. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ADDUCTION

R. Hand ———
L. Hand - - - -

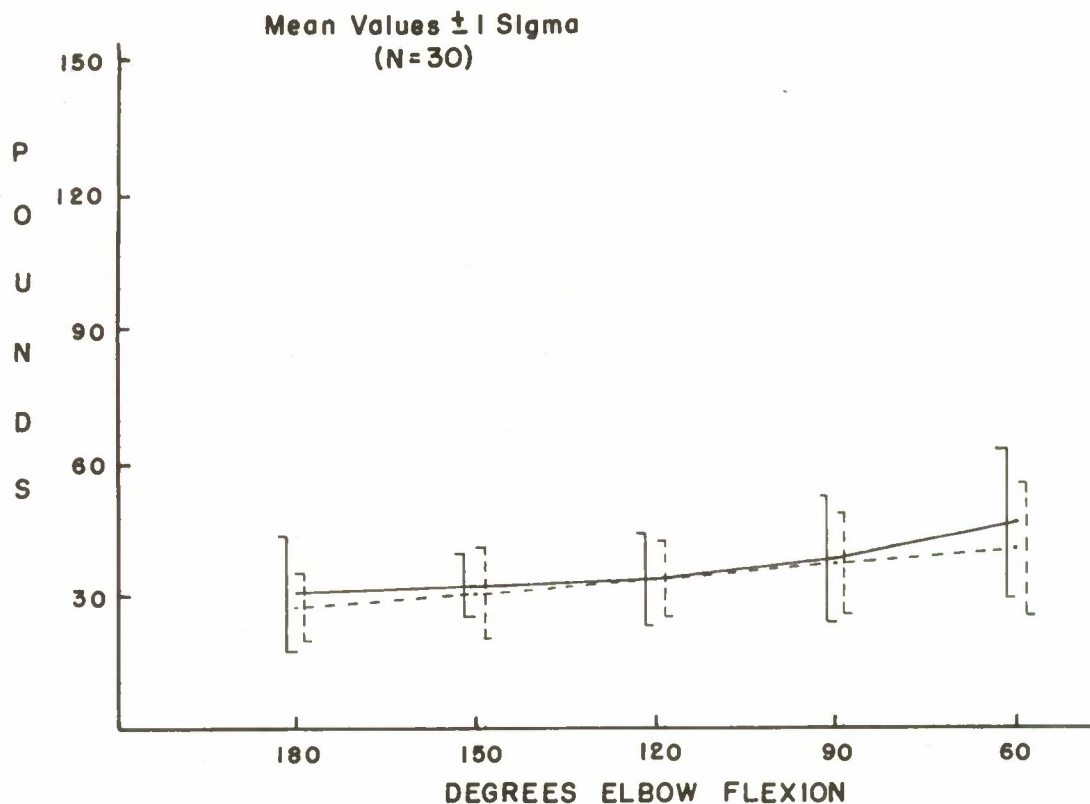


TABLE 7

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ADDUCTION

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	16	18	15	16	16	15	17	17	17	20
10	19	20	21	22	23	19	20	21	21	23
20	21	23	25	27	23	21	21	27	29	29
30	24	25	28	33	38	23	24	28	31	34
40	27	29	32	37	43	25	26	29	35	39
50	27	29	34	39	47	25	26	33	38	43
60	31	33	35	41	52	28	30	37	41	47
70	33	36	39	43	56	31	31	38	43	48
80	35	38	41	46	64	33	34	39	45	52
90	45	44	47	53	70	36	47	43	48	55
95	57	45	47	59	73	41	54	53	60	66
Low Score	12	15	16	15	15	14	15	16	16	17
High Score	58	56	59	83	84	55	70	55	67	72
Number	30	30	30	30	30	30	30	30	30	30
Mean	31	32	34	39	48	28	31	34	38	42
Std. Dev.	13	7	11	15	18	8	11	8	12	15

Fig. 13. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: FORWARD

R. Hand ———
L. Hand - - - -

Mean Values ± 1 Sigma
(N=30)

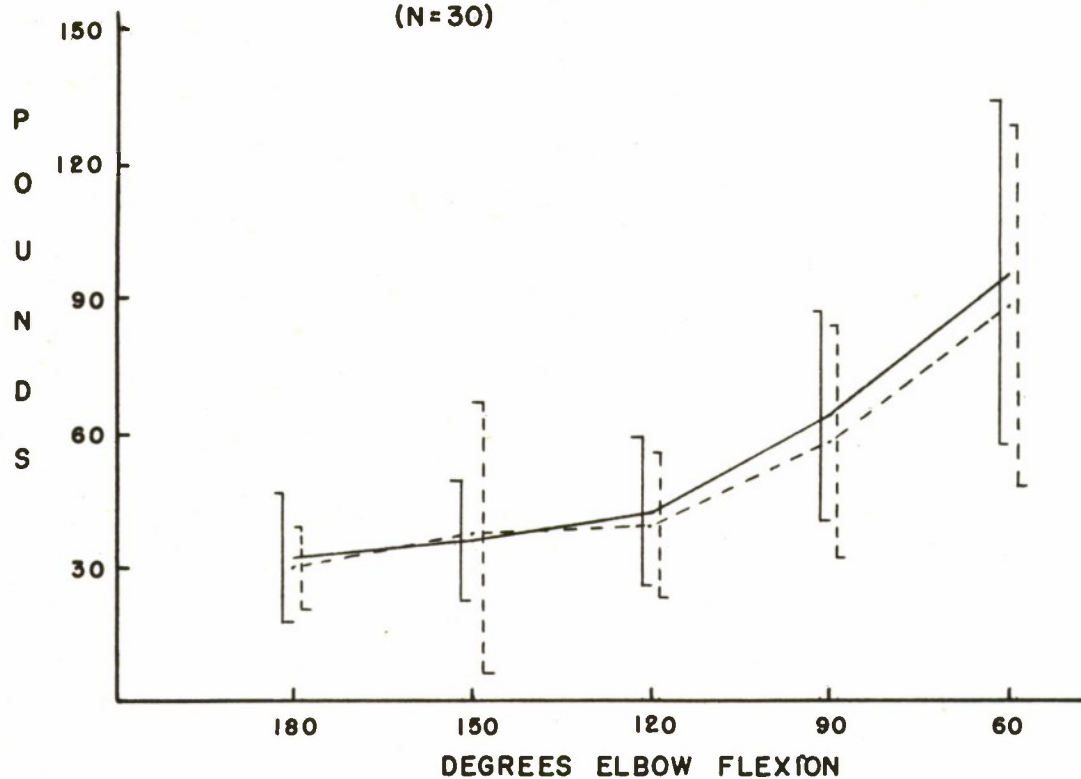


TABLE 8

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: FORWARD

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	12	17	20	25	34	14	13	15	25	35
10	17	21	25	31	53	18	13	19	31	48
20	20	26	28	43	67	19	22	27	36	55
30	24	28	35	53	74	23	29	28	42	64
40	29	29	38	55	79	26	31	32	50	72
50	30	33	41	59	86	30	32	35	55	77
60	31	38	44	62	104	33	36	40	59	89
70	34	39	48	74	109	34	40	44	65	92
80	39	45	56	78	122	36	42	50	73	113
90	55	56	64	94	141	38	58	59	89	160
95	58	59	71	117	172	47	69	80	104	176
Low Score	11	14	15	24	29	11	13	14	18	20
High Score	61	76	83	121	188	58	167	81	140	195
Number	30	30	30	30	30	30	30	30	30	30
Mean	32	36	43	65	96	30	38	40	59	89
Std. Dev.	15	14	17	24	39	10	30	18	27	42

Fig. 14. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: BACK

R.Hand ———
L.Hand - - - -

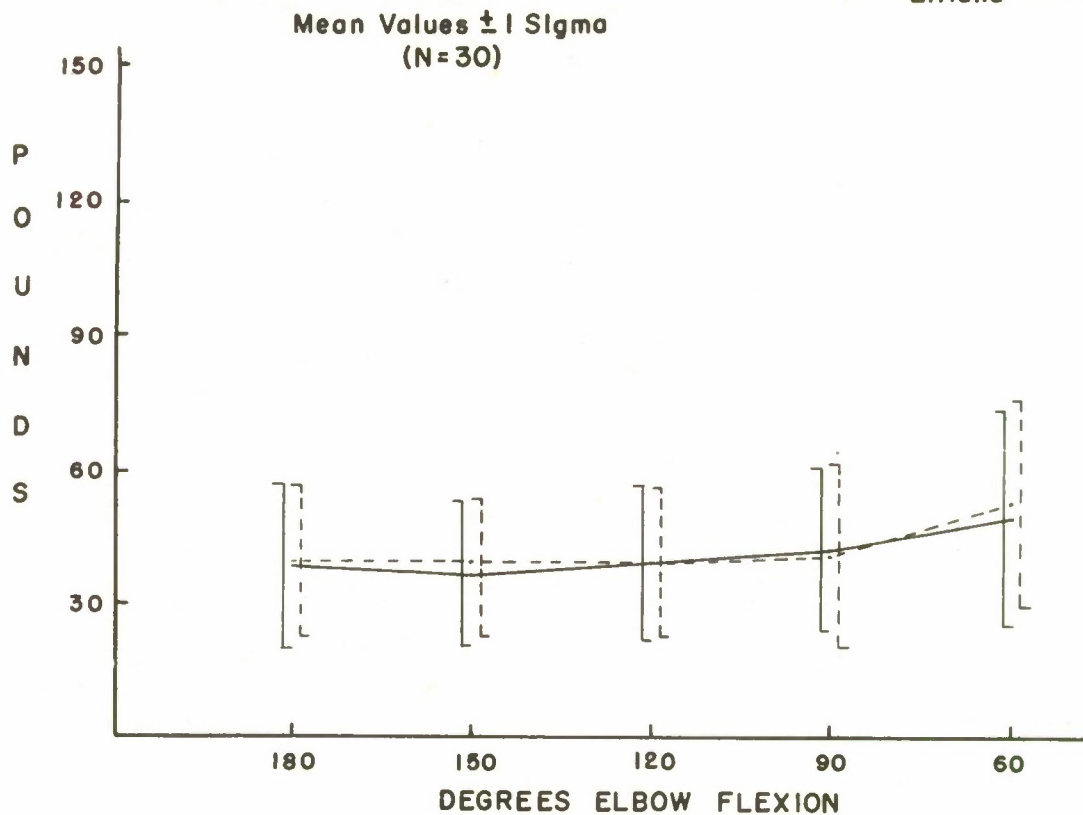


TABLE 9

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: BACK

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	15	11	11	13	16	17	16	14	13	23
10	17	15	16	19	23	19	22	18	15	28
20	22	21	22	22	27	22	24	22	21	31
30	26	27	28	30	34	28	27	26	27	36
40	30	28	36	31	37	35	31	34	34	48
50	36	34	39	41	49	38	39	38	42	53
60	40	40	46	43	54	40	43	43	47	56
70	43	44	51	52	64	45	46	48	50	61
80	56	53	57	54	66	51	52	56	56	71
90	65	57	61	66	72	63	61	58	61	83
95	73	66	63	74	93	70	62	66	68	87
Low Score	14	11	8	10	11	16	14	11	11	19
High Score	77	74	64	100	123	91	83	92	114	123
Number	30	30	30	30	30	30	30	30	30	30
Mean	39	37	40	43	51	40	40	40	42	54
Std. Dev.	19	17	17	19	25	18	15	18	21	23

Wrists Supinated, Pull Up (Table 10, Fig. 15)

The greatest amount of strength could be exerted in this movement with the largest mean values for both arms when the elbows were extended to 180° . As the elbows were flexed to 150° , 120° , 90° and 60° the strength decreased. The two curves closely approximated each other. The weakest mean value for the right arm was 39 percent of the maximum and in the case of the left arm it was 44 percent. Once again there was a considerable range of scores and the middle two-thirds of the distribution scored between 79 and 147 pounds (right) and 71 to 151 (left).

Wrists Supinated, Push Down (Table 11, Fig. 16)

In pushing down the greatest strength was obtained when the elbows were at 150° or 120° . There was actually little difference between these two positions; one pound with the right arm and no difference with the left. The minimum force with the right arm at 60° was 64 percent of the maximum of 93 pounds at 150° . With the left arm the minimum of 58 pounds at 60° was 69 percent of the 84-pound maximum at 120° or 150° . The strongest subject was able to exert more than nine times as much strength as the weakest in this action. Once again the two curves ran fairly parallel with quite a drop-off between 90° and 60° .

Wrists Supinated, Abduction (Table 12, Fig. 17)

Abduction was one of the weaker movements of the six tested. In both the right and left arm actions the maximum strength was exerted with the elbows at 60° . The right arm strength increased as the elbow flexion changed from 180° through the five positions to 60° . In the case of the left arm the scores were approximately the same at the first three positions and then increased some at 90° and 60° . The one sigma range extended from 25 to 63 pounds (right) and from 23 to 61 pounds (left). The lowest score was approximately one-fifth the highest.

Wrists Supinated, Adduction (Table 13, Fig. 18)

Once again it was difficult to exert much strength in this movement. In fact, the action was the weakest of the six tested. The highest mean values, at 60° flexion, were only 36 and 38 pounds for the right and left arms. The two curves ran practically together from the 180° plot to the 60° plot. The middle two-thirds of the scores ranged from 19 to 53 pounds (right) and from 26 to 50 pounds (left). The strongest subject in this action was able to exert over seven times as much force as the weakest. The degrees of elbow flexion did not influence these scores appreciably.

Fig. 15.

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: UP

R. Hand ———
L. Hand - - - -

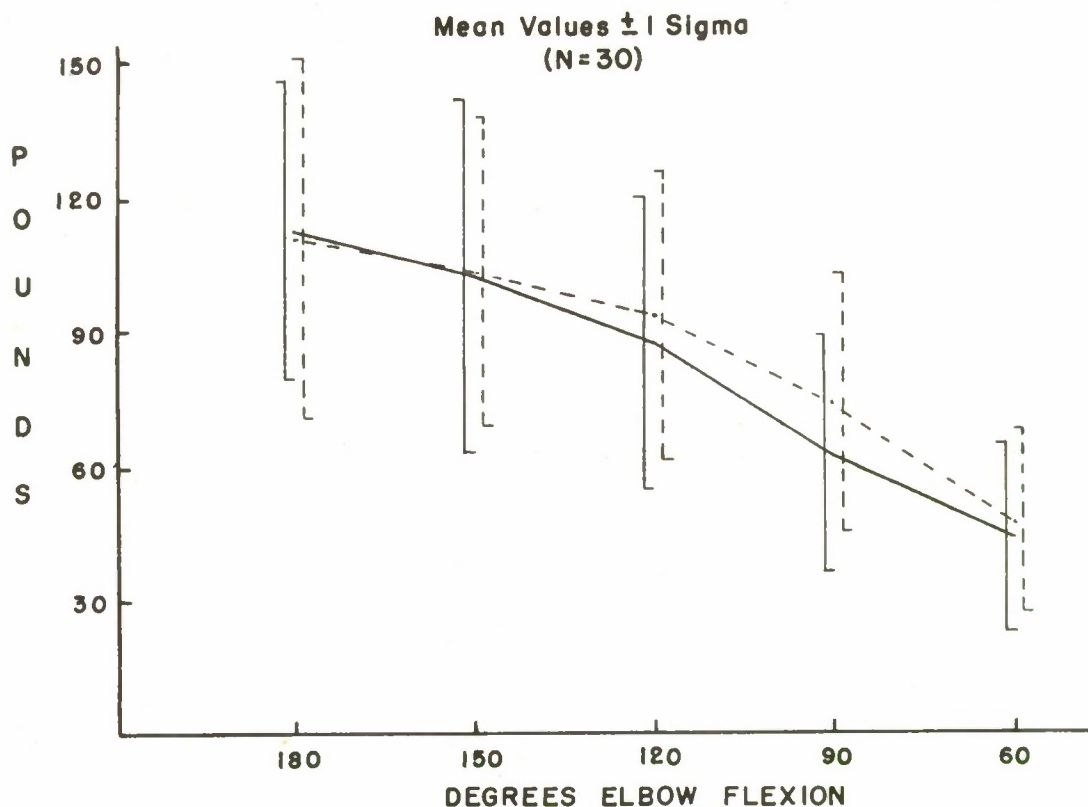


TABLE 10

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: UP

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	51	37	41	21	17	45	44	38	24	20
10	66	42	41	29	20	60	58	45	30	27
20	78	62	59	31	26	69	68	69	51	32
30	87	79	73	49	31	77	74	80	55	35
40	98	94	80	58	35	91	89	86	63	40
50	119	108	84	64	42	102	101	94	77	43
60	123	115	93	69	47	135	117	100	82	47
70	135	125	103	76	50	139	126	105	86	58
80	143	134	109	83	60	144	138	111	88	66
90	147	139	118	90	68	171	143	124	95	82
95	165	161	143	107	78	173	164	152	131	89
Low Score	41	36	40	18	16	40	42	34	23	17
High Score	185	188	164	123	112	175	175	176	151	93
Number	30	30	30	30	30	30	30	30	30	30
Mean	113	103	88	63	45	111	104	94	75	49
Std. Dev.	34	40	33	27	22	40	36	33	29	22

Fig. 16. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: DOWN

R.Hand ———
L.Hand - - - -

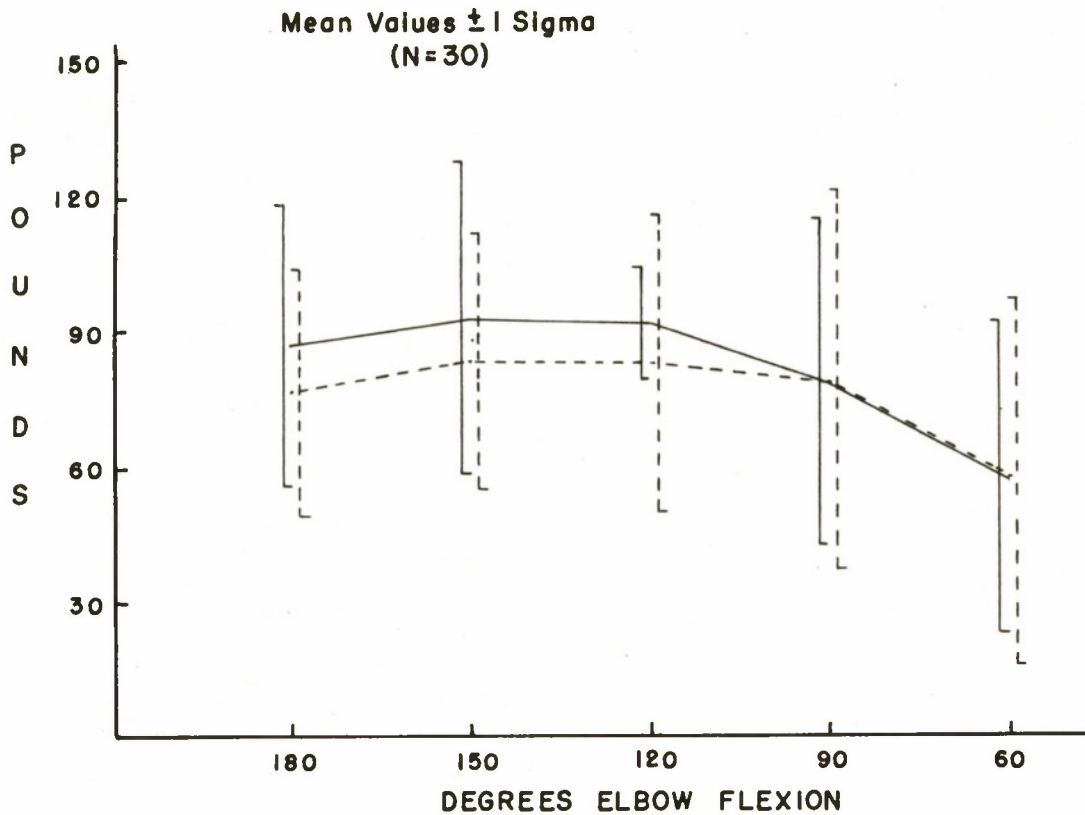


TABLE 11

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: DOWN

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	44	37	29	17	20	36	43	35	23	20
10	52	43	45	24	22	40	48	41	24	21
20	59	55	61	46	28	54	57	49	37	25
30	62	69	71	56	37	58	67	64	55	33
40	69	80	72	67	43	75	74	71	64	36
50	83	83	91	74	51	77	78	77	78	39
60	89	101	103	81	59	80	82	90	85	53
70	102	113	105	93	65	82	90	95	95	70
80	111	128	130	106	74	92	99	110	112	78
90	123	136	137	129	86	112	114	121	122	101
95	135	150	148	143	132	124	136	136	160	138
Low Score	41	34	27	15	19	34	38	30	23	20
High Score	179	178	173	166	172	172	174	175	181	189
Number	30	30	30	30	30	30	30	30	30	30
Mean	87	93	92	80	59	78	84	84	80	58
Std. Dev.	32	35	13	37	35	28	29	33	43	41

Fig. 17. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ABDUCTION

R.Hand ———
L.Hand - - - -

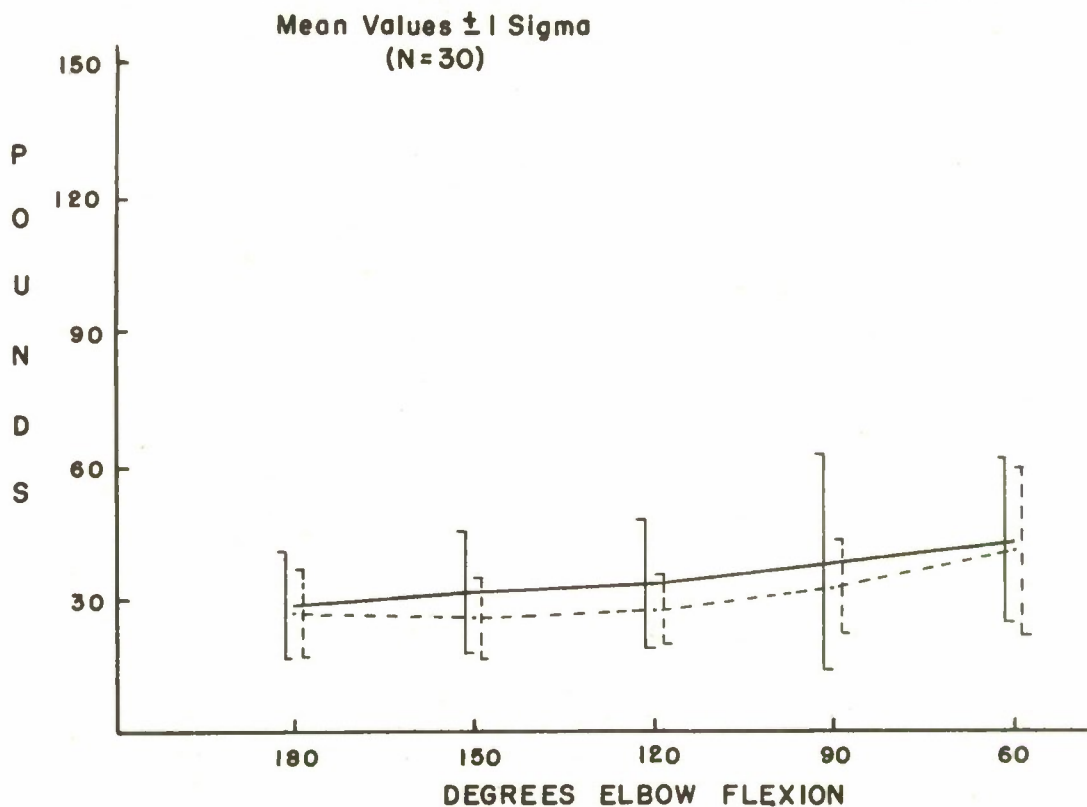


TABLE 12

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ABDUCTION

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	14	15	17	18	18	8	12	14	16	17
10	18	19	18	18	19	12	15	15	17	22
20	19	23	20	27	27	18	18	19	21	25
30	22	25	25	31	31	23	22	21	25	29
40	25	27	28	34	34	25	26	25	28	30
50	26	28	31	35	40	26	26	27	30	34
60	30	28	36	38	44	28	26	29	34	39
70	32	30	38	44	49	30	28	30	36	45
80	39	37	41	46	58	32	31	35	41	57
90	41	47	51	63	69	37	36	41	49	74
95	48	60	64	72	73	44	43	45	52	81
Low Score	12	14	16	17	18	6	10	13	16	16
High Score	67	80	76	77	94	52	47	45	70	93
Number	30	30	30	30	30	30	30	30	30	30
Mean	29	32	34	39	44	27	26	28	33	42
Std. Dev.	12	14	15	24	19	10	10	8	12	20

Fig. 18. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ADDUCTION

R. Hand ———
L. Hand - - - -

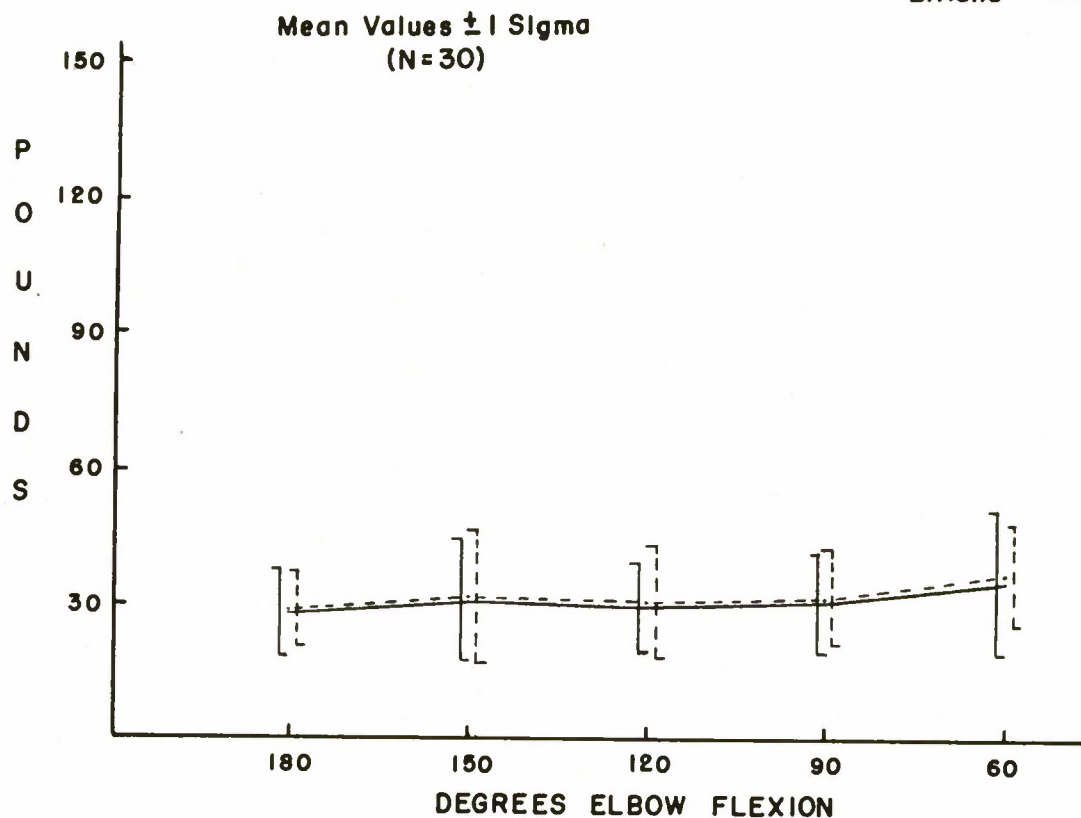


TABLE 13

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ADDUCTION

%iles	Elbow Flexion									
	Right Arm					Left Arm				
	180°	150°	120°	90°	60°	180°	150°	120°	90°	60°
5	10	12	12	13	13	12	12	14	12	16
10	17	13	21	16	18	14	13	16	15	22
20	19	22	22	22	24	17	20	22	22	23
30	21	24	23	26	28	21	23	22	25	30
40	25	25	25	28	31	26	26	26	28	32
50	29	30	28	28	34	28	30	28	31	34
60	29	32	33	33	36	31	35	33	34	36
70	32	36	35	36	38	34	37	35	38	41
80	37	37	39	37	41	36	39	40	38	47
90	42	47	45	42	43	42	49	44	44	54
95	44	52	46	48	70	43	62	55	46	64
Low Score	9	12	10	11	12	10	11	12	8	12
High Score	49	78	50	70	93	58	68	61	70	69
Number	30	30	30	30	30	30	30	30	30	30
Mean	28	31	30	31	36	29	32	31	32	38
Std. Dev.	10	14	11	12	17	9	15	13	12	12

SECTION IV

WRIST PRONATION AND SUPINATION STRENGTH

After completing the first phase of the research it was decided to test the amount of strength young men could exert during wrist pronation and wrist supination. These movements seemed important because they are called for in numerous manually-operated control systems. Since some of the subjects used in the other strength tests were no longer available a new sample had to be drawn. Once again it seemed important the same regard be given for the physical characteristics of the sample. A total of 25 subjects were selected based on the anthropometric measurements given in the Hertzberg, Daniels and Churchill report (6). The subjects were all students at the University of Michigan and like the previous sample were paid for their services.



Fig. 19. Wrist Pronation-Supination

The actual tests were carried out on a Kellogg Universal Dynamometer. This is part of the laboratory equipment in the Physical Education Research Laboratory at the University. The dynamometer operates on the principle of a piston displacing mercury. It is more fully described in an article by Hunsicker and Donnelly (8). Each subject was asked to sit erect, with both feet on the floor, elbows at a right angle and hand grasping the handle of the dynamometer (Fig. 19).

With the testee in the correct position, the four strength tests were given in this order:

1. Pronation, right hand.
2. Supination, left hand.
3. Pronation, left hand.
4. Supination, right hand.

The subject was asked to put forth a maximum effort in each instance and this was recorded. Since the dynamometer is equipped with a maximum stop hand which holds until reset by the operator this presented no problem.

TABLE 14
WRIST PRONATION AND SUPINATION STRENGTH

%iles	Pronation		Supination	
	Right	Left	Right	Left
5	29	31	35	30
10	38	35	41	38
20	43	45	48	42
30	45	48	52	47
40	57	56	55	59
50	67	63	59	62
60	73	69	66	65
70	82	88	74	71
80	98	99	80	78
90	113	111	83	82
95	119	132	93	88
Low Score	27	29	33	28
High Score	120	140	107	97
Number	25	25	25	25
Mean	71	71	64	62
Std. Dev.	28	31	18	16

An examination of the results of these tests (Table 14) indicates that a moderately high amount of strength was possible in pronation and supination. The average strength in pronation was 71 pounds (right) with two-thirds of the distribution between 43 and 99 pounds, and with the left hand the mean was the same and the one sigma range extended from 40 to 102 pounds. There was very little difference between the strength of the right hand as compared to the left. The difference between the low and high scores were not as marked in this action as they were in most of the other strength tests.

SECTION V

STRENGTH DECREMENT WITH LOSS OF SLEEP

The third phase of the testing program involved administering strength tests to selected subjects whose sleep had been restricted. A cue was taken from the routine which the aircrew members followed during the B-52 flight around the world. It was decided to allow the testees a total of four hours sleep in a 48-hour period.

Because of the nature of the restrictions placed on the subjects and because of expenses involved the sample was limited to six subjects. Here again an effort was made to span the range of physical characteristics of aircrew members. Two of the subjects were below the average in size; two were about average; and the other two were above average with one of these toward the upper end of the distribution.

The subjects were asked to adhere to the following schedule for the test period:

1. Rise at approximately 7 AM, Saturday.
2. Report to the laboratory at noon Saturday.
3. Briefing regarding test procedure and design of research. Opportunity to familiarize subjects with test apparatus and chance for trial runs.
4. First test trials at approximately 2 PM, Saturday.
5. Tests approximately every hour thereafter until 7 AM, Monday (total of 42 trials).
6. Subjects confined to laboratory and adjacent area except for two meals on Saturday and Sunday evenings.
7. Subjects had coffee, fruit, milk, cookies, etc., at their disposal in the laboratory.
8. Subjects were permitted a total of four hours sleep in the laboratory. Five took advantage of this but Subject T did not sleep during the entire period.
9. Subjects were permitted to read, study, listen to the radio, play cards or talk.

Description of Tests

The subject was seated to the left of the Kellogg Dynamometer and the dynamometer handle was adjusted so he could grasp it with the right arm fully extended (Fig. 20). On one trial the wrist was pronated and on the second it was supinated. On the signal "Go" the testee lifted up as hard as he could. The maximum reading was recorded. After finishing the two tests with the right arm the subject moved to a chair that was fixed to the floor on the right of the dynamometer and repeated the two tests with the left arm.



Fig. 20. Strength-Decrement Test Position

Test Results

Since only six subjects were tested in this phase of the research it seems wise to discuss the results as individual cases. In analyzing the data from the standpoint of strength decrement, both the right and left arm scores were summated to give a single score for pronation and one for supination. These are the strength readings which appear in Table 15 and form the bases for Figures 21-26.

TABLE 15

STRENGTH DECREMENT WITH LOSS OF SLEEP

Hours	Subject											
	E		H		L		P		S		T	
	Pron.	Sup.	Pron.	Sup.	Pron.	Sup.	Pron.	Sup.	Pron.	Sup.	Pron.	Sup.
1	302	304	239	235	256	319	233	287	172	218	248	265
2	280	329	243	238	278	288	273	277	196	232	286	313
3	281	296	214	221	290	300	244	298	205	199	271	322
4	294	274	228	264	278	304	253	318	165	178	281	317
5	273	291	247	257	291	302	284	342	157	201	272	311
6	248	258	253	238	288	315	273	323	172	211	265	289
7	265	243	254	248	276	298	260	291	167	244	275	303
8	225	252	239	251	243	344	271	324	196	243	278	320
9	251	271	233	220	309	320	284	304	201	220	253	305
10	250	275	233	228	311	309	288	305	179	221	266	287
11	242	289	233	229	279	345	262	284	183	215	244	296
12	278	260	239	233	309	322	258	297	175	214	246	305
13	284	282	202	222	253	312	260	303	188	197	264	314
14	260	311	218	261	315	321	250	336	174	241	272	344
15	267	323	201	202	306	381	285	343	191	209	264	337
16	246	303	227	213	342	350	284	341	198	206	276	323
17	268	301	219	212	342	373	270	361	195	200	279	323
18	215	246	220	240	292	313	255	351	197	208	244	294
19	244	256	220	269	234	315	259	347	196	208	246	302
20	261	268	211	217	324	393	273	349	198	209	259	309
21	238	257	206	226	338	368	233	342	219	209	241	290
22	226	224	228	215	333	360	275	351	215	210	253	294
23	212	220	216	228	294	336	257	318	186	214	248	302
24	213	228	202	202	264	312	328	307	189	221	245	309
25	205	231	189	219	275	378	250	347	196	256	251	307
26	220	331	235	222	302	317	262	339	195	220	237	298
27	262	299	207	240	234	277	247	325	196	221	244	324
28	230	260	227	225	220	207	235	329	204	283	248	326
29	217	266	208	245	246	251	268	348	188	228	244	313
30	233	289	202	203	248	315	250	345	195	183	248	318
31	252	280	222	244	247	354	213	312	202	244	238	305
32	281	262	207	208	250	328	248	274	209	230	243	297
33	212	247	209	216	314	329	247	282	181	233	224	321
34	202	223	156	178	291	335	224	288	201	263	241	291
35	205	247	142	135	252	271	233	277	175	211	229	297
36	199	285	127	165	219	279	189	276	200	230	220	310
37	203	305	185	201	240	287	239	317	204	233	239	289
38	184	217	180	177	262	266	198	273	204	210	247	279
39	124	141	170	182	164	212	224	275	192	244	225	261
40	140	196	156	203	149	251	233	284	173	215	225	283
41	156	184	181	205	166	239	194	227	171	210	222	294
42	146	205	188	232	190	199	228	298	200	260	237	299

Fig. 21
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT E)

PRONATION (RIGHT + LEFT) ---
SUPINATION (RIGHT + LEFT) —

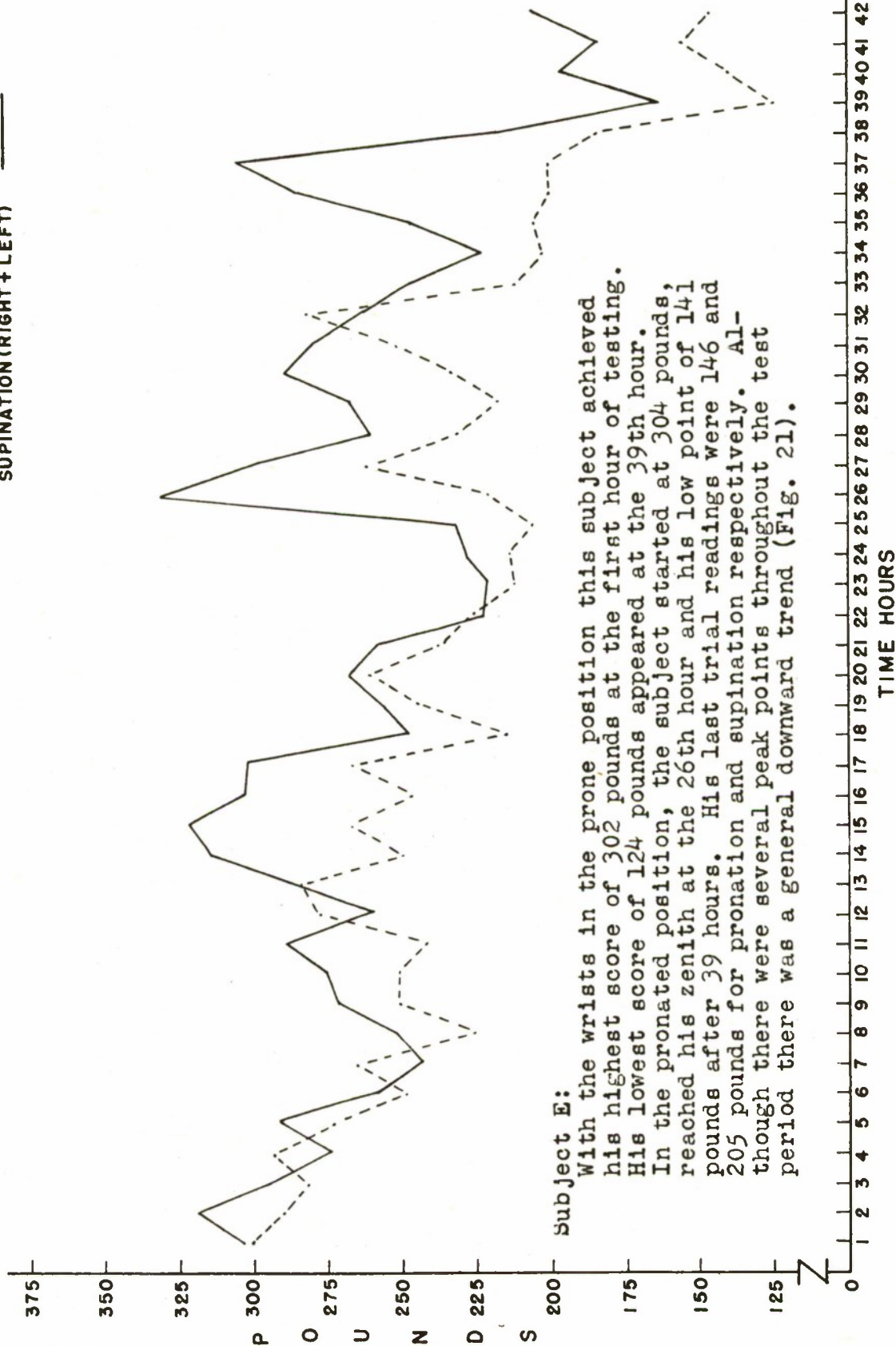


Fig. 22
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT H)

PRONATION (RIGHT + LEFT) -----
SUPINATION (RIGHT + LEFT) -----

Subject H:

The testee started at 239 pounds for the pronated position and 235 pounds for supination. His greatest strength effort appeared at the 7th hour (pronation) and the 19th hour (supination). His lowest scores were 127 and 135 pounds and came at the 36th and 35th hours respectively. These were about 50 percent of his maximum lifts. His final scores were 188 (pronation) and 232 (supination). His weakest period was between the 33rd and 40th hours (Fig. 22).

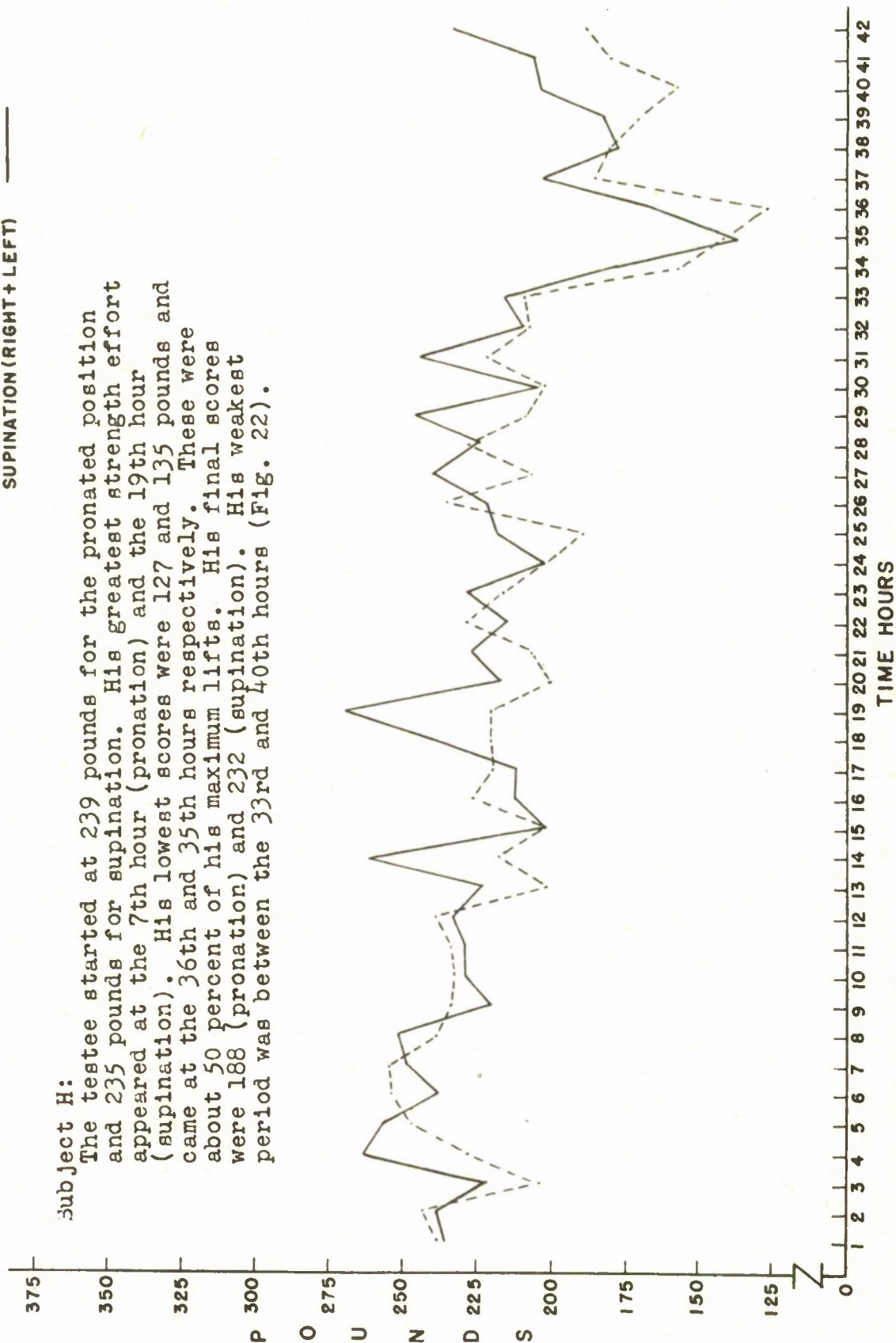
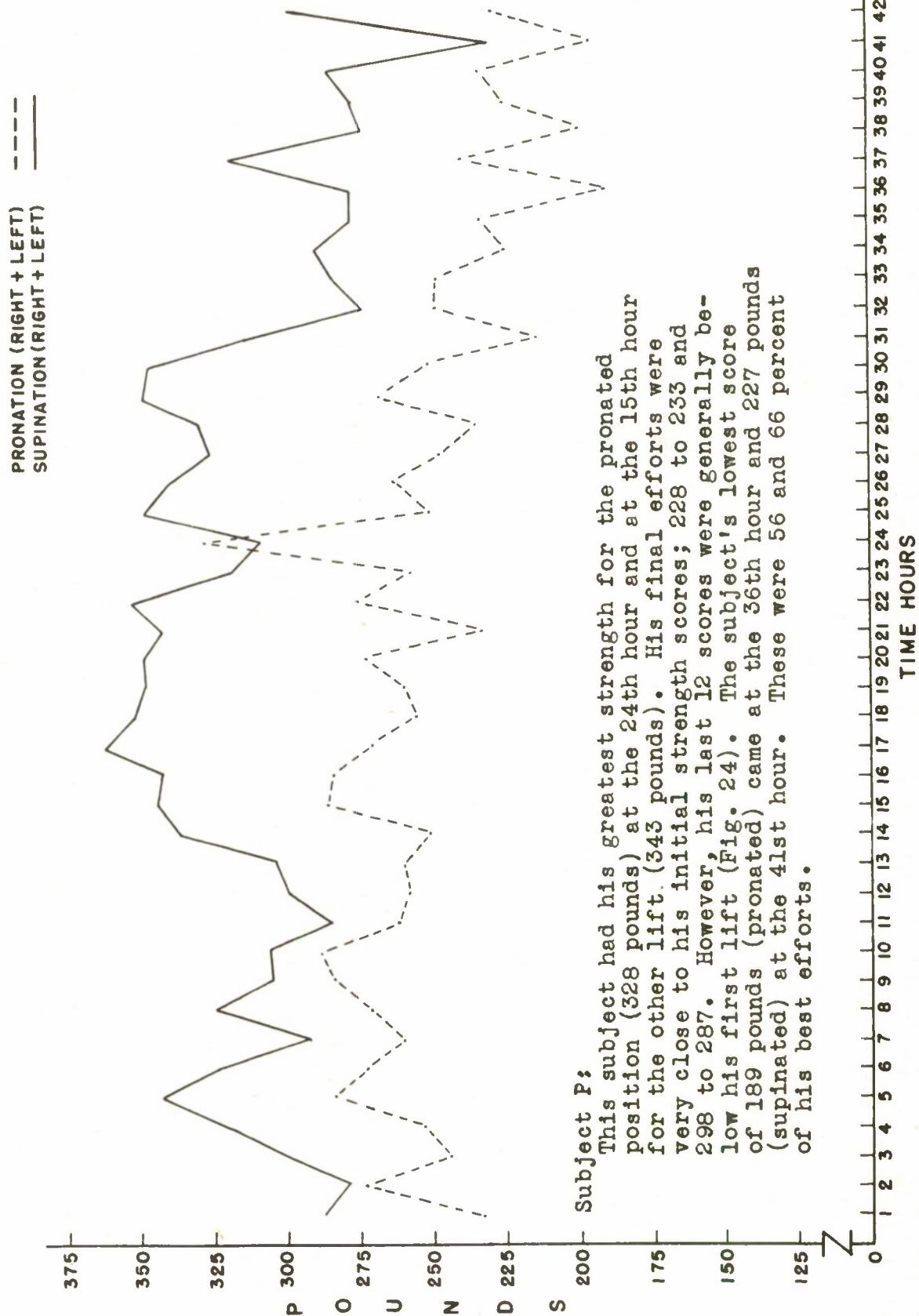


Fig. 23
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT L)



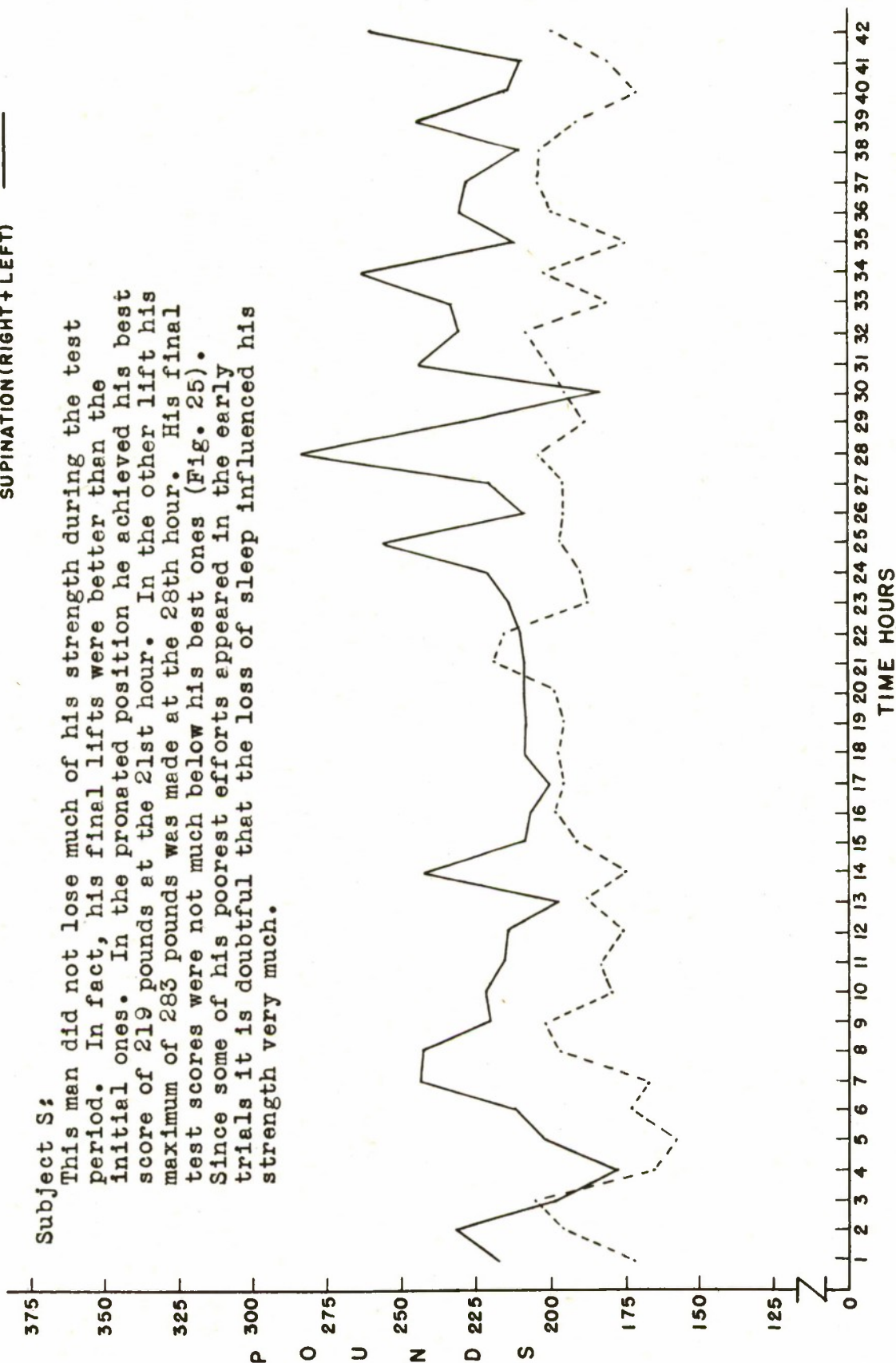
Fig. 24
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT P)



Subject P:
 This subject had his greatest strength for the pronated position (328 pounds) at the 24th hour and at the 15th hour for the other lift (343 pounds). His final efforts were very close to his initial strength scores; 228 to 233 and 298 to 287. However, his last 12 scores were generally below his first lift (Fig. 24). The subject's lowest score of 189 pounds (pronated) came at the 36th hour and 227 pounds (supinated) at the 41st hour. These were 56 and 66 percent of his best efforts.

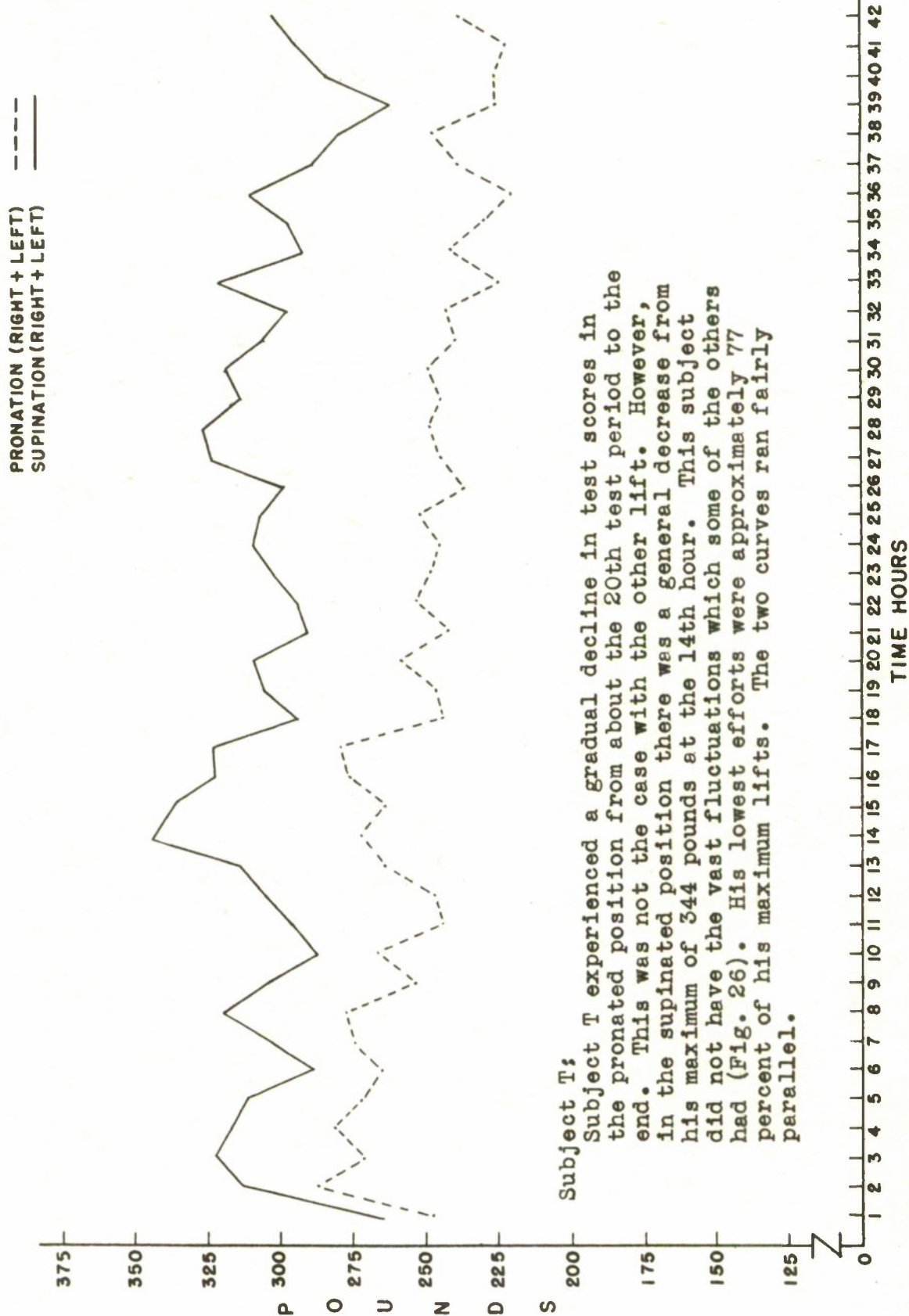
Fig. 25
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT S)

PRONATION (RIGHT + LEFT) ---
SUPINATION (RIGHT + LEFT) —



Subject S:
This man did not lose much of his strength during the test period. In fact, his final lifts were better than the initial ones. In the pronated position he achieved his best score of 219 pounds at the 21st hour. In the other lift his maximum of 283 pounds was made at the 28th hour. His final test scores were not much below his best ones (Fig. 25). Since some of his poorest efforts appeared in the early trials it is doubtful that the loss of sleep influenced his strength very much.

Fig. 26
STRENGTH DECUREMENT
WITH FATIGUE
(SUBJECT T)



Subject T:
 Subject T experienced a gradual decline in test scores in the pronated position from about the 20th test period to the end. This was not the case with the other lift. However, in the supinated position there was a general decrease from his maximum of 344 pounds at the 14th hour. This subject did not have the vast fluctuations which some of the others had (Fig. 26). His lowest efforts were approximately 77 percent of his maximum lifts. The two curves ran fairly parallel.

SECTION VI

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The investigation was concerned with three problems and three samples of subjects were employed. The initial testing involved 30 men to determine the strength which they could exert, while seated in a simulated pilot-seat, with the arms and hands in selected positions. One hundred and twenty tests were required of each subject. Since each strength test called for three exposures a total of 10,800 resultants were calculated as a basis for describing these data. The second phase of the research called for four tests on 25 subjects and information was gathered on human strength in wrist pronation and wrist supination. The final test period was designed to ascertain the strength decrement over a 42-hour period. Each of the six subjects was given four tests every hour during the test period. From these data the following conclusions may be drawn:

1. With the subject in a sitting position a greater amount of strength could be exerted with the wrists in a supinated position than in the pronated position. The one exception was in adduction. In the forward, back, up, down and abducted movements the supinated position was superior by an average of 14 percent.

2. In examining the data for maximum values and degrees of elbow flexion, 16 maximum strength scores were attained at 60° of flexion; 1 at 120; 5 at 150; and 2 at 180°.

3. The mean values for any particular movement were influenced by the degrees of elbow flexion. The average reduction between the maximum and minimum strength score for a particular elbow position was 40 percent. That is, the minimum mean value was 60 percent of the maximum mean.

4. A study of the extreme scores indicated that on the average the maximum score was 5.3 times larger with the wrists pronated and 6.1 times greater in the supinated position than the minimum strength scores. It was once again apparent that there are tremendous differences in human strength and that some people are capable of exerting 10 times as much strength as their fellow-man.

5. In general the right side was stronger than the left and the average in these cases was about 10 percent. In three instances the left side averaged 5 percent more than the right.

6. The curves for the right and left arms, relating strength with elbow position, closely paralleled each other in practically all movements.

7. With the subject in the sitting position the three strongest movements were the lift up, push forward and push down. The same order held for both the right and left arms and for the supinated as well as the pronated positions. The other three actions, back pull, abduction and adduction were, in general, less

than half as strong.

8. Wrist pronation and supination were moderately strong movements and the differences between the right and left hands were slight.

✓ 9. An examination of the strength-decrement data covering the 42-hour test period indicated that in general there was a falling-off in strength but that it was possible for a subject to marshal sufficient reserve strength for a single maximum effort that was called for in this research to attain a value that was as good as his initial test. In a number of instances the final score was actually better than the first. But the general pattern was a decline during the latter stages of the test period.

Recommendations

The following recommendations seem appropriate:

1. This report and the previous one by the author (7) give a fair amount of information regarding arm strength and it might be timely to investigate leg strength.

2. In designing hand levers that are at the side of a pilot and where the pilot's arms are extended vertically down and in a perpendicular line with the external canthus, it should be remembered that the maximum strength in a forward push, back pull, abduction and adduction can be applied with the elbows at 60° flexion. A lever requiring a lift up or push down might better be fixed so the elbows are between 150 and 180°.

3. With the wrists in line with the external canthus leverage systems that call for a strong movement should operate from a forward push, a lift up or a downward push.

4. The subject of fatigue should be further explored. It might prove fruitful to design a research which imposes a constant muscular stress of a low magnitude on a subject and observe the strength decrement under these conditions.

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APPENDIX A
CALIBRATION FOR RIGHT DYNAMOMETER
(X-X Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.63	0.39	53	-7.18	2.72
6	-9.58	0.43	54	-7.13	2.76
7	-9.53	0.47	55	-7.08	2.80
8	-9.48	0.51	56	-7.04	2.85
9	-9.43	0.55	57	-7.00	2.91
10	-9.37	0.60	58	-6.96	2.97
11	-9.33	0.65	59	-6.92	3.03
12	-9.28	0.70	60	-6.88	3.09
13	-9.23	0.72	61	-6.82	3.14
14	-9.18	0.75	62	-6.76	3.18
15	-9.14	0.85	63	-6.70	3.22
16	-9.09	0.90	64	-6.65	3.26
17	-9.03	0.95	65	-6.60	3.30
18	-8.98	0.99	66	-6.54	3.35
19	-8.93	1.04	67	-6.48	3.40
20	-8.88	1.09	68	-6.42	3.45
21	-8.83	1.14	69	-6.37	3.50
22	-8.79	1.19	70	-6.31	3.55
23	-8.75	1.23	71	-6.27	3.61
24	-8.71	1.28	72	-6.23	3.66
25	-8.67	1.32	73	-6.19	3.71
26	-8.61	1.36	74	-6.16	3.76
27	-8.55	1.40	75	-6.13	3.81
28	-8.49	1.44	76	-6.07	3.87
29	-8.43	1.48	77	-6.01	3.93
30	-8.38	1.53	78	-5.95	3.98
31	-8.33	1.59	79	-5.90	4.03
32	-8.28	1.64	80	-5.85	4.08
33	-8.23	1.69	81	-5.80	4.12
34	-8.18	1.74	82	-5.75	4.16
35	-8.13	1.79	83	-5.70	4.21
36	-8.07	1.86	84	-5.65	4.25
37	-8.01	1.93	85	-5.60	4.30
38	-7.96	1.99	86	-5.58	4.36
39	-7.91	2.06	87	-5.55	4.42
40	-7.85	2.12	88	-5.53	4.48
41	-7.80	2.15	89	-5.51	4.54
42	-7.76	2.18	90	-5.49	4.60
43	-7.71	2.21	91	-5.41	4.65
44	-7.66	2.25	92	-5.34	4.70
45	-7.62	2.29	93	-5.27	4.74
46	-7.56	2.35	94	-5.20	4.78
47	-7.50	2.41	95	-5.12	4.83
48	-7.45	2.47	96	-5.07	4.88
49	-7.40	2.53	97	-5.02	4.93
50	-7.35	2.58	98	-4.97	4.98
51	-7.29	2.63	99	-4.92	5.03
52	-7.23	2.67	100	-4.87	5.07

APPENDIX A
(Cont'd)

Pounds	Dial Reading		Pounds	Dial Reading	
101	-4.81	5.15	136	-3.19	6.95
102	-4.76	5.23	137	-3.13	7.02
103	-4.71	5.31	138	-3.07	7.09
104	-4.66	5.38	139	-3.02	7.15
105	-4.61	5.45	140	-2.97	7.21
106	-4.56	5.49	141	-2.92	7.23
107	-4.52	5.53	142	-2.87	7.25
108	-4.48	5.56	143	-2.82	7.27
109	-4.43	5.59	144	-2.77	7.29
110	-4.38	5.62	145	-2.73	7.32
111	-4.34	5.66	146	-2.68	7.39
112	-4.31	5.70	147	-2.63	7.45
113	-4.28	5.74	148	-2.59	7.52
114	-4.25	5.78	149	-2.55	7.59
115	-4.22	5.82	150	-2.50	7.65
116	-4.16	5.88	151	-2.45	7.71
117	-4.10	5.94	152	-2.40	7.77
118	-4.04	6.00	153	-2.35	7.83
119	-3.98	6.06	154	-2.30	7.85
120	-3.92	6.12	155	-2.25	7.95
121	-3.88	6.17	156	-2.20	8.00
122	-3.84	6.22	157	-2.15	8.05
123	-3.80	6.27	158	-2.10	8.10
124	-3.77	6.31	159	-2.05	8.15
125	-3.74	6.35	160	-2.00	8.20
126	-3.68	6.41	161	-1.95	8.26
127	-3.62	6.47	162	-1.90	8.32
128	-3.56	6.52	163	-1.85	8.38
129	-3.50	6.57	164	-1.80	8.44
130	-3.45	6.62	165	-1.75	8.50
131	-3.41	6.68	166	-1.70	8.55
132	-3.37	6.73	167	-1.65	8.60
133	-3.33	6.78	168	-1.60	8.65
134	-3.29	6.83	169	-1.55	8.70
135	-3.25	6.88	170	-1.50	8.75

APPENDIX B
CALIBRATION FOR RIGHT DYNAMOMETER
(Y-Y Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.75	0.31	53	-7.25	2.87
6	-9.70	0.37	54	-7.20	2.93
7	-9.64	0.43	55	-7.15	2.99
8	-9.57	0.48	56	-7.10	3.04
9	-9.52	0.53	57	-7.05	3.08
10	-9.47	0.58	58	-7.00	3.12
11	-9.41	0.64	59	-6.95	3.16
12	-9.34	0.70	60	-6.90	3.20
13	-9.28	0.76	61	-6.85	3.25
14	-9.21	0.82	62	-6.80	3.30
15	-9.15	0.88	63	-6.75	3.34
16	-9.10	0.92	64	-6.70	3.38
17	-9.05	0.96	65	-6.66	3.42
18	-9.00	0.99	66	-6.61	3.47
19	-8.95	1.02	67	-6.56	3.51
20	-8.90	1.05	68	-6.51	3.56
21	-8.84	1.11	69	-6.46	3.61
22	-8.78	1.17	70	-6.42	3.65
23	-8.72	1.23	71	-6.37	3.70
24	-8.66	1.29	72	-6.32	3.74
25	-8.60	1.35	73	-6.27	3.79
26	-8.56	1.41	74	-6.22	3.83
27	-8.51	1.47	75	-6.16	3.87
28	-8.46	1.52	76	-6.10	3.93
29	-8.41	1.57	77	-6.05	3.99
30	-8.36	1.62	78	-6.00	4.05
31	-8.30	1.66	79	-5.95	4.10
32	-8.25	1.69	80	-5.90	4.15
33	-8.20	1.72	81	-5.84	4.20
34	-8.15	1.75	82	-5.78	4.25
35	-8.10	1.78	83	-5.72	4.30
36	-8.06	1.85	84	-5.67	4.35
37	-8.02	1.92	85	-5.62	4.39
38	-7.98	1.98	86	-5.56	4.44
39	-7.94	2.05	87	-5.50	4.49
40	-7.90	2.12	88	-5.45	4.53
41	-7.85	2.18	89	-5.40	4.57
42	-7.79	2.24	90	-5.35	4.61
43	-7.72	2.30	91	-5.30	4.66
44	-7.67	2.36	92	-5.25	4.71
45	-7.62	2.42	93	-5.20	4.76
46	-7.58	2.48	94	-5.16	4.81
47	-7.53	2.54	95	-5.12	4.85
48	-7.49	2.59	96	-5.07	4.91
49	-7.44	2.64	97	-5.02	4.96
50	-7.40	2.69	98	-4.98	5.01
51	-7.35	2.75	99	-4.94	5.06
52	-7.30	2.81	100	-4.90	5.11

APPENDIX B
(Cont'd)

Pounds	Dial Reading		Pounds	Dial Reading	
101	-4.85	5.18	114	-4.20	5.74
102	-4.80	5.25	115	-4.16	5.80
103	-4.75	5.32	116	-4.11	5.85
104	-4.70	5.39	117	-4.06	5.89
105	-4.65	5.45	118	-4.01	5.93
106	-4.60	5.47	119	-3.96	5.97
107	-4.55	5.49	120	-3.92	6.02
108	-4.50	5.51	121	-3.87	6.06
109	-4.45	5.52	122	-3.82	6.10
110	-4.40	5.54	123	-3.77	6.13
111	-4.35	5.59	124	-3.72	6.16
112	-4.30	5.64	125	-3.68	6.19
113	-4.25	5.69			

APPENDIX C
CALIBRATION FOR RIGHT DYNAMOMETER
(Z-Z Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.25	0.71	53	-4.53	5.49
6	-9.14	0.82	54	-4.45	5.59
7	-9.03	0.94	55	-4.38	5.69
8	-8.93	1.05	56	-4.30	5.79
9	-8.82	1.16	57	-4.22	5.88
10	-8.72	1.28	58	-4.15	5.97
11	-8.61	1.39	59	-4.07	6.06
12	-8.49	1.51	60	-4.00	6.15
13	-8.38	1.62	61	-3.91	6.26
14	-8.26	1.73	62	-3.82	6.36
15	-8.15	1.85	63	-3.74	6.46
16	-8.04	1.94	64	-3.66	6.56
17	-7.93	2.03	65	-3.58	6.66
18	-7.83	2.12	66	-3.52	6.77
19	-7.73	2.21	67	-3.45	6.87
20	-7.63	2.30	68	-3.39	6.97
21	-7.52	2.40	69	-3.33	7.07
22	-7.42	2.50	70	-3.27	7.17
23	-7.32	2.60	71	-3.18	7.28
24	-7.22	2.70	72	-3.09	7.39
25	-7.12	2.80	73	-3.00	7.50
26	-7.01	2.90	74	-2.90	7.60
27	-6.91	3.00	75	-2.81	7.70
28	-6.81	3.09	76	-2.70	7.79
29	-6.71	3.19	77	-2.59	7.88
30	-6.61	3.29	78	-2.48	7.97
31	-6.50	3.39	79	-2.38	8.06
32	-6.38	3.48	80	-2.28	8.15
33	-6.27	3.57	81	-2.19	8.25
34	-6.16	3.66	82	-2.10	8.35
35	-6.05	3.75	83	-2.02	8.44
36	-5.94	3.84	84	-1.94	8.53
37	-5.83	3.93	85	-1.85	8.62
38	-5.72	4.02	86	-1.76	8.72
39	-5.62	4.11	87	-1.67	8.82
40	-5.52	4.20	88	-1.59	8.92
41	-5.47	4.31	89	-1.51	9.02
42	-5.41	4.42	90	-1.42	9.12
43	-5.35	4.52	91	-1.28	9.21
44	-5.30	4.63	92	-1.14	9.30
45	-5.25	4.73	93	-1.00	9.39
46	-5.15	4.82	94	-0.86	9.47
47	-5.05	4.91	95	-0.72	9.55
48	-4.95	5.01	96	-0.62	9.64
49	-4.85	5.11	97	-0.52	9.73
50	-4.75	5.21	98	-0.42	9.82
51	-4.68	5.30	99	-0.32	9.91
52	-4.60	5.39	100	-0.21	9.99

APPENDIX D
CALIBRATION FOR LEFT DYNAMOMETER
(X-X Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.63	0.45	53	-6.89	3.08
6	-9.57	0.50	54	-6.81	3.14
7	-9.50	0.55	55	-6.73	3.20
8	-9.43	0.60	56	-6.67	3.26
9	-9.36	0.65	57	-6.61	3.32
10	-9.29	0.69	58	-6.55	3.38
11	-9.23	0.74	59	-6.49	3.44
12	-9.17	0.79	60	-6.42	3.50
13	-9.11	0.84	61	-6.37	3.55
14	-9.05	0.89	62	-6.32	3.60
15	-9.00	0.94	63	-6.27	3.65
16	-8.95	0.98	64	-6.22	3.70
17	-8.90	1.03	65	-6.18	3.74
18	-8.85	1.08	66	-6.12	3.79
19	-8.79	1.13	67	-6.07	3.83
20	-8.73	1.18	68	-6.01	3.87
21	-8.66	1.24	69	-5.95	3.91
22	-8.60	1.30	70	-5.90	3.95
23	-8.53	1.36	71	-5.78	4.07
24	-8.47	1.42	72	-5.78	4.07
25	-8.41	1.48	73	-5.72	4.13
26	-8.35	1.52	74	-5.65	4.19
27	-8.30	1.57	75	-5.60	4.25
28	-8.25	1.62	76	-5.52	4.30
29	-8.20	1.67	77	-5.45	4.35
30	-8.15	1.72	78	-5.37	4.40
31	-8.10	1.80	79	-5.30	4.45
32	-8.05	1.88	80	-5.22	4.50
33	-8.00	1.96	81	-5.17	4.56
34	-7.95	2.04	82	-5.12	4.62
35	-7.89	2.12	83	-5.06	4.68
36	-7.86	2.17	84	-5.00	4.74
37	-7.82	2.21	85	-4.95	4.80
38	-7.79	2.25	86	-4.89	4.85
39	-7.76	2.29	87	-4.82	4.90
40	-7.72	2.33	88	-4.75	4.95
41	-7.67	2.36	89	-4.68	5.00
42	-7.61	2.42	90	-4.61	5.05
43	-7.56	2.48	91	-4.57	5.13
44	-7.50	2.54	92	-4.52	5.20
45	-7.45	2.63	93	-4.48	5.28
46	-7.39	2.69	94	-4.43	5.35
47	-7.33	2.74	95	-4.39	5.42
48	-7.27	2.79	96	-4.34	5.47
49	-7.21	2.84	97	-4.29	5.52
50	-7.15	2.89	98	-4.25	5.56
51	-7.07	2.96	99	-4.20	5.60
52	-6.98	3.02	100	-4.15	5.65

APPENDIX D
(Cont'd)

Pounds	Dial Reading		Pounds	Dial Reading	
101	-4.10	5.71	136	-2.20	7.58
102	-4.05	5.78	137	-2.15	7.64
103	-4.00	5.84	138	-2.10	7.69
104	-3.95	5.90	139	-2.05	7.74
105	-3.90	5.95	140	-1.99	7.80
106	-3.84	6.01	141	-1.93	7.86
107	-3.78	6.08	142	-1.86	7.92
108	-3.72	6.14	143	-1.80	7.98
109	-3.66	6.21	144	-1.73	8.04
110	-3.60	6.28	145	-1.67	8.10
111	-3.56	6.33	146	-1.60	8.16
112	-3.52	6.37	147	-1.54	8.22
113	-3.48	6.41	148	-1.47	8.28
114	-3.44	6.45	149	-1.41	8.34
115	-3.40	6.50	150	-1.35	8.42
116	-3.34	6.55	151	-1.29	8.48
117	-3.28	6.60	152	-1.23	8.54
118	-3.22	6.65	153	-1.17	8.60
119	-3.16	6.70	154	-1.11	8.66
120	-3.10	6.75	155	-1.05	8.72
121	-3.04	6.80	156	-0.99	8.78
122	-2.98	6.85	157	-0.93	8.84
123	-2.92	6.90	158	-0.87	8.90
124	-2.86	6.95	159	-0.81	8.96
125	-2.80	6.99	160	-0.75	9.12
126	-2.76	7.05	161	-0.69	9.18
127	-2.72	7.11	162	-0.63	9.24
128	-2.68	7.17	163	-0.57	9.30
129	-2.64	7.23	164	-0.51	9.36
130	-2.60	7.28	165	-0.45	9.42
131	-2.53	7.33	166	-0.39	9.48
132	-2.46	7.38	167	-0.33	9.54
133	-2.39	7.43	168	-0.26	9.60
134	-2.32	7.48	169	-0.21	9.66
135	-2.25	7.53	170	-0.15	9.72

APPENDIX E
CALIBRATION OF LEFT DYNAMOMETER
(Y-Y Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.59	0.39	53	-6.72	3.15
6	-9.53	0.46	54	-6.66	3.20
7	-9.48	0.53	55	-6.60	3.25
8	-9.42	0.59	56	-6.54	3.31
9	-9.36	0.65	57	-6.48	3.37
10	-9.30	0.71	58	-6.43	3.43
11	-9.24	0.77	59	-6.38	3.49
12	-9.18	0.82	60	-6.33	3.56
13	-9.12	0.87	61	-6.26	3.62
14	-9.06	0.92	62	-6.20	3.67
15	-9.00	0.98	63	-6.13	3.73
16	-8.94	1.04	64	-6.06	3.79
17	-8.88	1.09	65	-6.00	3.85
18	-8.83	1.15	66	-5.95	3.91
19	-8.87	1.20	67	-5.89	3.97
20	-8.72	1.25	68	-5.83	4.03
21	-8.66	1.30	69	-5.78	4.08
22	-8.60	1.35	70	-5.72	4.14
23	-8.54	1.40	71	-5.66	4.20
24	-8.48	1.45	72	-5.60	4.27
25	-8.42	1.50	73	-5.55	4.33
26	-8.36	1.56	74	-5.50	4.39
27	-8.30	1.62	75	-5.44	4.45
28	-8.23	1.68	76	-5.38	4.51
29	-8.16	1.74	77	-5.32	4.57
30	-8.10	1.80	78	-5.26	4.63
31	-8.04	1.86	79	-5.20	4.69
32	-7.99	1.92	80	-5.13	4.74
33	-7.93	1.98	81	-5.06	4.81
34	-7.87	2.04	82	-4.99	4.88
35	-7.82	2.10	83	-4.93	4.95
36	-7.76	2.17	84	-4.86	5.03
37	-7.71	2.24	85	-4.80	5.10
38	-7.65	2.31	86	-4.76	5.14
39	-7.60	2.38	87	-4.72	5.19
40	-7.55	2.45	88	-4.68	5.23
41	-7.48	2.51	89	-4.64	5.27
42	-7.41	2.57	90	-4.60	5.31
43	-7.34	2.62	91	-4.54	5.37
44	-7.27	2.67	92	-4.48	5.43
45	-7.20	2.72	93	-4.42	5.49
46	-7.14	2.78	94	-4.36	5.55
47	-7.08	2.83	95	-4.30	5.61
48	-7.02	2.89	96	-4.23	5.67
49	-6.96	2.95	97	-4.17	5.72
50	-6.90	3.00	98	-4.11	5.78
51	-6.84	3.05	99	-4.05	5.83
52	-6.78	3.10	100	-3.98	5.89

APPENDIX E
(Cont'd)

Pounds	Dial Reading		Pounds	Dial Reading	
101	-3.92	5.95	114	-3.09	6.70
102	-3.86	6.01	115	-3.02	6.75
103	-3.80	6.07	116	-2.97	6.81
104	-3.74	6.13	117	-2.92	6.87
105	-3.68	6.20	118	-2.87	6.93
106	-3.61	6.25	119	-2.82	6.99
107	-3.54	6.30	120	-2.77	7.05
108	-3.48	6.35	121	-2.70	7.10
109	-3.42	6.40	122	-2.63	7.15
110	-3.35	6.44	123	-2.57	7.20
111	-3.28	6.51	124	-2.51	7.25
112	-3.21	6.58	125	-2.45	7.30
113	-3.15	6.64			

APPENDIX F
CALIBRATION OF LEFT DYNAMOMETER
(Z-Z Axis)

Pounds	Dial Reading		Pounds	Dial Reading	
5	-9.25	0.71	46	-4.52	5.31
6	-9.15	0.83	47	-4.44	5.42
7	-9.05	0.94	48	-4.36	5.53
8	-8.95	1.06	49	-4.28	5.64
9	-8.85	1.17	50	-4.20	5.75
10	-8.75	1.29	51	-4.07	5.86
11	-8.63	1.41	52	-3.94	5.96
12	-8.50	1.53	53	-3.81	6.07
13	-8.37	1.65	54	-3.68	6.17
14	-8.24	1.77	55	-3.55	6.28
15	-8.11	1.89	56	-3.47	6.40
16	-8.00	1.98	57	-3.39	6.51
17	-7.89	2.09	58	-3.31	6.63
18	-7.78	2.19	59	-3.23	6.75
19	-7.66	2.29	60	-3.15	6.87
20	-7.55	2.38	61	-3.02	6.98
21	-7.44	2.50	62	-2.89	7.08
22	-7.33	2.63	63	-2.75	7.18
23	-7.22	2.76	64	-2.63	7.28
24	-7.11	2.88	65	-2.52	7.38
25	-6.99	3.00	66	-2.41	7.48
26	-6.90	3.07	67	-2.31	7.59
27	-6.80	3.14	68	-2.20	7.60
28	-6.71	3.21	69	-2.10	7.71
29	-6.62	3.28	70	-2.00	7.92
30	-6.53	3.35	71	-1.84	8.04
31	-6.41	3.48	72	-1.69	8.15
32	-6.29	3.60	73	-1.53	8.27
33	-6.17	3.73	74	-1.38	8.38
34	-6.06	3.86	75	-1.23	8.50
35	-5.96	3.99	76	-1.13	8.58
36	-5.82	4.12	77	-1.02	8.66
37	-5.67	4.25	78	-0.92	8.74
38	-5.53	4.38	79	-0.82	8.82
39	-5.38	4.50	80	-0.72	8.90
40	-5.24	4.62	81	-0.62	8.98
41	-5.11	4.74	82	-0.52	9.06
42	-4.98	4.86	83	-0.42	9.14
43	-4.86	4.97	84	-0.32	9.22
44	-4.74	5.08	85	-0.22	9.30
45	-4.61	5.20			

AD-131 08A University of Michigan, Ann Arbor. A STUDY OF MUSCLE FORCES AND FATIGUE, by Paul A. Hunsicker. December 1957. 47p. incl. illus., 15 refs. (Proj. 7214; Task 71727) (WADC TR 57-586) (Contract AF 33(616)-3461) Unclassified report The first phase of the research deals with the strength test results taken on 30 subjects, covering 120 strength tests. The subjects were seated in a simulated pilot-seat, and six movements were tested. The results are presented in percentile tables and graphic (over)	UNCLASSIFIED	AD-131 08A University of Michigan, Ann Arbor. A STUDY OF MUSCLE FORCES AND FATIGUE, by Paul A. Hunsicker. December 1957. 47p. incl. illus., 15 refs. (Proj. 7214; Task 71727) (WADC TR 57-586) (Contract AF 33(616)-3461) Unclassified report The first phase of the research deals with the strength test results taken on 30 subjects, covering 120 strength tests. The subjects were seated in a simulated pilot-seat, and six movements were tested. The results are presented in percentile tables and graphic (over)	UNCLASSIFIED
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