

CHAPTER VII HUMAN MUSCULAR STRENGTH

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The purposes of this chapter are to review and summarize selected studies of human muscle strength for the guidance of design engineers in dealing with a large volume of often contradictory strength data, and to present specific data for direct utilization in workspace design for a widely variable population. Included in our discussion will be the following topic areas:

- (1) a general review of human muscular strength;
- (2) specificity of muscular strength;
- (3) relationships between static and dynamic muscular strength;
- (4) strength within the arm reach envelope of the seated subject;
- (5) comparative muscular strength of men and women.

Many of the theoretical aspects of muscular strength capabilities have been discussed in some detail by Roebuck, Kroemer, and Thompson (1975) in their book entitled Engineering Anthropometry Methods. For the reader who is interested in pursuing a discussion of the measurement of muscular strength capabilities, we recommend Chapter IV, pp. 108-128 in that publication. Other recommended reviews assessing human muscular strength capabilities have been published by Caldwell (1964), Caldwell et al. (1974), Chaffin (1975), Clarke (1973), Clarke (1966 and 1971), Hettinger (1961), Hunsicker and Greey (1957), Ikai and Steinhaus (1961), Kroemer (1970), Kroemer and Howard (1974), and Pipes and Wilmore (1975).

Handbooks that contain data pertinent to muscle strength design problems include those written or edited by Damon, Stoudt, and McFarland (1966), Van Cott and Kinkade (1972), and Webb (1964). These handbooks are extremely useful sources of information to the designer engineer.

Specificity of Muscular Strength

The specificity* of human muscular strength is of major importance for the engineering application of strength data. The concept of strength specificity deals with the fact that strength scores, even when exerted

*Specificity is the percentage of variance accounted for by other variables than x and is determined by $1 - r^2$. Generality is defined as the percentage of variance of y accounted for by x and is determined by r^2 . A correlation coefficient of at least .71 is required to show more generality than specificity: $r^2 \times 100 = 50$ percent or more.

by the same subjects, do not correlate well with each other. Pursuing this topic in some detail, Whitley and Allan (1971) have extensively reviewed the strength related literature. On the basis of their review, of 23 studies representing a variety of strength tests and measurement techniques, the authors point out "...that individual differences in static strength ability demonstrate more specificity than generality."

This concept was further elucidated by Thordsen, Kroemer, and Laubach (1972) and Laubach, Kroemer, and Thordsen (1972). They asked their subjects to exert maximum static force in 44 different exertions. Less than 2% of the 946 intercorrelations among the force exertions exceeded .71, indicating that such correlations may not be very useful in predicting force capabilities. The authors concluded that "...if data are desired on forces exerable in other locations or directions, i.e., under other conditions, than those previously investigated, the information generally has to be gathered experimentally rather than computed from other force data."

The implications from the above quoted research clearly indicate that there is no single quantitative function that can be called general static strength.

Static vs. Dynamic Muscular Strength

The relationship between static and dynamic muscular strength in man is of great concern to design engineers. The ability to predict an operator's success in performing a dynamic strength task from a measurement of static muscular strength would be a tremendous asset for the design engineer who must be concerned with dynamic performance. A large body of literature has been devoted to the question of whether the amount of force that can be exerted in a static muscular contraction is a good or a poor indicator of the amount of force that can be exerted dynamically. Unfortunately, very few unequivocal answers have resulted. A thorough review of the literature, however, does yield provisional answers to the following questions pertaining to the relationships between static and dynamic muscular strength:

- (1) Has there been a definite relationship established between static and dynamic muscular strength?
- (2) Do static muscular force measurements yield larger values than dynamic force measurements.
- (3) During a dynamic muscular contraction, does a concentric or an eccentric contraction yield the larger value?
- (4) What is the relationship between static and dynamic muscular force during different phases of the contractions?
- (5) Can dynamic muscular force be more accurately predicted from static force if the motion is linear or angular?

Comparisons that have been made between static and dynamic muscular strength have resulted in conflicting opinions about these relationships. In studies reported by Asmussen, Hansen and Lammert (1965), Berger and

Higginbotham (1970), Carlson (1970), Rasch (1957), Rasch and Pierson (1960, 1963) and Salter (1955), a high degree of correlation was found between measures of static and dynamic strength.

Doss and Karpovich (1965), Lagasse (1970), Singh and Karpovich (1966) and Start (1966), on the other hand, have reported erratic results between measures of static and dynamic strength. In a discussion pertaining to the differing results between static and dynamic strength obtained by various investigators Bender and Kaplan (1966) state:

Such conclusions, however, are partly derived from reports in which force was evaluated by the amount of weight that the individual could lift through a range of motion and then hold terminally, whereas the isometric measurement was taken at another point, usually midway, in the joint range of motion. This raises the question of whether these testing procedures are comparing the same activity. It is likely that different muscles or muscle groups are being evaluated when the testing occurs at distinctly different points within the range of motion.

Other reasons for these conflicting opinions have been that researchers have (1) inadequately defined the testing terminology, (2) utilized varying intensities of effort, and (3) used different testing positions.

From a thorough review of the muscle strength testing literature, Hunsicker and Greey (1957) concluded that there is a difference between static strength (as defined by a single maximum effort with the subject in a fixed position) and dynamic strength (as defined by repetitious efforts) and that the mathematical relationship between the two is not high.

Doss and Karpovich (1965) compared concentric,* eccentric,** and isometric strength of the elbow flexor muscles. Each subject was given three tests, repeated three times to measure the maximum force during concentric and eccentric movements between 75° and 165° of the elbow angle. The execution of the concentric and eccentric movements took 18 seconds each. The isometric measures were taken between 87° and 150° of the elbow angle and the contractions were maintained at least one second at each angle. When the three force exertions (concentric, eccentric, and isometric) were compared at corresponding elbow joint angles, it was found that the mean maximum concentric (pushing) force was 23% smaller and the eccentric (pulling) force was 13.5% greater than the isometric force.

In a study similar to that of Doss and Karpovich, Singh and Karpovich (1966) studied the relationships among maximum concentric, eccentric, and isometric forces of the forearm flexors and extensors. The mean eccentric

*Concentric indicates that the muscle shortens actively against a resistance.

**Eccentric indicates that the muscle is lengthened passively by an external force.

forces of the flexors and the extensors were 32.7% and 14.2% greater than the concentric forces, respectively. The isometric forces of the flexors were 41.6% greater than the isometric forces of the extensors. Singh and Karpovich conclude that it is possible to predict the concentric, eccentric, and isometric forces of the flexor muscles from one another. The same conclusion holds true for predicting the three forces of the extensors from one another. However, the chances of predicting the different forces of the flexors from the extensors, or vice versa, are quite limited.

Using the factor analysis approach, Start and others (1966) studied the relationships between static strength and power of the lower limb. Total leg strength was measured using a back and leg dynamometer. The bilateral strength of the ankle plantar flexors, the knee extensors, and the hip extensors were determined using cable tensiometer techniques. Power was determined via the power jump, the Sargent jump, the squat jump, and the standing broad jump. The authors concluded that power bore little relationship to static strength and that the two seemed to be separate entities.

Asmussen, Hansen, and Lammert (1965) designed a special dynamometer to measure isometric, concentric, and eccentric muscle forces of the arm-shoulder complex. The distances of travel and velocities were expressed relative to arm length. The subjects were 18 men whose ages ranged from 18 to 30 years. For fairly rapid movements (corresponding to 60% of the arm length per second) the maximal concentric force is 75 to 80% of maximal isometric strength. In resisting a movement of the same velocity, 125 to 130% of the maximal isometric strength can be produced. The concentric and eccentric strength curves at all movement velocities studied were practically parallel to the isometric strength curves with the exception of the first part of the movement in concentric contraction. The authors reported a correlation of 0.80 between dynamic strength (at a velocity of 15% arm length per second) and isometric strength.

In a well-planned study, Carlson (1970) studied the relationship between isometric and isotonic strength of the right elbow flexor muscles. Carlson found the mean isometric strength value to be 78.1 lbs. and the mean isotonic strength value to be 68.3 lbs., resulting in a difference of 13%. The correlation coefficient between isotonic and isometric strength was found to be 0.83. The author concluded.

...that the difference between the two tests is highly significant. The validity of the substitution of a test of isometric strength, therefore, is contingent upon the use of test results. If the purpose of the test is to discriminate between strong and weak persons, the substitution is a valid one. If the purpose of the test is to determine the level of muscular strength, however, the substitution is not valid because of the differences between results of the two tests.

Berger and Higginbotham (1970) studied the relationship between static and dynamic strength of the knee flexors at the joint angles of 35°, 61°, 89°, 135°, and 167°. The following table summarizes the results of the strength testing as reported by Berger and Higginbotham:

TABLE 1
STATIC AND DYNAMIC STRENGTH OF KNEE FLEXORS

<u>Knee Angle</u>	<u>Static Strength X</u>	<u>Dynamic Strength X</u>	<u>r</u>
35°	415 lbs.	275 lbs.	.79
61°	339 lbs.	329 lbs.	.96
89°	490 lbs.	489 lbs.	.99
135°	974 lbs.	966 lbs.	.99
167°	1050 lbs.	1045 lbs.	.99

The correlations between static and dynamic strength of the knee flexors as reported by Berger and Higginbotham are the highest reported relationships found in the literature.

Using a two-hand crank ergometer, Kogi, Mueller and Rohmert (1965) related the isometric moments of rotation at 12 different crank positions to dynamic force measurements performed for 30 minutes at 60 revolutions per minute at differing outputs. The results are depicted in Figure 1. The dashed line --- illustrates the maximum static strength that the subjects were able to exert at 30 degree intervals from 0° through 330° (0°, 30°, ...330°) on the crank ergometer. The solid line — illustrates the dynamic moment of rotation (at 2, 7, ...37 kpm/sec) at the same hand positions as the static measurements. It is interesting to note that although the dynamic measurements do not reach the same magnitude as the static measurements, the force measurement curves demonstrate remarkably similar profiles.

In summary, the authors found that (1) the nature of the dynamic curve remains essentially unchanged with an increase in output, (2) the curves possess two maximum points, i.e., at positions 90° and 270°, (3) the exertion of strength was always greater with pulling than it was with pushing, and (4) strength curves at high dynamic outputs approach (but never attain) the maximum isometric strength.

Stothart (1970) examined the relationship between specific characteristics of static elbow flexion performance and biomechanical aspects of dynamic elbow flexion performance under each of three different loads. For the three dynamic test conditions, A (minimum load), B (twice the minimum load), and C (three times the minimum load), the maximum dynamic torque means were 51.4%, 60.9%, and 66.8% of the maximum static torque means, respectively. Stothart reported the following correlations between maximum static torque and selected dynamic variables:

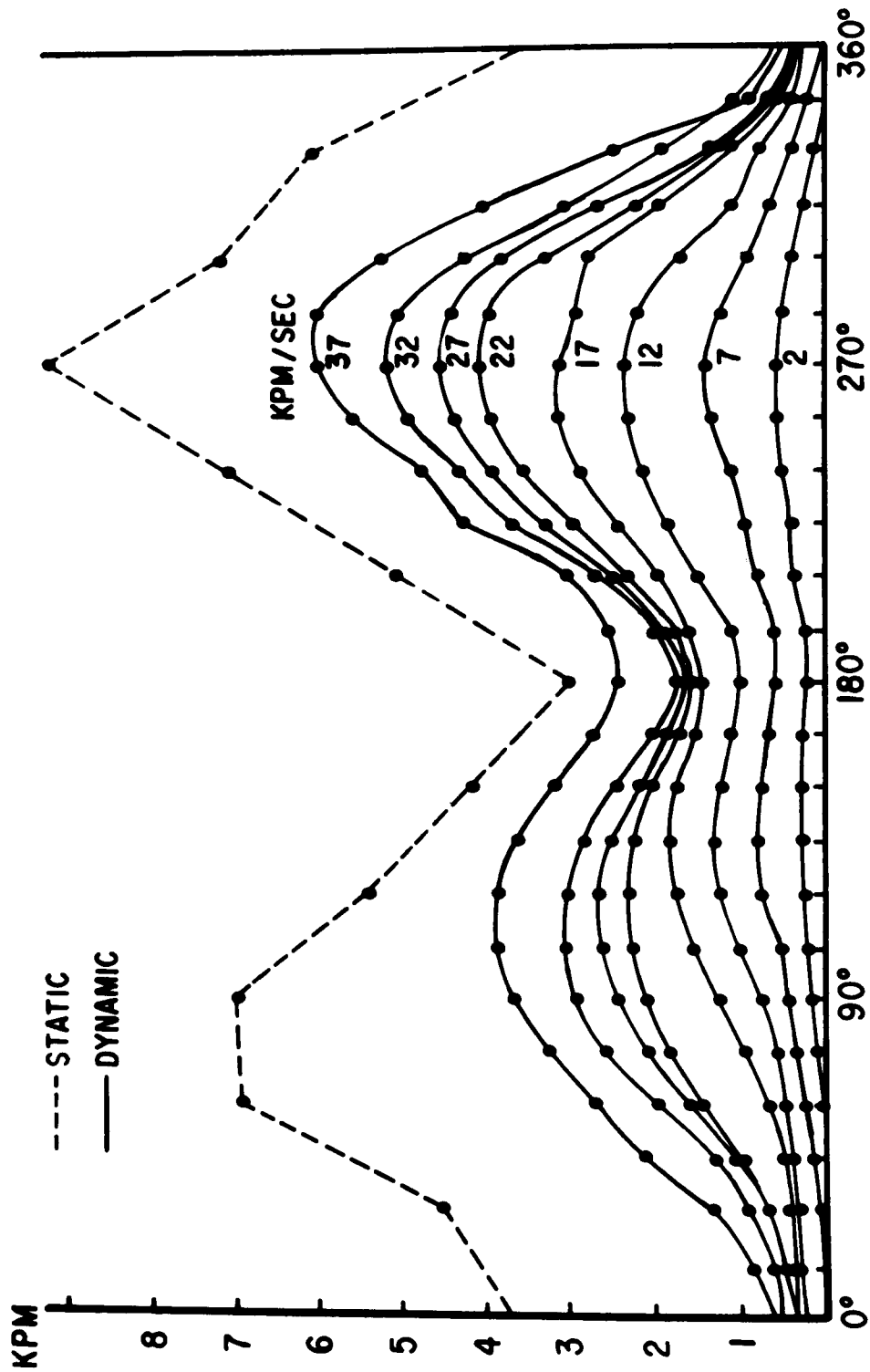


Figure 1. Results of static and dynamic strength testing as reported by Berger and Higginbotham (1970).

TABLE 2
CORRELATIONS BETWEEN STATIC AND DYNAMIC ELBOW FLEXION PERFORMANCE

	<u>Condi- tion A</u>	<u>Condi- tion B</u>	<u>Condi- tion C</u>
Maximum Dynamic Torque	.73	.71	.76
Dynamic Torque at 15°	.70	.75	.73
Dynamic Torque at 30°	.60	.66	.70
Dynamic Torque at 45°	.47	.59	.58
Dynamic Torque at 60°	.25	.45	.37
Dynamic Torque at 75°	-.02	.19	.08
Dynamic Torque at 90°	-.16	-.13	-.12
Dynamic Torque at 105°	-.05	-.20	-.25

The above correlations between dynamic and static torque variables show that the relationship pattern was moderate ($r \approx .70$) during early phases of the movement and dropped exponentially to negative values at the end of the movement. Stothart concludes that static and dynamic force are moderately related in early phases of movement where very little excursion (movement) has occurred.

Summary of Major Findings

1. An intensive review of the literature indicates that the relationship between static and dynamic muscular forces has not been definitely established. Various evaluations of static and dynamic muscular force have resulted in conflicting opinions about these relationships. The following correlation table is a selected summary of those investigations that have particular relevance to our problem. The correlation coefficients shown are the reported relationships between static and dynamic strength.

TABLE 3
A SELECTED SUMMARY TABLE OF REPORTED RELATIONSHIPS
BETWEEN STATIC AND DYNAMIC STRENGTH

<u>Reference</u>	<u>Corre- lation</u>
Asmussen, Hansen, and Lammert (1965)	.80
Berger and Henderson (1966)	.60
Berger and Higginbotham (1970) (range)	.79 to .99
Carlson (1970)	.83
Lagasse (1970)	.47
Martens and Sharkey (1966)	.77
McClements (1966) (flexion strength and power)	.52
(extension strength and power)	.65
Rasch and Pierson (1963)	.69
Stothart (1970) (range)	.76 to -.25

The basic question to be answered in the application of these relationships is with what degree of accuracy do we want to be able to predict dynamic force from static force? Although the correlation between the two measures may be relatively high (i.e., $r=.83$) the standard error of estimate for predicting dynamic force from static force may be too large for the regression equation to be of practical value; e.g., if the standard error of estimate equals plus or minus 10 kiloponds from a regression mean of 70 kiloponds the error percentage is of a magnitude of 14%.

2. Static muscular force (whether it is measured in linear or angular motion) is usually larger than dynamic force. Dynamic force, depending on the velocity of the shortening muscles, amounts to about 50% to 90% of the maximal static force.

3. When dynamic force is expressed as a concentric contraction (muscles shortening during the action) or as an eccentric contraction (muscles lengthening during the action), the eccentric contraction yields the larger value.

4. Static and dynamic muscular forces are moderately related ($r \approx .70$) in early phases of the movement where little excursion has occurred; however, this relationship drops exponentially to negative values at the end of the movement.

5. It appears that dynamic force may be more accurately predicted from static force measurements when the motion to be evaluated is angular rather than linear.

Human Force Exertions Within the Arm Reach Envelope of the Seated Subject

This portion of this chapter describes experiments designed to measure the maximum static push forces that seated subjects can exert throughout selected positions of the arm reach envelope. A total of 76 arm force exertions were measured on a sample of 55 young male subjects whose mean age was 21.3 years with a standard deviation of 3.2 years; mean weight was 75.1 kg (165.6 lbs) with a standard deviation of 14.0 kg (30.9 lbs); mean stature was 176.9 cm (69.6 in) with a standard deviation of 5.6 cm (2.2 in). Because this material has not been previously published, we will discuss the equipment used and the experimental protocol in more detail than was done in other previously reported studies. The equipment used for this experiment consisted mainly of a seat, a three-dimensional strain gauge force transducer, and two pieces of recording equipment (See Figure 2).

The seat, complete with belts, simulated a standard aircraft seat with hard surfaces replacing the usual seat cushions. It was constructed in such a way that the seat back angle could be changed to any given angle currently used or considered for use in USAF aircraft. Built on a track, the movable seat could be brought forward and backward and left and right in relation to the handle assembly. The handle assembly was constructed in such a way that it could be raised or lowered, making it possible to

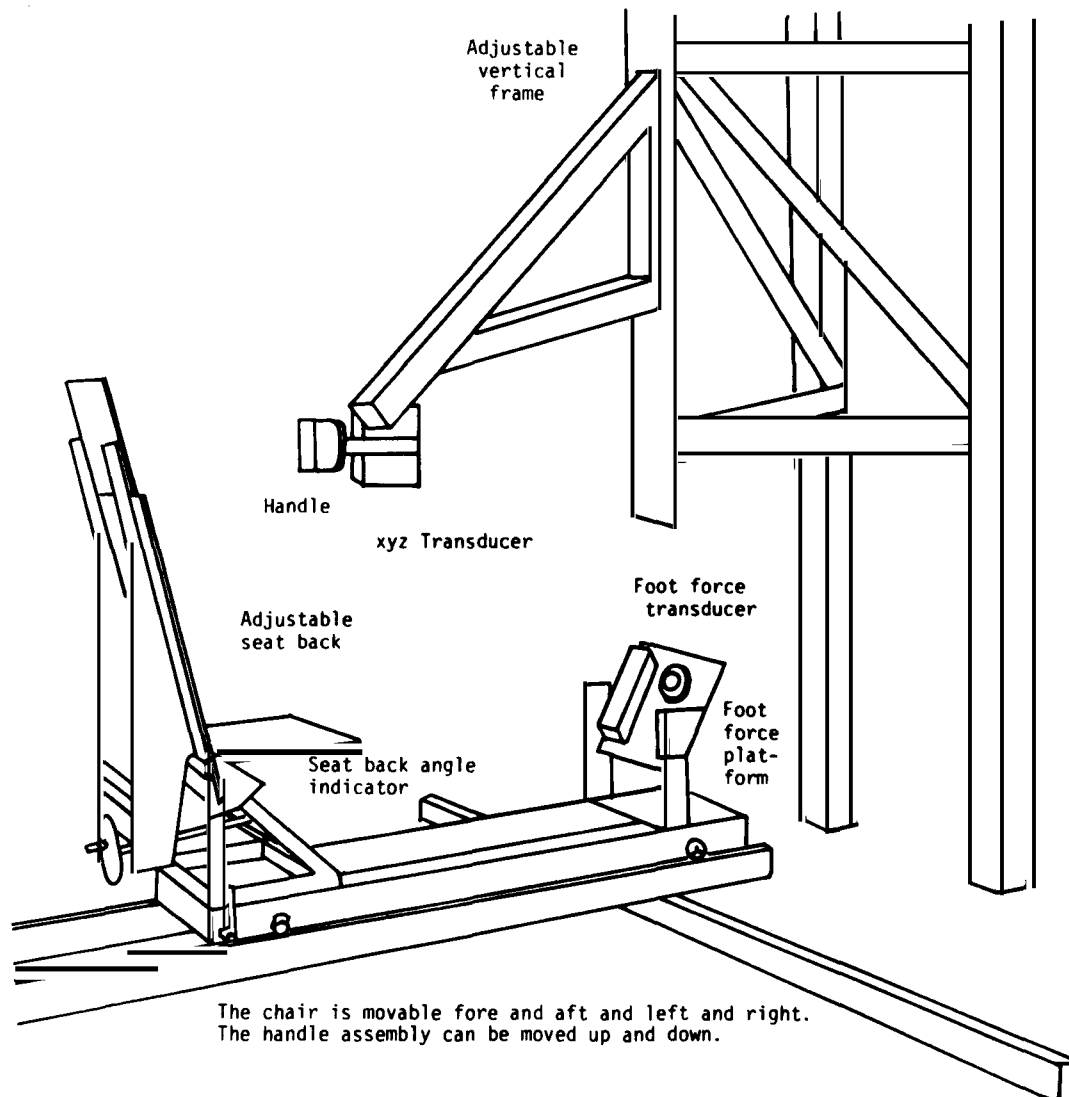


Figure 2. Equipment for measurement of maximum static push forces of seated subject.

locate the handle at any desired spatial location with respect to seat reference point (SRP).*

The handle used in measuring arm forces consisted of an aluminum cylinder with a diameter of 3.8 cm (1.5 in) and a length of 12 cm (4.7 in). Knurled to minimize slippage when grasped, the handle was attached to a Lebow three-dimensional strain gauge force transducer. Inside the transducer were three pairs of strain gauges arranged perpendicularly to each other, operating on the Wheatstone bridge arrangement. When a force was exerted on the handle, the balance between the three pairs of strain gauges was altered accordingly. The range of the transducer in any of the three coordinates was 135 kiloponds. However, to simplify data-reporting in this chapter, we have chosen to present only the push force in a horizontal plane in the forward direction.

Location of the Handle Assembly in Relation to Seat Reference Point

The spatial locations of the handle assembly (See Figure 2) for the arm force exertions were selected from an analysis of unpublished arm reach data gathered by Kenneth W. Kennedy, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. These test positions were established using the fifth percentile arm reach envelopes of the USAF population for each of the three different seat back angles (13° , 25° , and 65°) established for this research.

The final test positions for the arm exertions numbered 76 and included 34 exertions with a seat back angle of 13° , 27 exertions with a seat back angle of 25° , and 15 exertions with a seat back angle of 65° . The exact locations of the 76 final test positions with respect to seat reference point and seat centerline are listed in Tables 4, 5 and 6.

Procedure

The subject sat in the seat, restrained by a regular lap belt, grasping the handle assembly during the arm force exertions. His feet were required to rest "on the deck" during the arm exertions. The subject was not allowed to grasp the chair with his free hand during the exertion.

The general testing instructions for the static muscular strength evaluation of each subject followed, in general, the procedures and techniques reported by Caldwell et al., 1974. From the record of each arm force exertion, the largest amplitude ("peak") value was read; these are the values reported here.

*Seat reference point (SRP) is the point of intersection of the midline of the seat pan with the midline of the seat back.

Data Presentation

We have chosen to present the descriptive statistical data generated from this study in a series of 20 illustrations (Figures 3 through 22). Eight of these illustrations represent arm strength data within the reach envelope of the seated subject at a seat back angle of 13° ; seven illustrations present data at the 25° seat back angle; and the remaining five illustrations give data for the 65° seat back angle. These illustrations show the summary statistics, including the mean, standard deviation, and fifth and ninety-fifth percentiles, for a specific seat back angle and handle assembly location in relation to seat reference point and seat centerline. Tables 4, 5 and 6 give the exact location of the handle assembly in relation to seat reference point and seat centerline, as well as listing statistical data for the arm force exertions in tabular form.

Effects of Seat Back Angle Upon the Magnitude of Arm Forces

When the position of the seat back angle of the simulated aircraft seat was positioned at 13° , maximal strength scores seemed to be obtained when the handle assembly was located 76 to 89 centimeters above seat reference point from 13 to 26 centimeters left or right of seat reference point, and from 55 to 65 centimeters forward of seat reference point. The lowest strength values obtained in this position occurred when the handle assembly was located from 38 to 51 centimeters^a above seat reference point.

In general, the largest arm strength values obtained when the seat back angle was positioned at 25° occurred when the handle assembly was located 76 to 89 centimeters above seat reference point, from 13 to 25 centimeters left or right of seat reference point, and 40 to 50 centimeters forward of seat reference point.

When arm force exertions were measured at the 65° seat back angle, the greatest strength scores occurred when the handle assembly was located from 64 to 76 centimeters above seat reference point, and from 15 to 25 centimeters forward of seat reference point.

These strength data used in conjunction with existing data pertaining to human force exertions for the seated operator (Laubach, Kroemer, and Thordsen, 1972; Thordsen, Kroemer, and Laubach, 1972; and Kroemer, 1975) and the standing operator (Rohmert, 1966; and Rohmert and Jenik, 1971) should aid the design engineer in the selection and arrangement of controls that must be located within the arm reach of the seated and standing operator.

Comparative Muscular Strength of Men and Women

This section will draw heavily upon two recently published articles by Laubach (1976, a and b). The latter report presents detailed, statistical information on comparative muscular strength parameters of men and women

TABLE 4
13° SEAT BACK ANGLE
LOCATION OF THE HANDLE ASSEMBLY IN RELATION TO SEAT
REFERENCE POINT AND SEAT CENTERLINE*

Above SRP	Forward of SRP	Left of SRP	Right of SRP	Centerline of Seat	Arm Force Exertions (Kp)			
					Mean	S.D.	5%ile	95%ile
38 cm	46 cm	25 cm			33.7	8.3	19.6	46.9
38 cm	48 cm			X	31.4	8.7	18.9	47.5
38 cm	48 cm		13 cm		35.5	10.5	21.6	56.2
38 cm	41 cm		38 cm		30.7	7.8	18.2	44.2
38 cm	30 cm		51 cm		25.3	6.8	15.0	37.3
51 cm	41 cm		51 cm		32.1	8.4	20.1	48.3
51 cm	51 cm		25 cm		43.1	11.0	27.3	63.6
51 cm	51 cm		13 cm		42.6	11.5	25.5	63.4
51 cm	53 cm			X	36.5	10.2	22.3	56.8
51 cm	51 cm	13 cm			44.3	11.3	24.9	61.8
64 cm	58 cm	25 cm			60.2	15.1	34.3	83.4
64 cm	69 cm			X	48.5	11.2	28.3	62.2
64 cm	58 cm		38 cm		54.5	16.2	31.4	86.4
64 cm	38 cm		64 cm		29.5	8.8	18.3	46.9
76 cm	53 cm		51 cm		46.3	14.9	23.2	73.8
76 cm	64 cm		25 cm		68.2	18.2	37.4	99.5
76 cm	64 cm			X	60.0	14.2	34.2	81.7
76 cm	58 cm	13 cm			65.5	16.4	39.7	95.0
76 cm	25 cm	38 cm			37.1	9.4	23.4	53.9
89 cm	46 cm	25 cm			52.2	15.1	28.9	77.9
89 cm	61 cm			X	67.6	16.7	40.8	95.6
89 cm	61 cm		13 cm		73.9	18.2	48.4	106.0
89 cm	56 cm		38 cm		66.5	19.6	33.2	100.5
89 cm	8 cm		76 cm		17.0	4.7	10.4	26.2
102 cm	25 cm		64 cm		26.2	7.2	15.5	39.6
102 cm	53 cm		25 cm		72.2	19.3	43.9	106.1
102 cm	51 cm			X	51.6	15.3	31.4	79.7
102 cm	48 cm	13 cm			52.5	17.5	29.6	85.1
114 cm	30 cm	13 cm			30.1	9.2	16.2	46.4
114 cm	38 cm			X	32.1	9.4	19.0	50.7
114 cm	20 cm		51 cm		28.4	6.5	19.7	40.4
127 cm	36 cm		13 cm		38.6	9.4	19.5	51.3
127 cm	33 cm			X	31.3	9.7	18.7	50.1
127 cm	25 cm	25 cm			32.5	8.4	20.6	48.0

*The orientation of the handle was always vertical and the requested direction of the exertion was in a horizontal plane in the forward direction.

TABLE 5
25° SEAT BACK ANGLE
LOCATION OF THE HANDLE ASSEMBLY IN RELATION TO SEAT
REFERENCE POINT AND SEAT CENTERLINE*

<u>Above SRP</u>	<u>Forward of SRP</u>	<u>Left of SRP</u>	<u>Right of SRP</u>	<u>Centerline of Seat</u>	<u>Arm Force Exertions (Kp)</u>			
					<u>Mean</u>	<u>S.D.</u>	<u>5%ile</u>	<u>95%ile</u>
38 cm	38 cm	25 cm			35.6	10.3	19.2	53.4
38 cm	43 cm			X	31.4	9.6	17.6	48.8
38 cm	41 cm		25 cm		36.1	10.9	21.7	59.5
51 cm	20 cm		64 cm		23.4	7.0	13.0	36.4
51 cm	38 cm		38 cm		41.7	12.7	24.9	66.1
51 cm	43 cm		13 cm		47.4	13.6	27.5	70.6
51 cm	46 cm	25 cm			48.3	13.6	28.8	71.9
64 cm	25 cm	38 cm			39.8	10.9	24.7	61.1
64 cm	56 cm	13 cm			54.8	14.0	33.1	81.6
64 cm	56 cm			X	49.4	11.1	32.6	66.3
64 cm	51 cm		25 cm		61.3	16.1	34.9	86.8
64 cm	38 cm		51 cm		40.8	11.9	23.6	60.3
76 cm	25 cm		64 cm		29.4	8.2	16.9	43.8
76 cm	46 cm		38 cm		59.6	17.9	37.2	90.2
76 cm	48 cm			X	64.1	15.1	36.9	87.7
76 cm	43 cm	25 cm			71.0	18.6	42.5	102.1
89 cm	46 cm	13 cm			71.3	21.8	34.6	110.4
89 cm	48 cm			X	69.6	18.0	39.7	100.5
89 cm	51 cm		25 cm		75.0	19.1	44.4	107.6
89 cm	41 cm		51 cm		50.2	17.6	25.9	83.3
102 cm	5 cm		64 cm		23.0	5.8	15.0	33.7
102 cm	41 cm		13 cm		66.2	20.9	36.1	97.8
102 cm	38 cm			X	52.9	16.5	31.1	85.4
102 cm	23 cm	25 cm			40.9	10.8	25.2	61.1
114 cm	13 cm	13 cm			30.5	10.4	16.2	49.0
114 cm	25 cm		25 cm		46.2	13.5	24.6	69.0
114 cm	20 cm		38 cm		40.3	11.3	23.2	60.0

*The orientation of the handle was always vertical and the requested direction of the exertion was in a horizontal plane in the forward direction.

TABLE 6
65° SEAT BACK ANGLE
LOCATION OF THE HANDLE ASSEMBLY IN RELATION TO SEAT
REFERENCE POINT AND SEAT CENTERLINE*

<u>Above SRP</u>	<u>Forward of SRP</u>	<u>Left of SRP</u>	<u>Right of SRP</u>	<u>Centerline of Seat</u>	<u>Mean</u>	Arm Force Exertions (Kp)		
						<u>S.D.</u>	<u>5%ile</u>	<u>95%ile</u>
38 cm	15 cm		51 cm		27.8	9.3	15.7	43.5
38 cm	15 cm		38 cm		37.0	11.3	19.5	54.6
51 cm	15 cm	25 cm			49.7	15.2	20.9	72.3
51 cm	30 cm			X	35.9	10.0	20.8	53.8
51 cm	13 cm		64 cm		23.3	8.3	11.8	39.3
64 cm	5 cm		64 cm		24.6	7.6	14.2	49.3
64 cm	28 cm		25 cm		54.5	15.2	32.9	82.1
64 cm	28 cm			X	49.3	12.6	30.4	66.5
64 cm	20 cm	13 cm			61.7	16.4	35.3	88.8
76 cm	3 cm	25 cm			49.8	18.1	24.1	84.2
76 cm	18 cm			X	57.1	16.0	30.4	81.5
76 cm	20 cm		13 cm		63.8	16.4	38.1	87.8
76 cm	8 cm		51 cm		32.7	9.9	18.4	49.8
89 cm	3 cm			X	40.2	15.9	17.9	69.7
89 cm	3 cm		25 cm		50.6	18.3	25.9	81.0

*The orientation of the handles was always vertical and the requested direction of the exertion was in a horizontal plane in the forward direction.

13 Degree Seat Back Angle
Handle at 38 cm above SRP

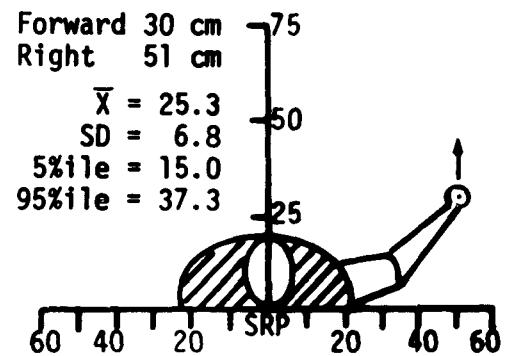
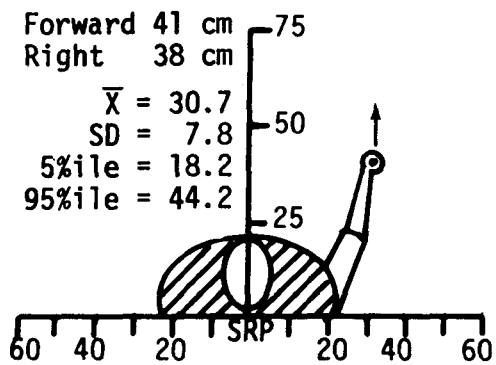
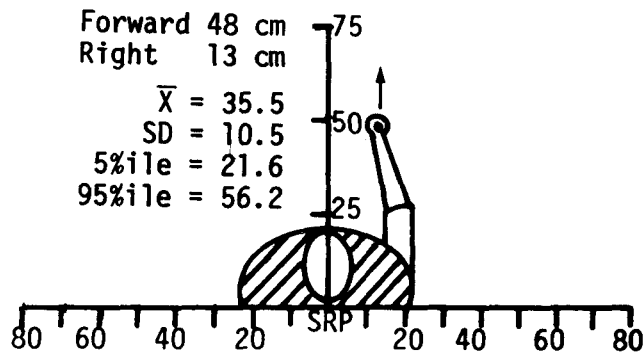
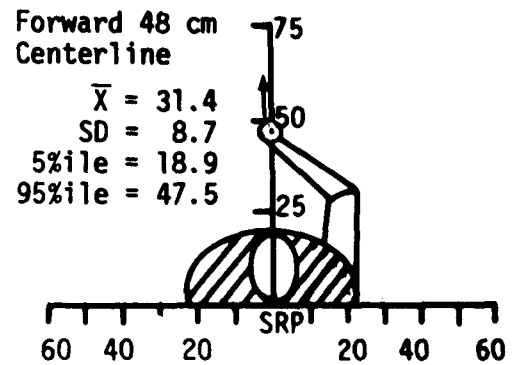
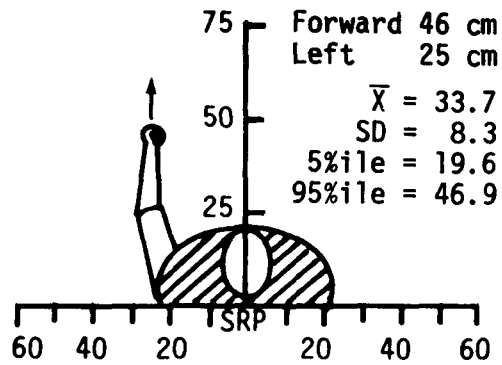


Figure 3. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 64 cm above SRP

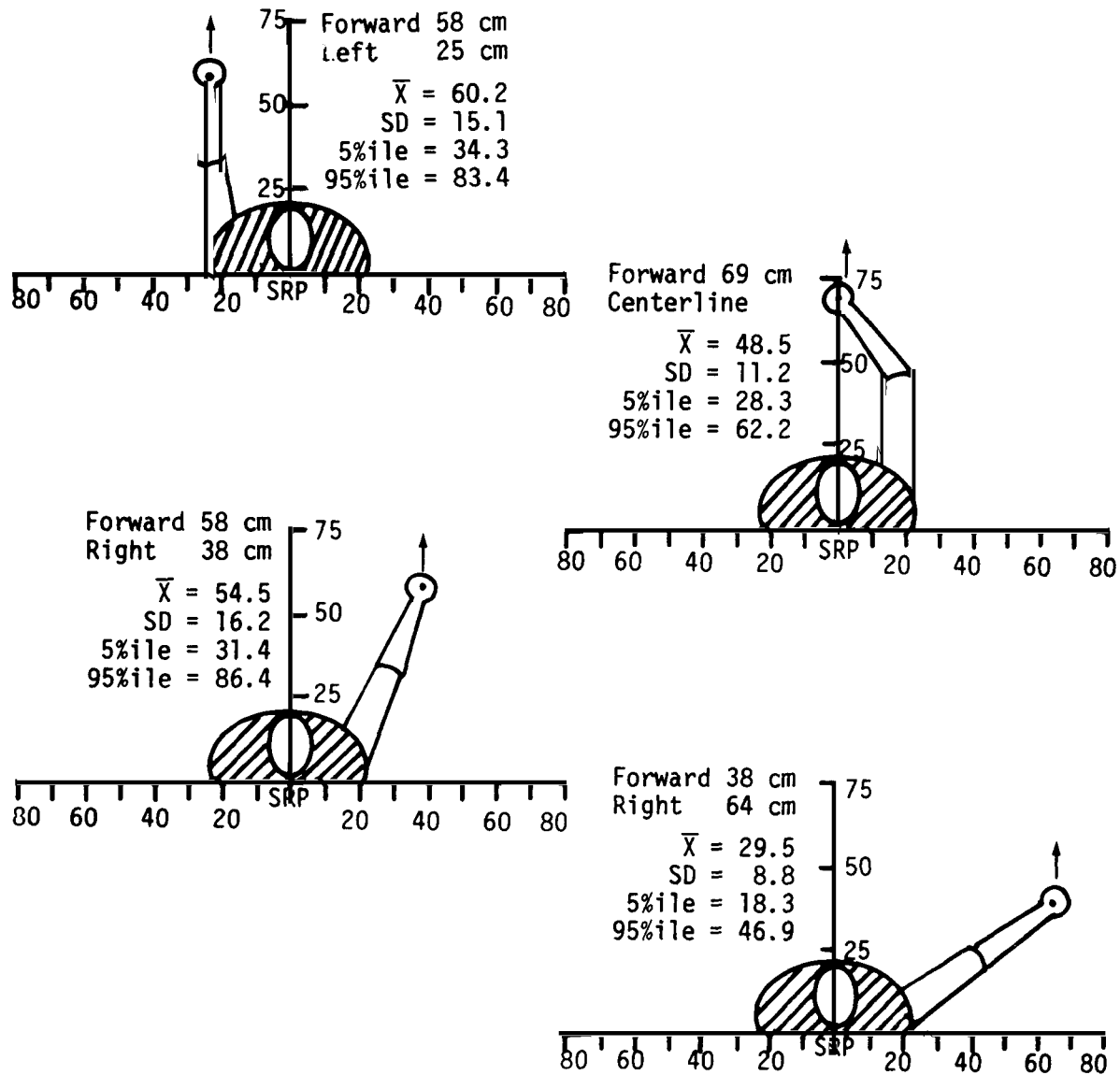


Figure 5. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 76 cm above SRP

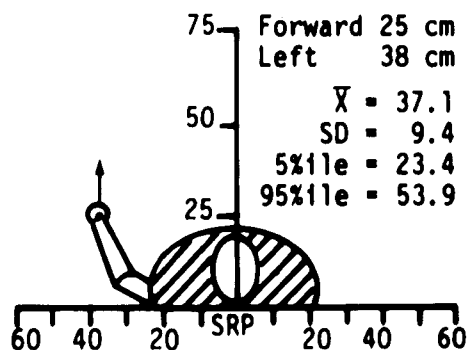
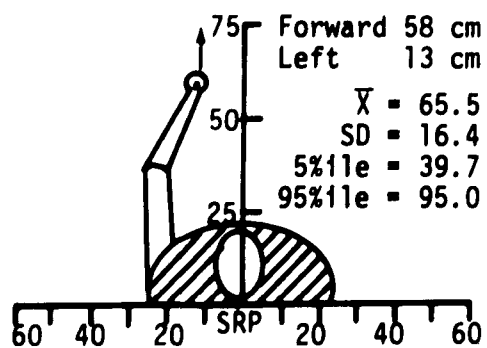
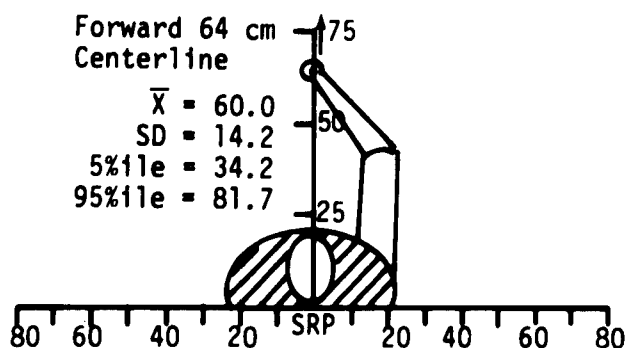
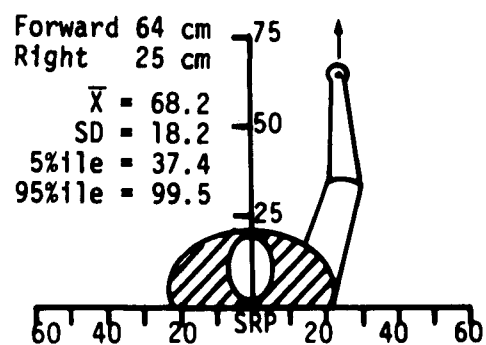
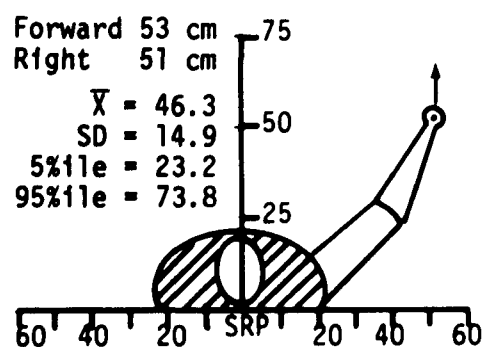


Figure 6. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 89 cm above SRP

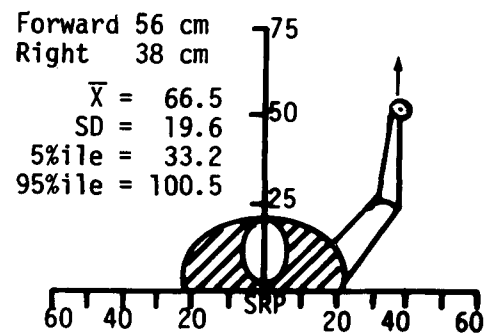
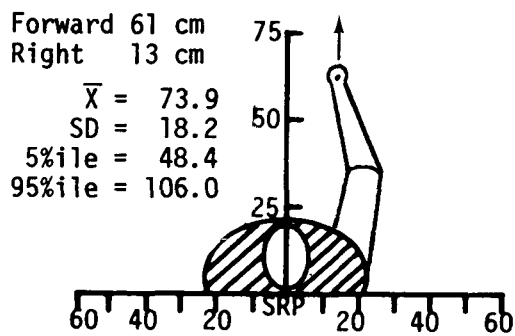
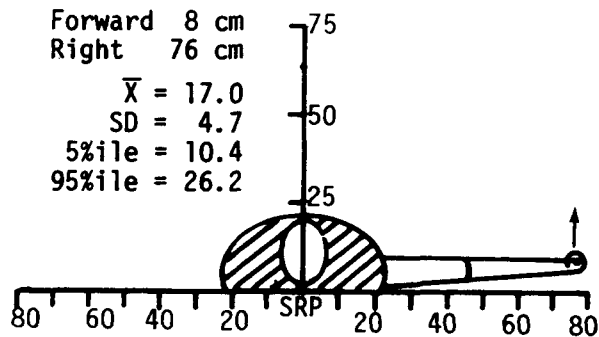
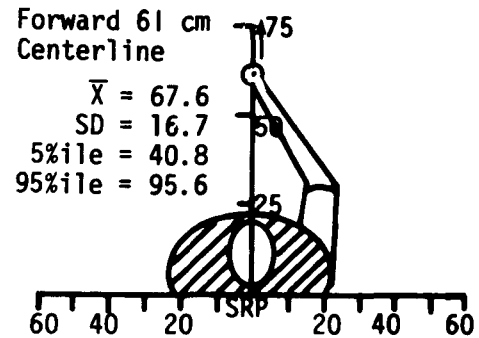
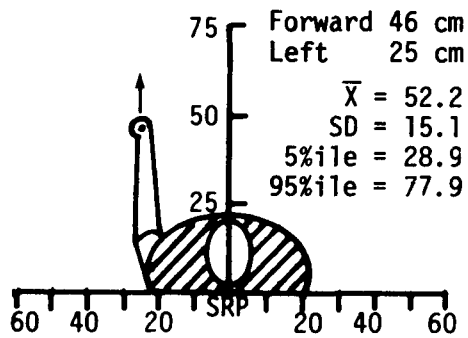


Figure 7. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 102 cm above SRP

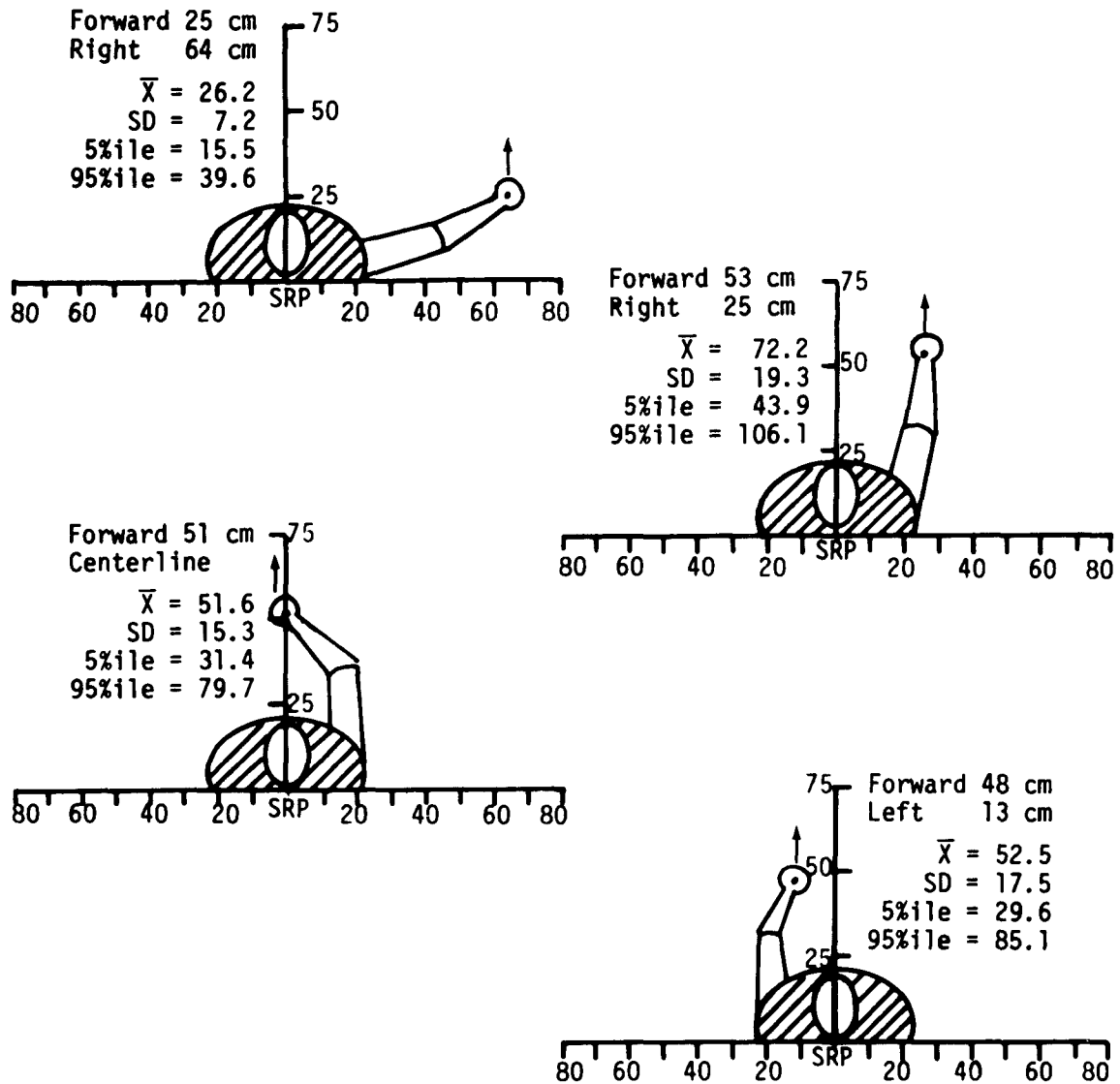


Figure 8. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 114 cm above SRP

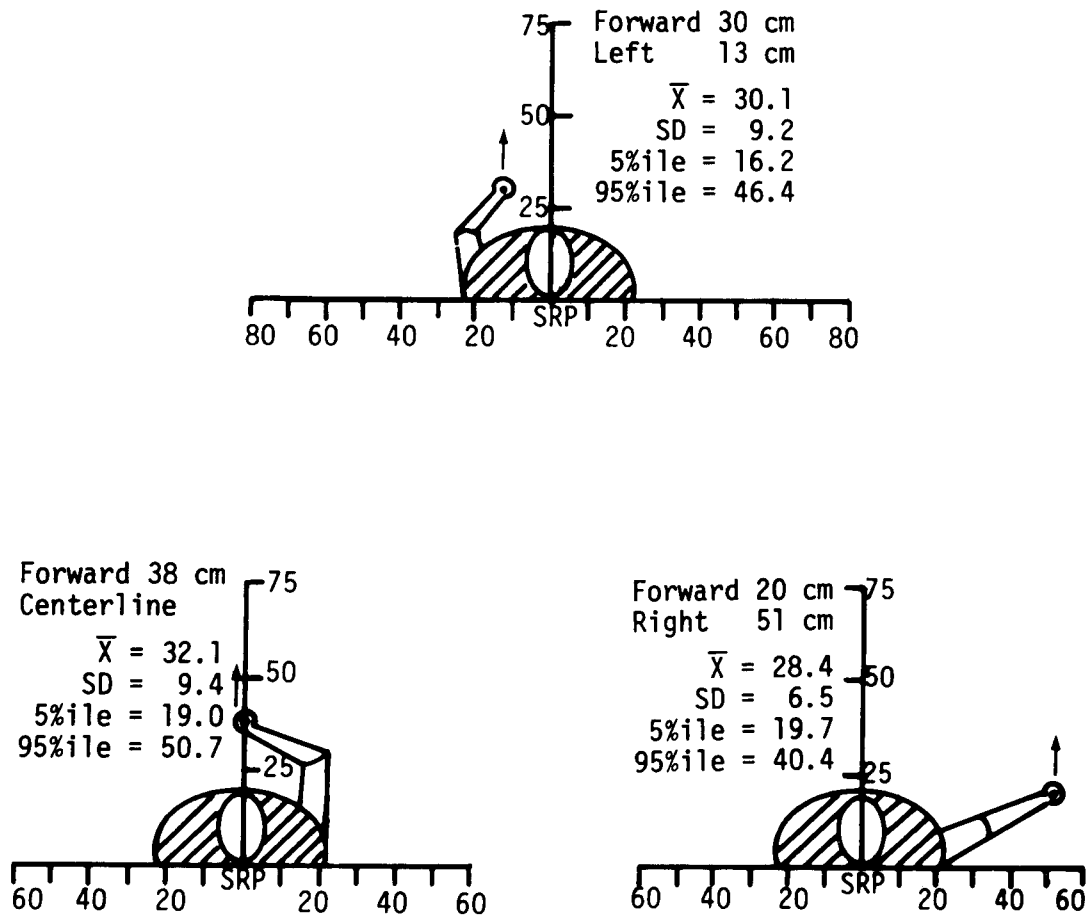


Figure 9. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

13 Degree Seat Back Angle
Handle at 127 cm above SRP

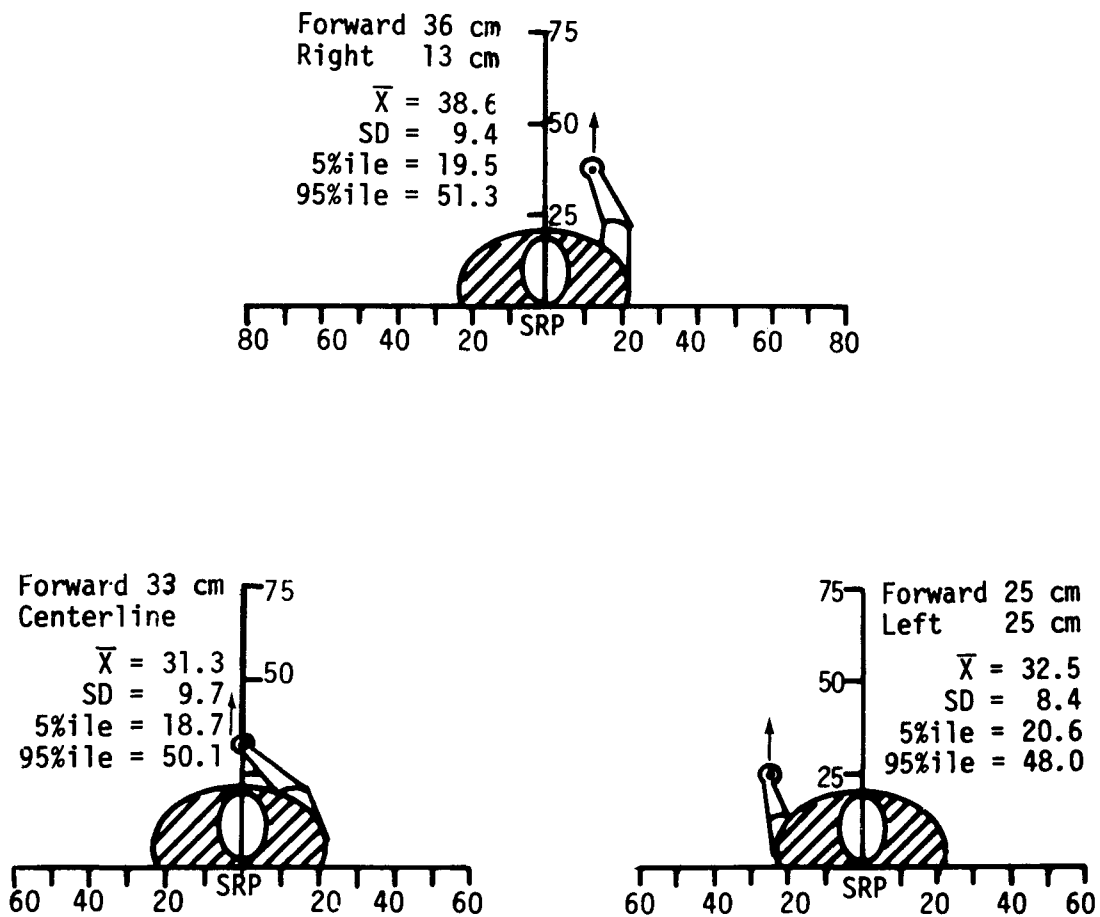


Figure 10. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 38 cm above SRP

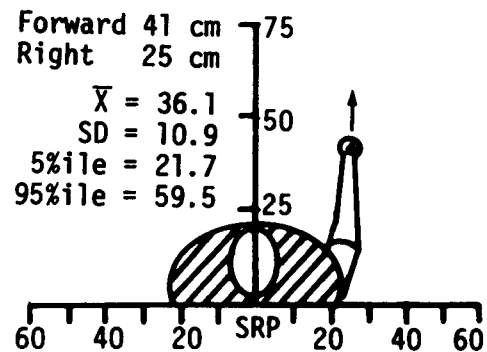
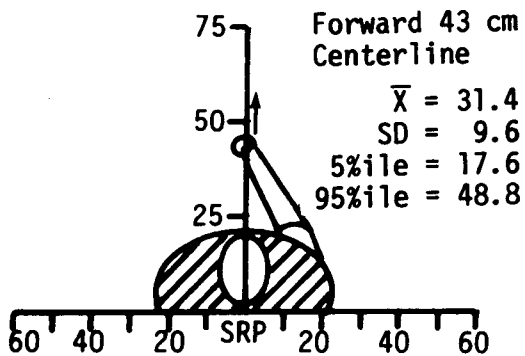
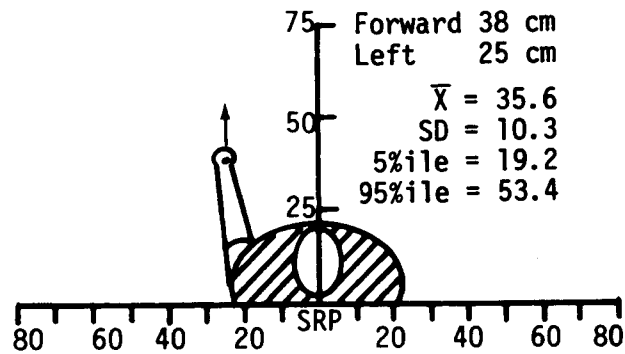


Figure 11. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 51 cm above SRP

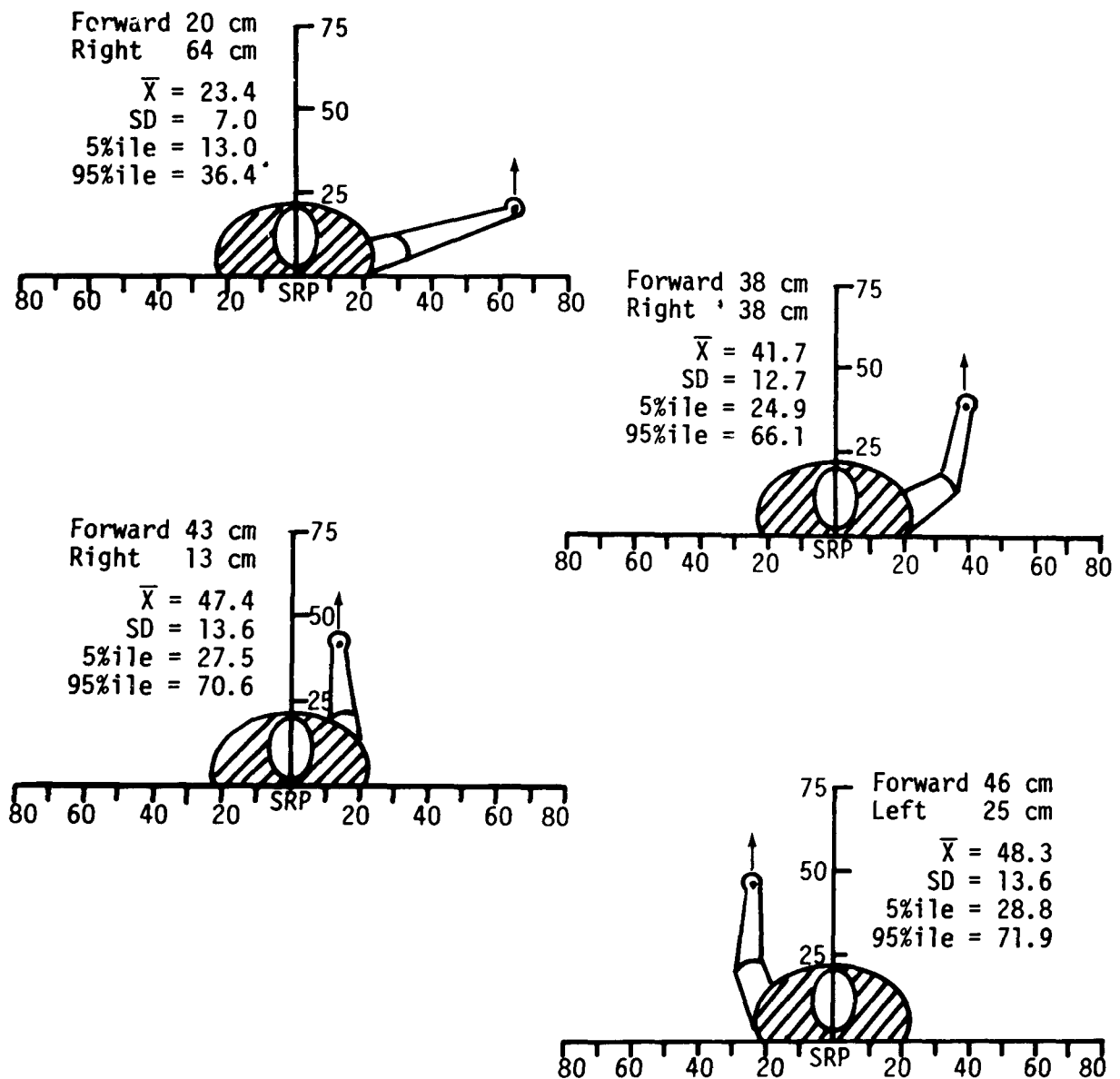


Figure 12. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 64 cm above SRP

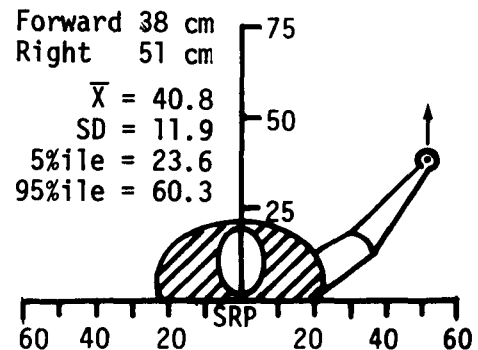
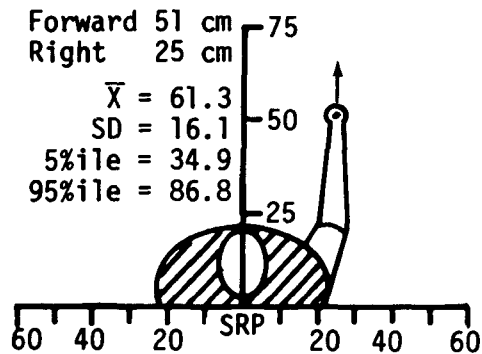
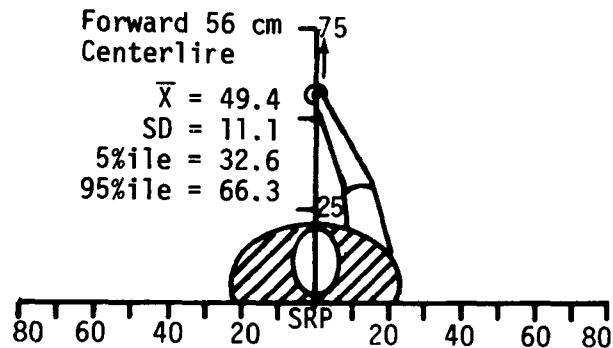
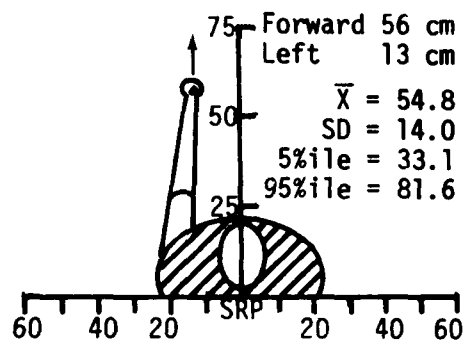
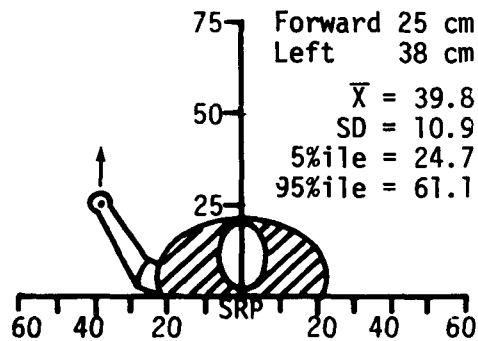


Figure 13. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 76 cm above SRP

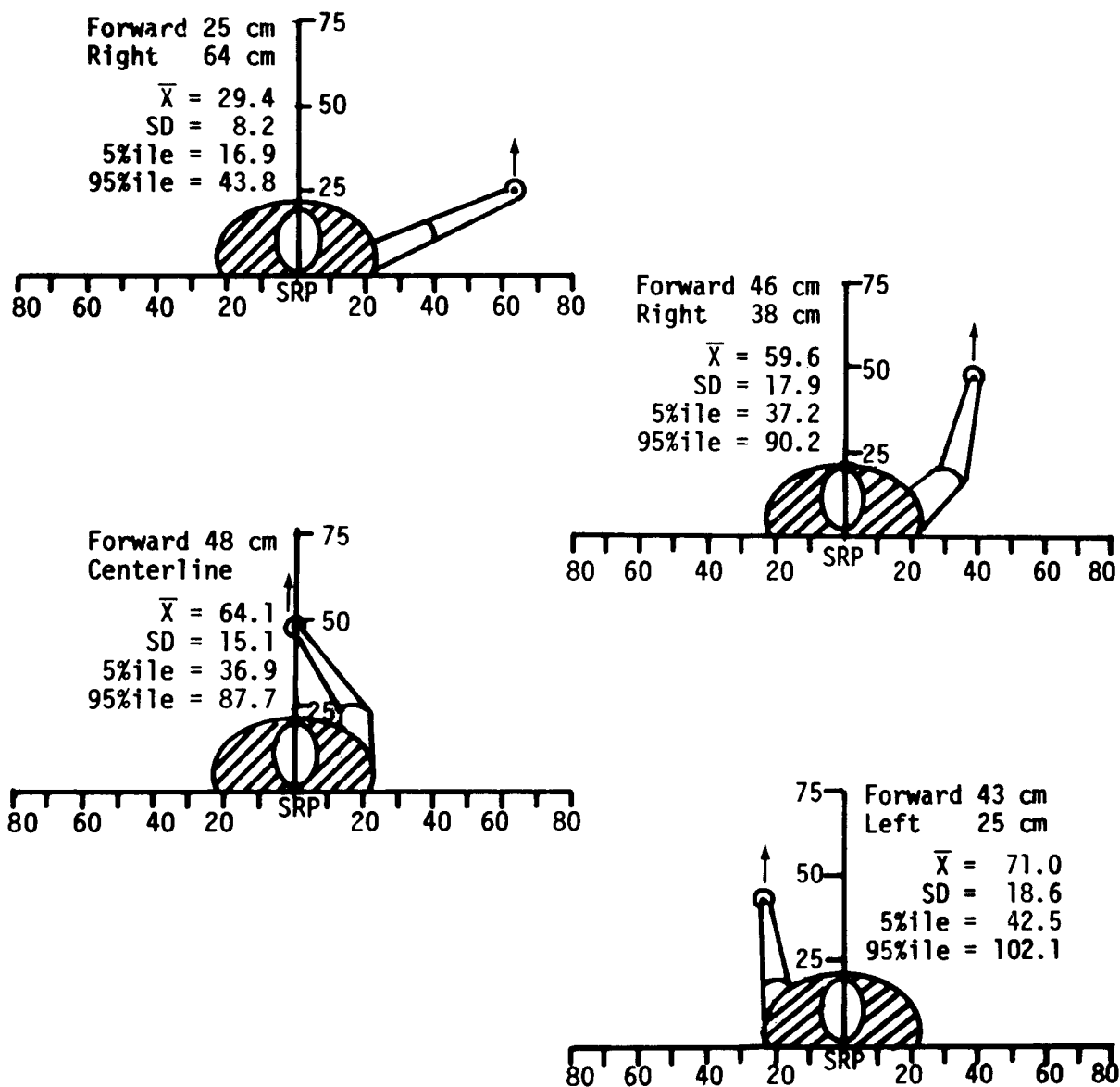


Figure 14. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 89 cm above SRP

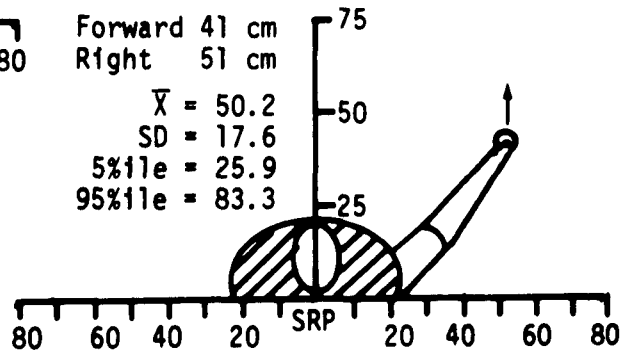
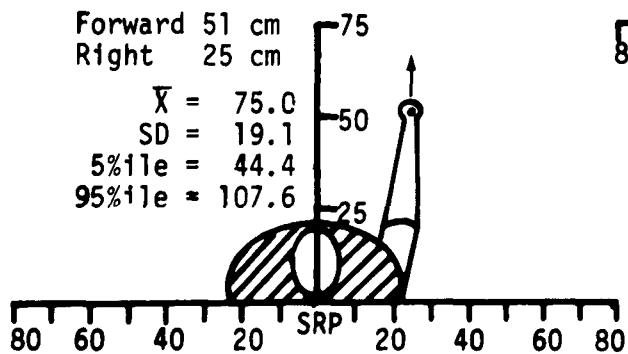
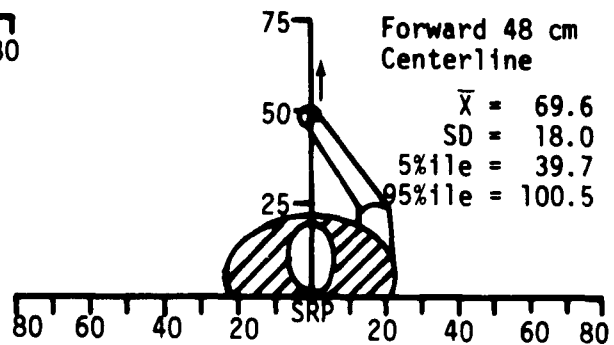
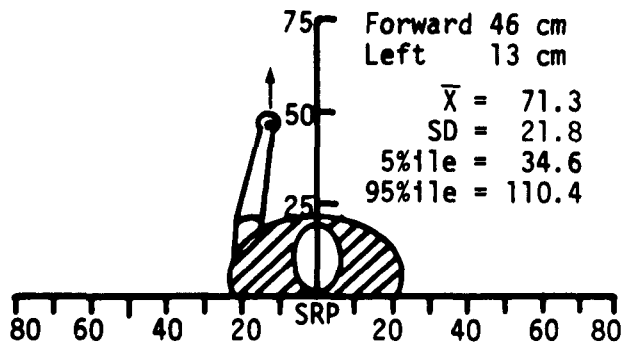


Figure 15. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 102 cm above SRP

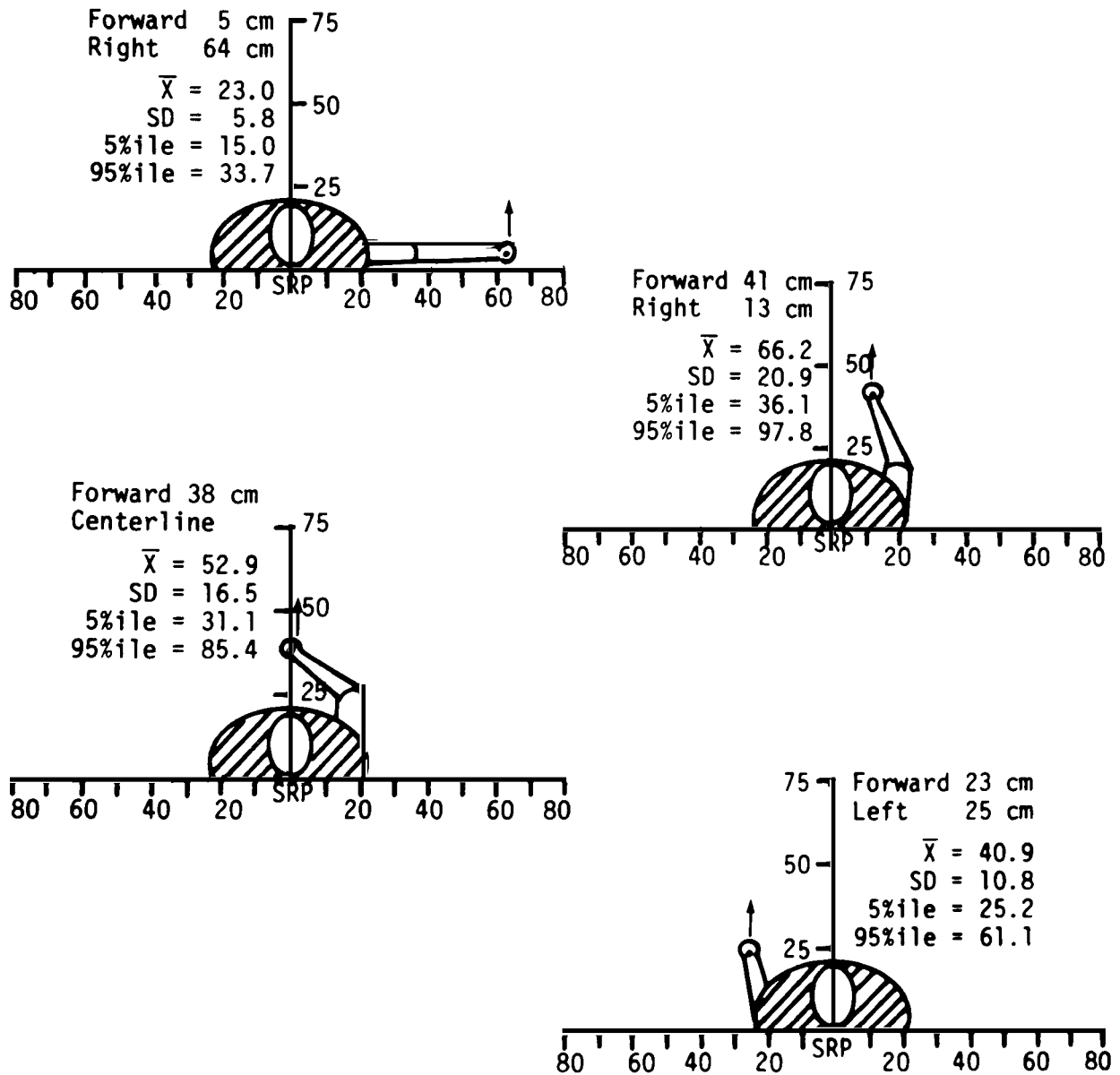


Figure 16. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

25 Degree Seat Back Angle
Handle at 114 cm above SRP

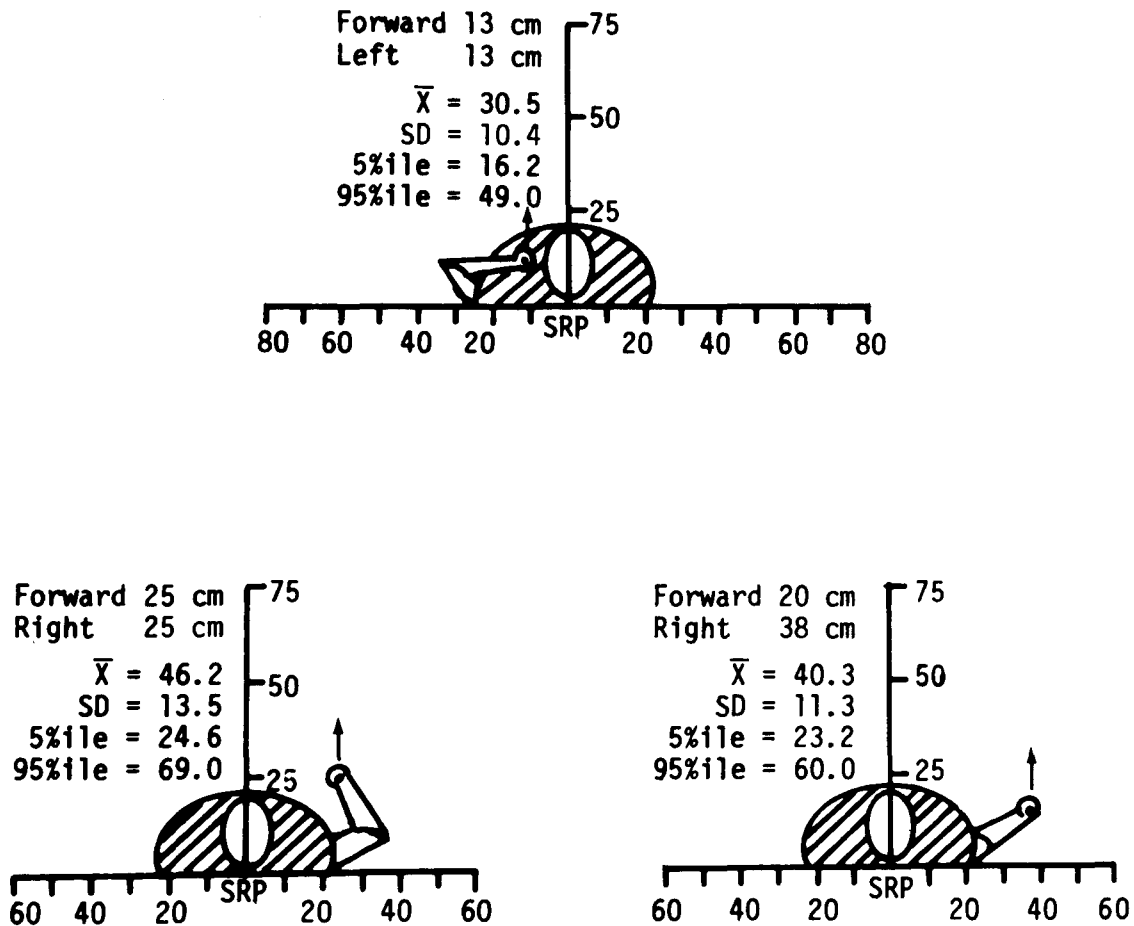


Figure 17. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

65 Degree Seat Back Angle
Handle at 38 cm above SRP

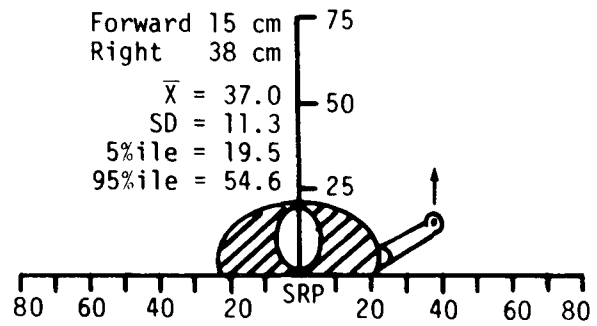
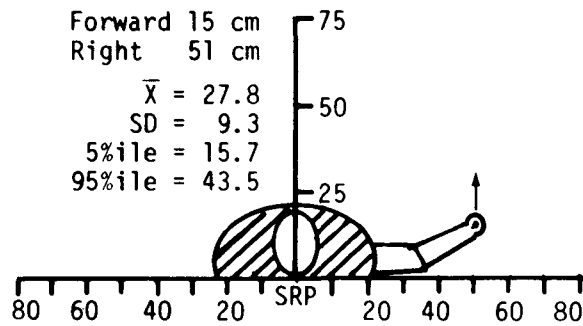


Figure 18. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

65 Degree Seat Back Angle
Handle at 51 cm above SRP

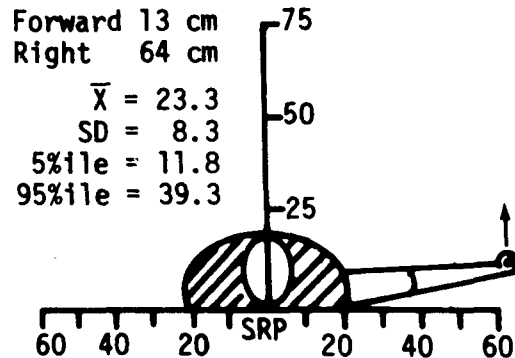
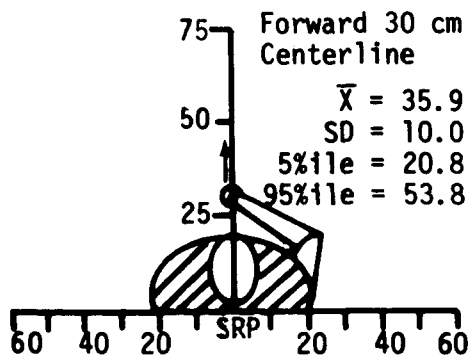
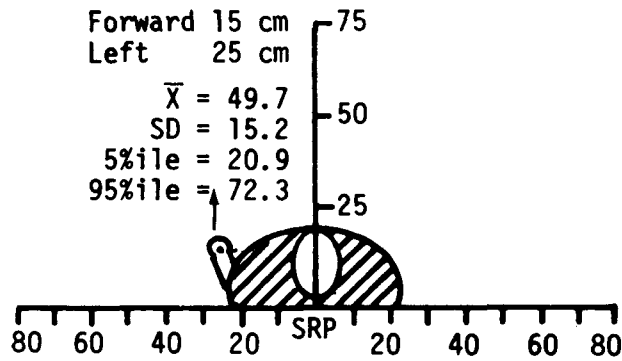


Figure 19. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

65 Degree Seat Back Angle
Handle at 64 cm above SRP

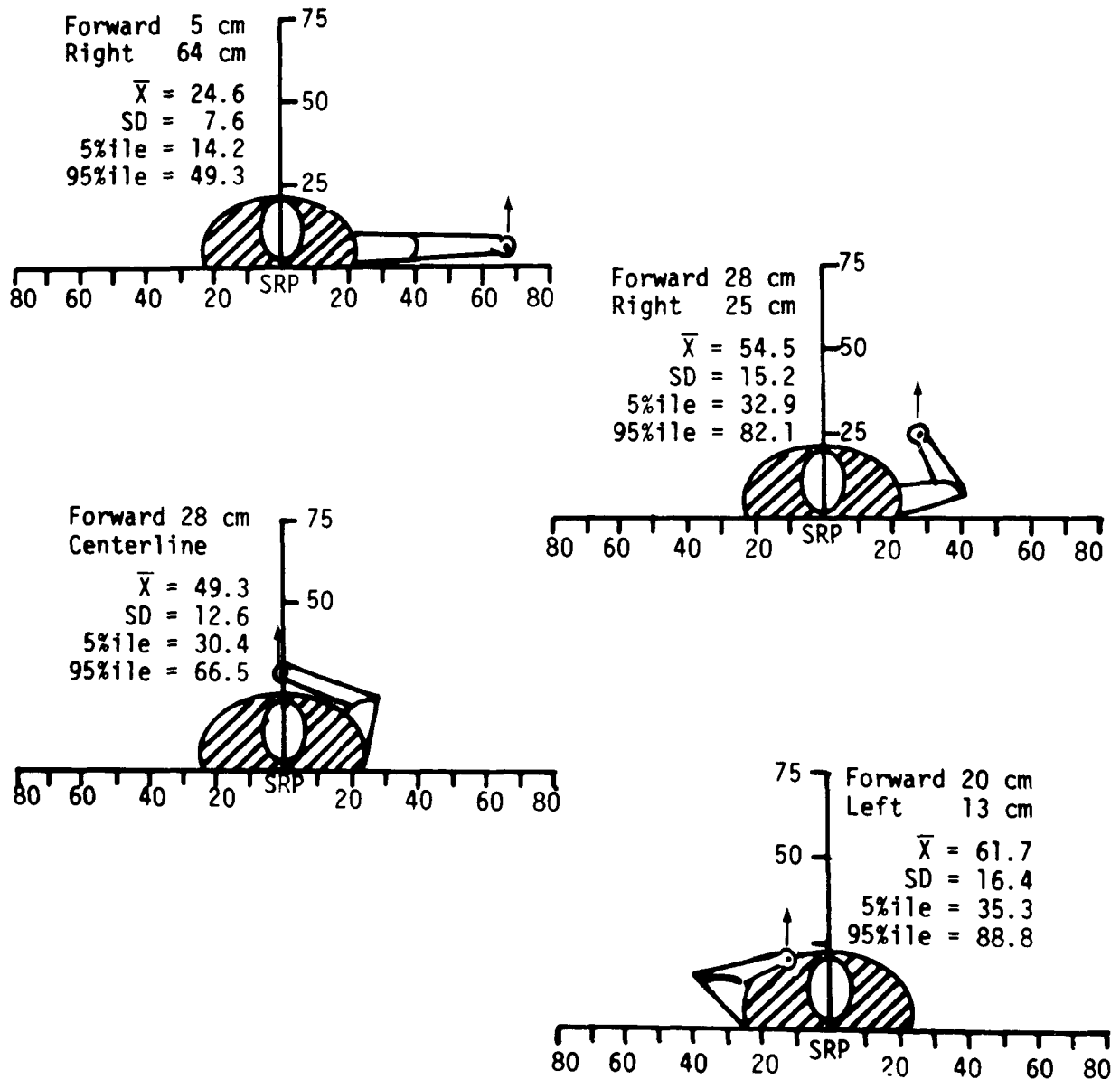


Figure 20. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

65 Degree Seat Back Angle
Handle at 76 cm above SRP

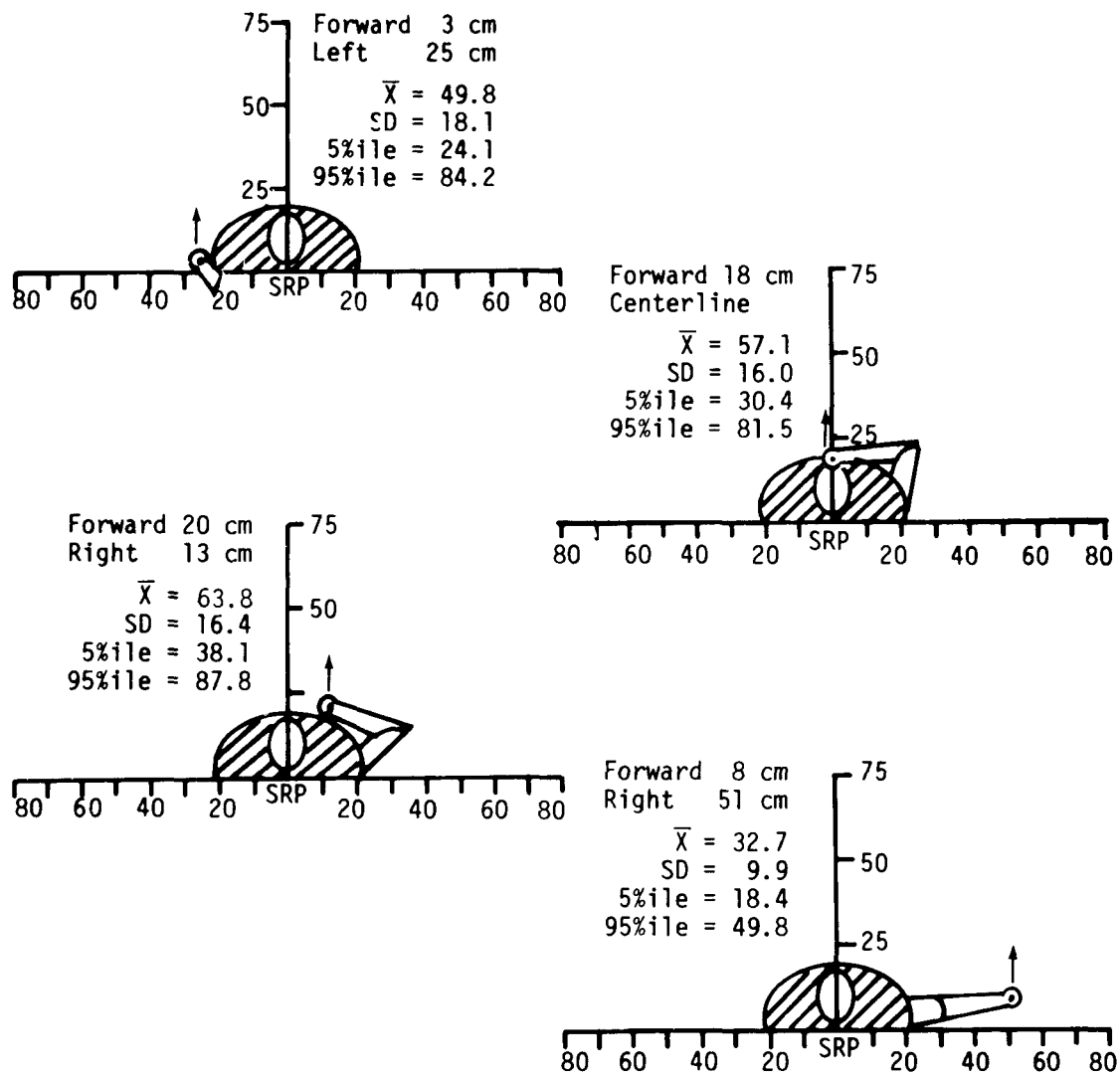


Figure 21. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

65 Degrees Seat Back Angle
Handle at 89 cm above SRP

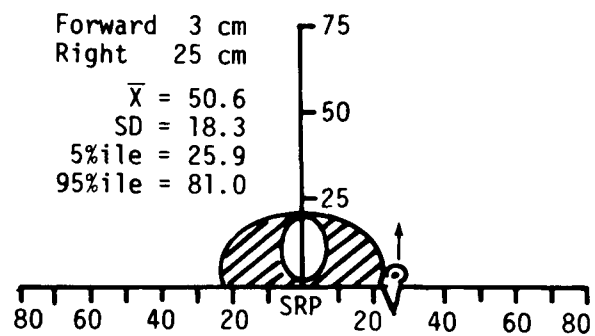
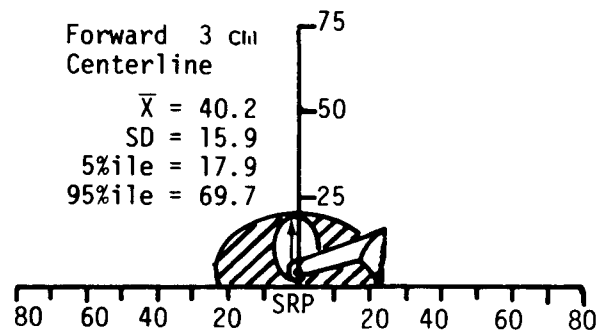


Figure 22. Force exerted on handle assembly at various locations relative to the seat reference point and seat centerline (values in kiloponds).

from approximately 70 static and dynamic strength measurements in both tabular and graphic form. Portions of this material selected for optimum usefulness to design engineers are presented here.

The relationship between muscle strength capacities of men and women is a research topic that has been under investigation since the early 1900's (Hettinger, 1961). Interest in this subject has been spurred recently in the United States by actions of the federal Occupational Health and Safety Administration in expanding opportunities for women under the impetus of the Equal Employment Opportunities Act. The National Aeronautics and Space Administration is obviously well aware of these developments with the proposed advent of female astronauts and mission payload specialists in the Space Shuttle Program.

Designers of equipment that require muscular strength capabilities for possible usage for both the male and female segment of the population tend to design around the oft-mentioned contention that "general muscle strength in women is about two-thirds that of men" (Hettinger, 1961). We will show in this section the fallacy of designing equipment capabilities around this classical two-thirds figure. Figures 23 through 46 illustrate in graphical form, the mean, ± 1 S.D., and the mean percentage of women's strength compared to men's for each measurement. As previously mentioned, readers desiring more detailed information are referred to the original sources, in this case, Laubach (1976, a and b).

Figure 47 is a summary of the data presented in Figures 23-46 and includes a calculation for "total body strength."* These values were derived by simply summing the mean percentage differences for each strength capacity and dividing by the number of measurements observed. The horizontal bar at the top indicates that the range of mean percentage differences in "total body strength" is from 35% to 86%. The average mean percentage difference (vertical line intersecting each horizontal bar) was 63.5% for "total body strength."

The major objective of Figure 47 is to emphasize the broad range of mean percentage differences that were found to exist in selected muscle strength dimensions. Figures 23 through 33, illustrating selected capabilities of the upper extremities, show that women's measurements range from 35 to 79% of men's with an average mean percentage of 55.8%. The strengths in the lower extremities (Figures 34-38) of women compared to men average 71.9% with a range of 57 to 86%. Trunk strength measurements (Figures 39-41) revealed that women averaged 63.8% of men with a range of 37 to 70%. The indicators of dynamic strength (Figures 42-46) showed that women ranged from 59 to 84% of men for an average mean percentage of 68.6%.

Laubach (1976b) has also noted that the fifth percentile value for a particular strength measurement for men often exceeds the ninety-fifth percentile value for women. This, obviously, is not the case in all situations but was found to be true in at least fifty percent of the reported

*Includes all static and dynamic measurements reported here.

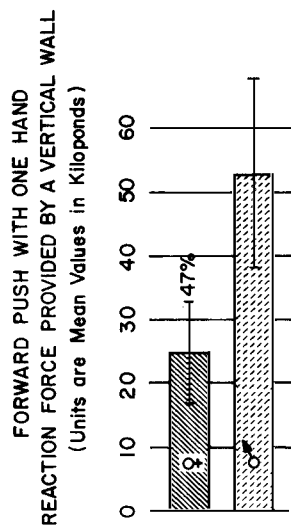
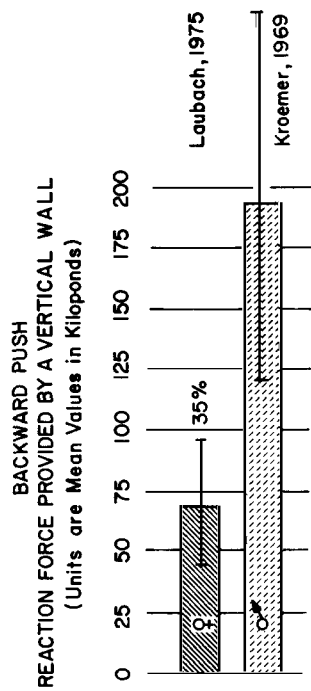


Figure 23. Female/male strength comparison: upper extremities.

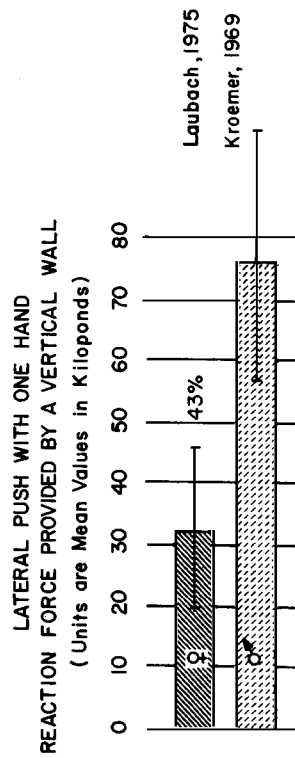
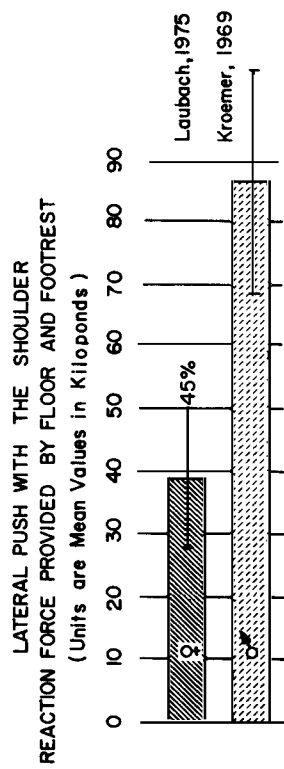


Figure 24. Female/male strength comparison: upper extremities.

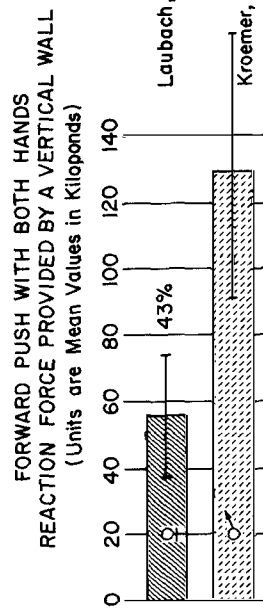
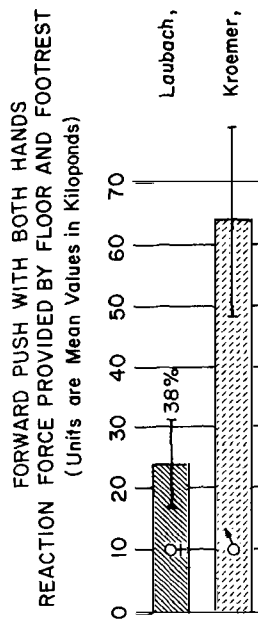


Figure 25. Female/male strength comparison: upper extremities.

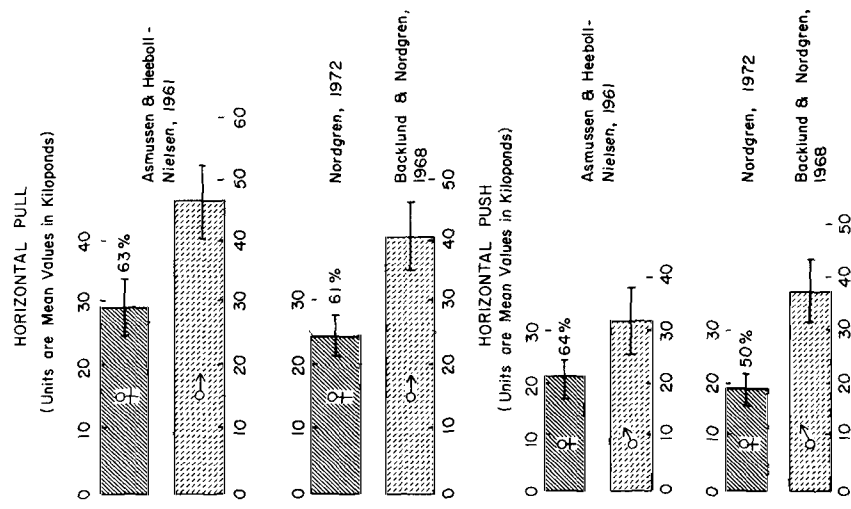


Figure 26. Female/male strength comparison: upper extremities.

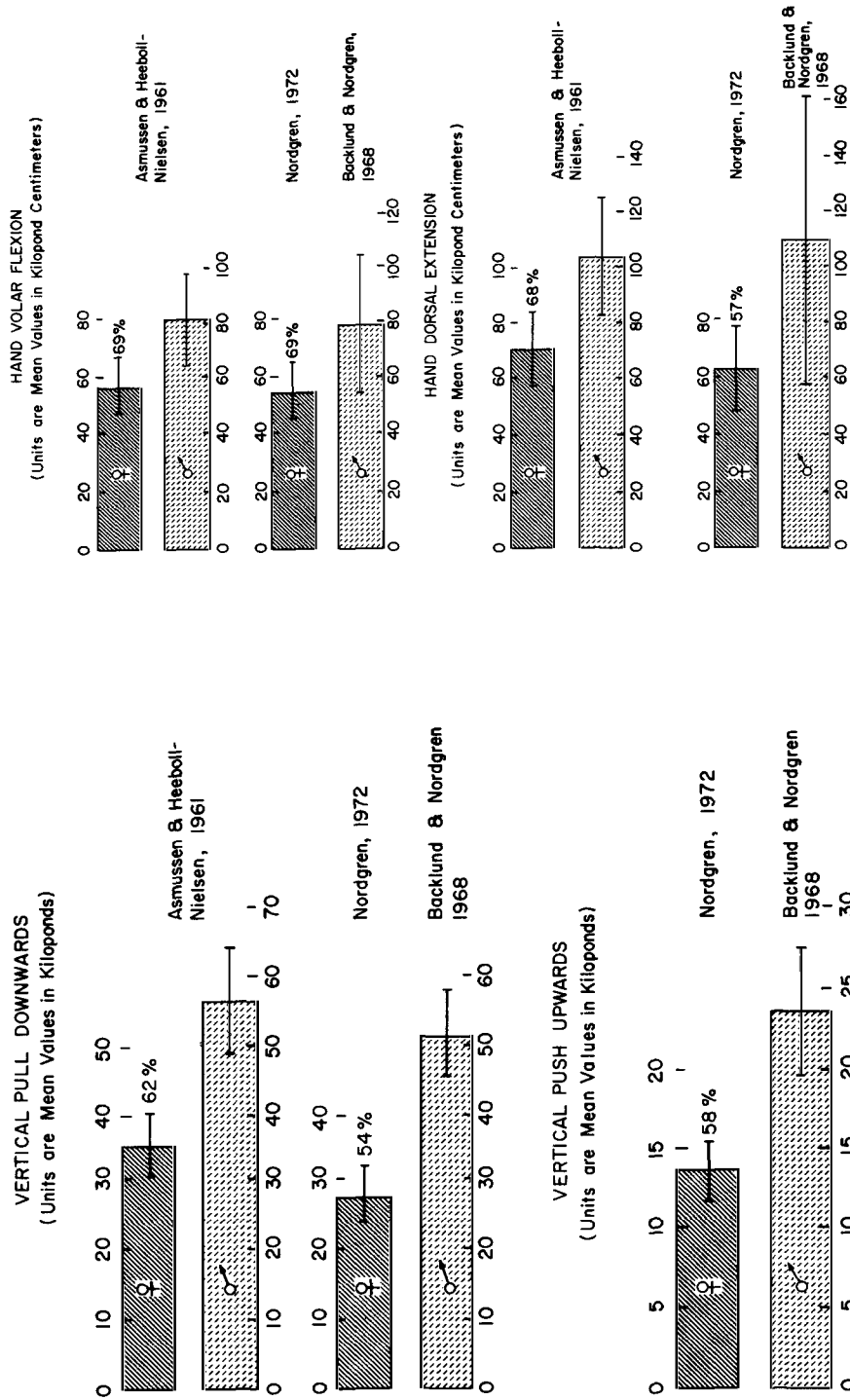
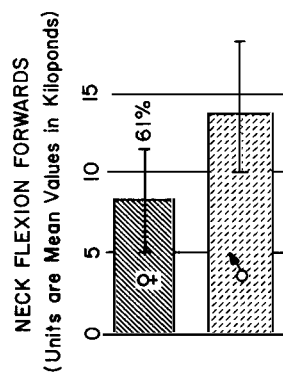


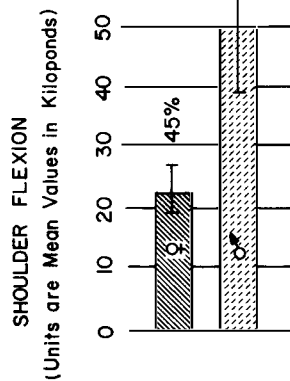
Figure 27. Female/male strength comparison: upper extremities.

Figure 28. Female/male strength comparison: upper extremities.



Nordgren, 1972

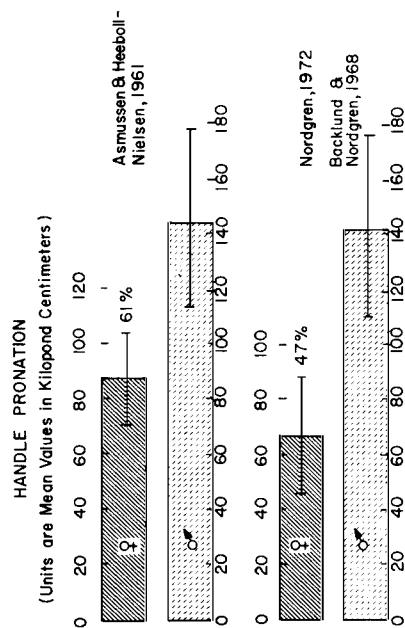
Backlund & Nordgren, 1968



Laubach, 1975

Laubach, Mc Conville, 1969

Figure 29. Female/male strength comparison: upper extremities.



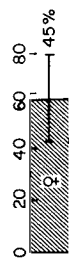
Asmusen & Heeboll-Nielsen, 1961

Nordgren, 1972

Backlund & Nordgren, 1968



Asmusen & Heeboll-Nielsen, 1961



Nordgren, 1972

Backlund & Nordgren, 1968

Figure 30. Female/male strength comparison: upper extremities.

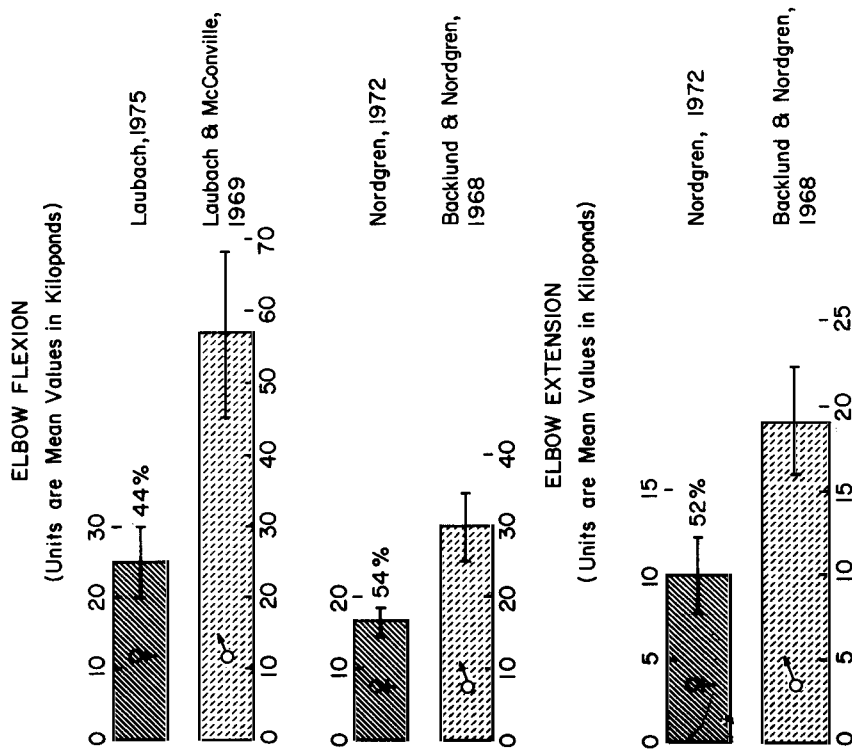


Figure 31. Female/male strength comparison: upper extremities.

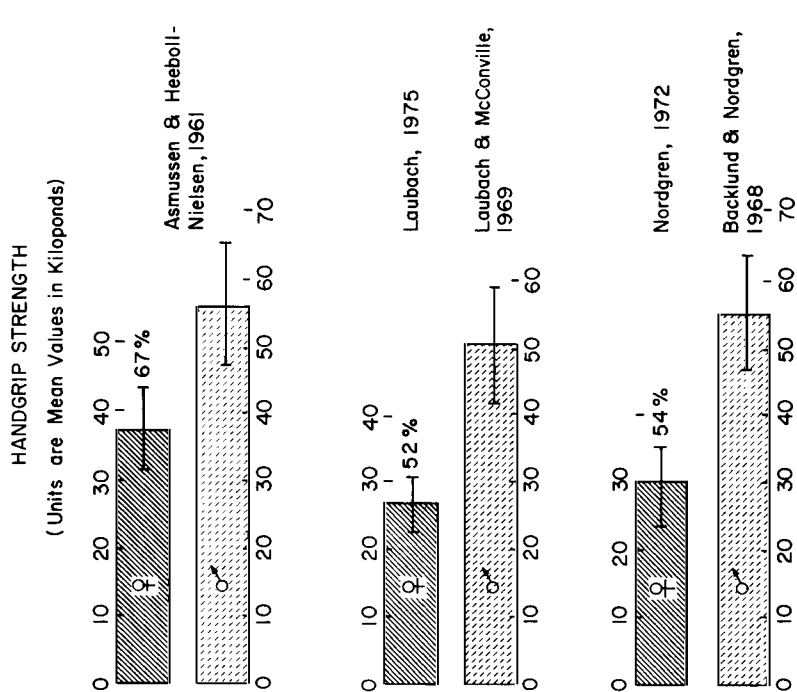


Figure 32. Female/male strength comparison: upper extremities.

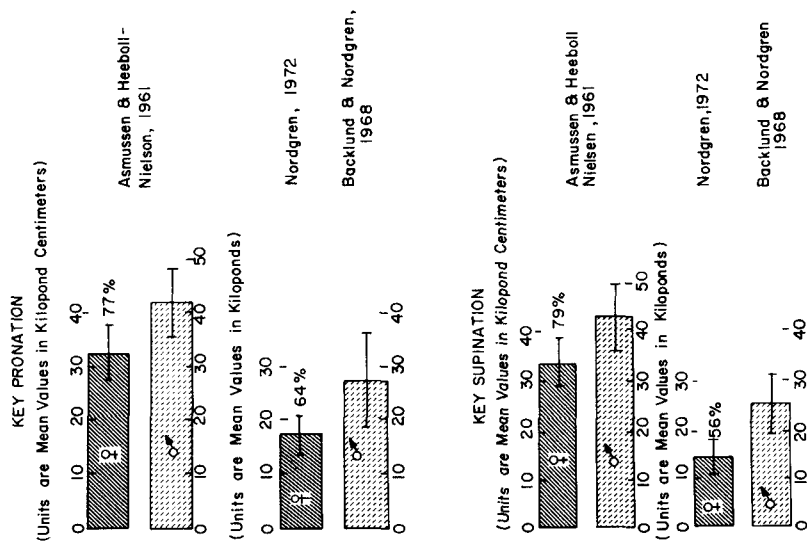


Figure 33. Female/male strength comparison:
upper extremities.

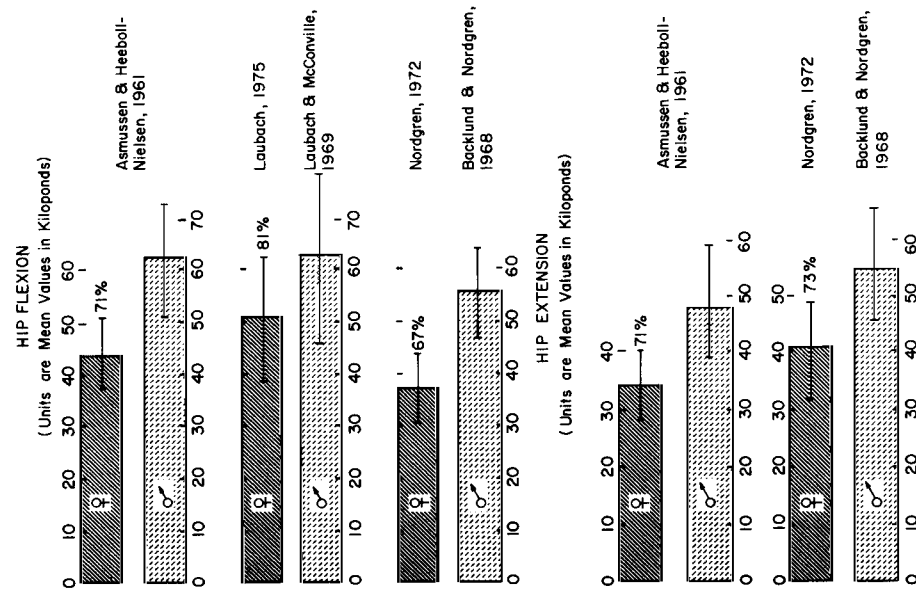


Figure 34. Female/male strength comparison: lower extremities.

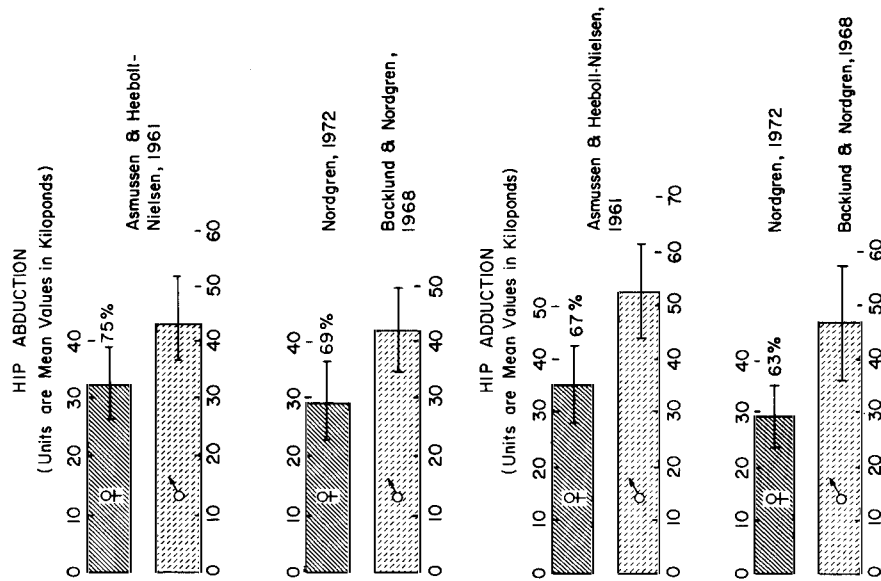


Figure 35. Female/male strength comparison: lower extremities.

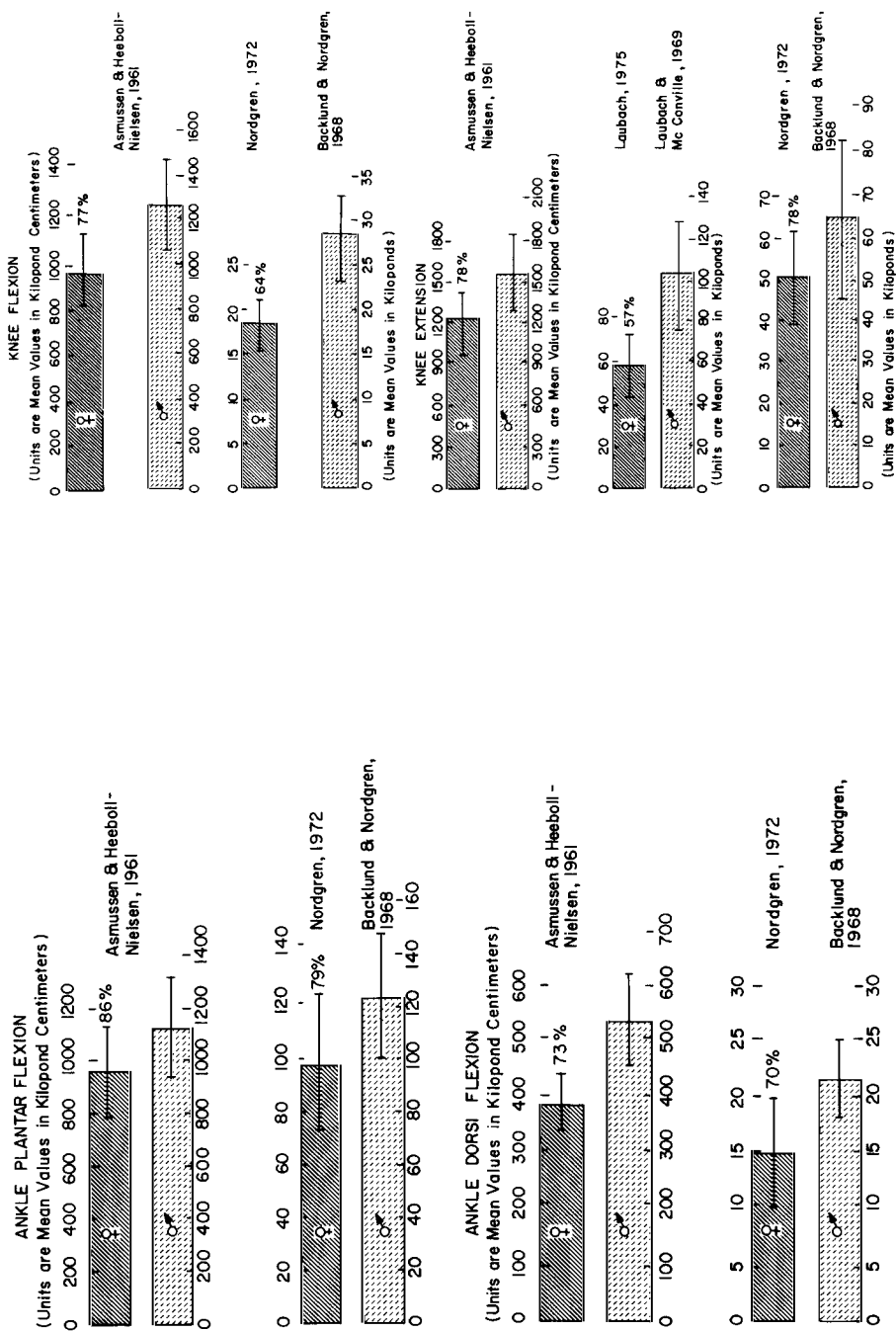


Figure 36. Female/male strength comparison: lower extremities.

Figure 37. Female/male strength comparison: lower extremities.

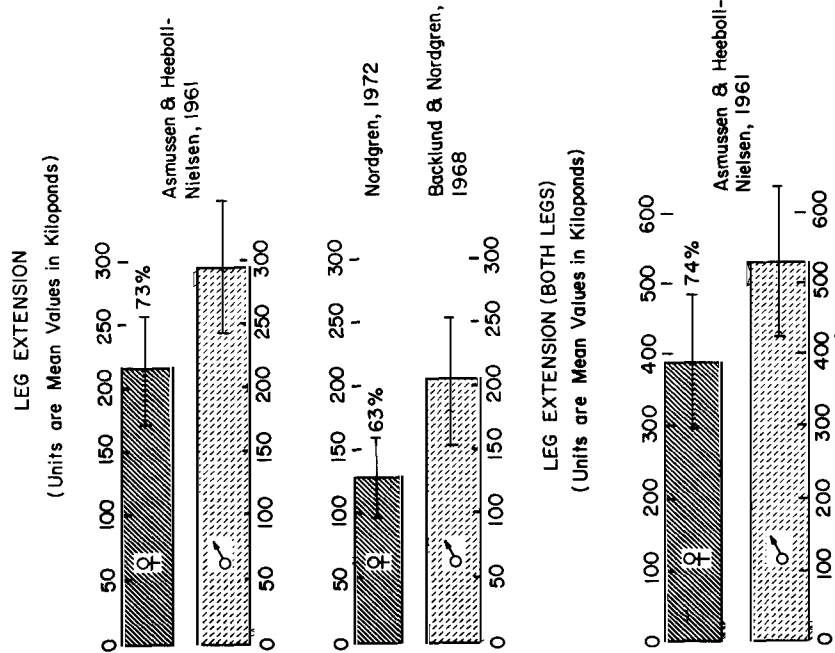


Figure 38. Female/male strength comparison: lower extremities.

TRUNK EXTENSION STRENGTH
(Units are Mean Values in Kiloponds)

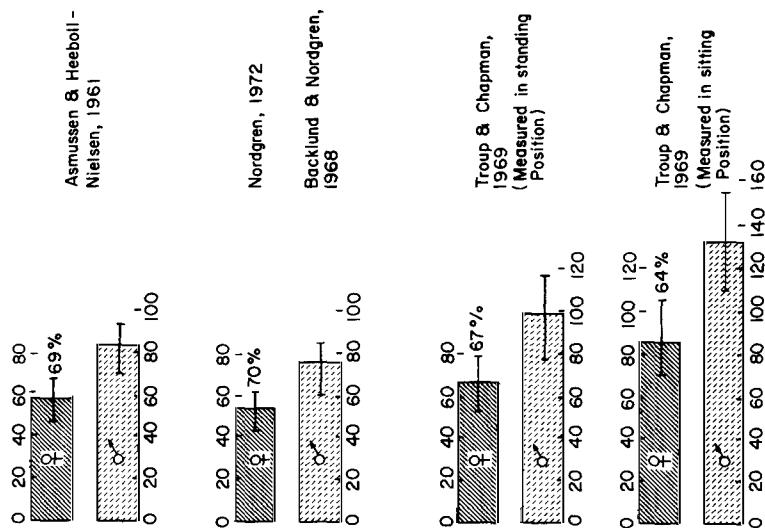


Figure 39. Female/male strength comparison: trunk.

TRUNK FLEXION STRENGTH
(Units are Mean Values in Kiloponds)

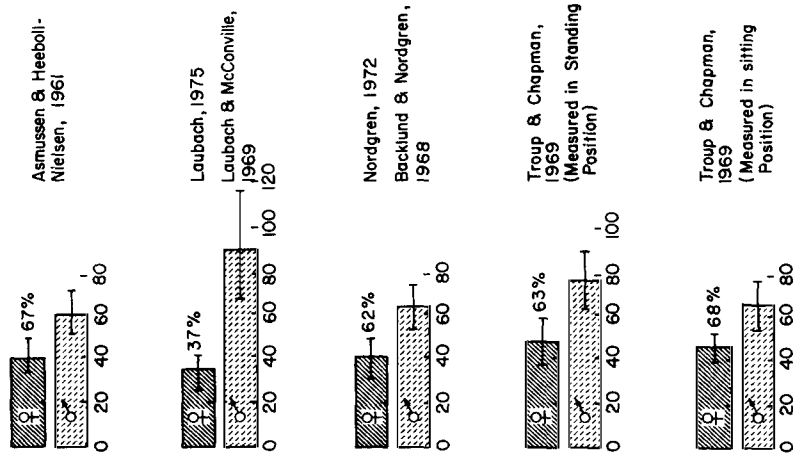


Figure 40. Female/male strength comparison: trunk.

TRUNK BENDING SIDEWAYS STRENGTH
(Units are Mean Values in Kiloponds)

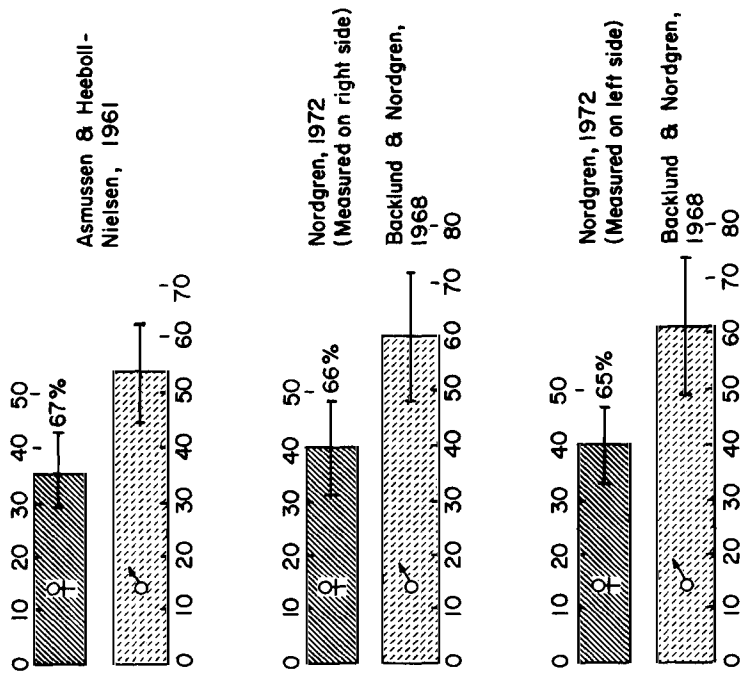
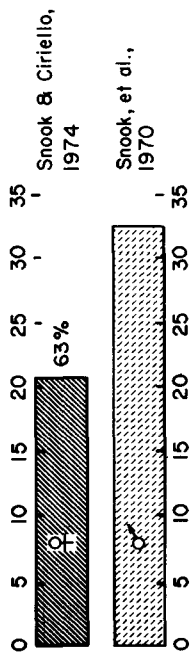
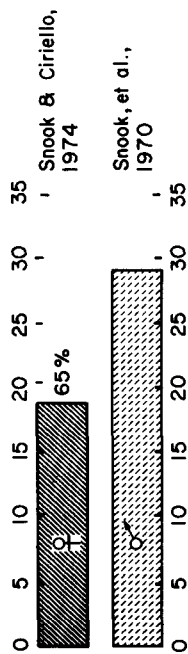


Figure 41. Female/male strength comparison: trunk.

STRAIGHT - ARM CARRY - 2.13 METERS CARRY
(Units are Median Values in Kiloponds)



STRAIGHT - ARM CARRY - 4.27 METERS CARRY
(Units are Median Values in Kiloponds)



STRAIGHT - ARM CARRY - 8.53 METERS CARRY
(Units are Median Values in Kiloponds)

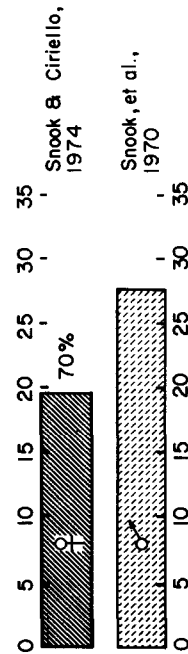
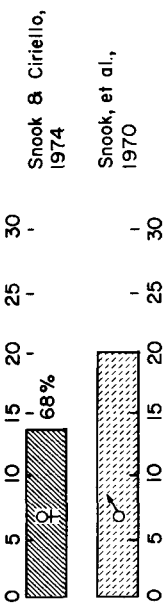
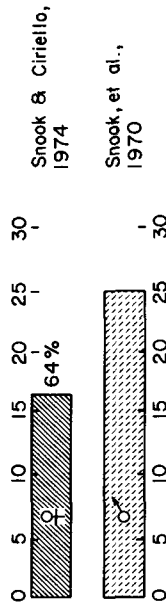


Figure 42. Female/male strength comparison: dynamic.

LOWERING - ARM REACH TO SHOULDER HEIGHT
(Units are Median Values in Kiloponds)



LOWERING - SHOULDER HEIGHT TO KNUCKLE HEIGHT
(Units are Median Values in Kiloponds)



LOWERING - KNUCKLE HEIGHT TO FLOOR LEVEL
(Units are Median Values in Kiloponds)

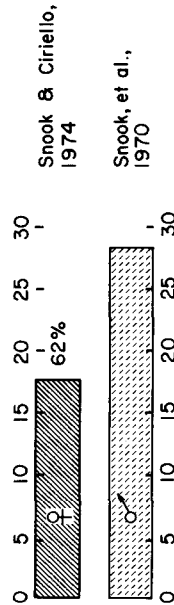


Figure 43. Female/male strength comparison: dynamic.

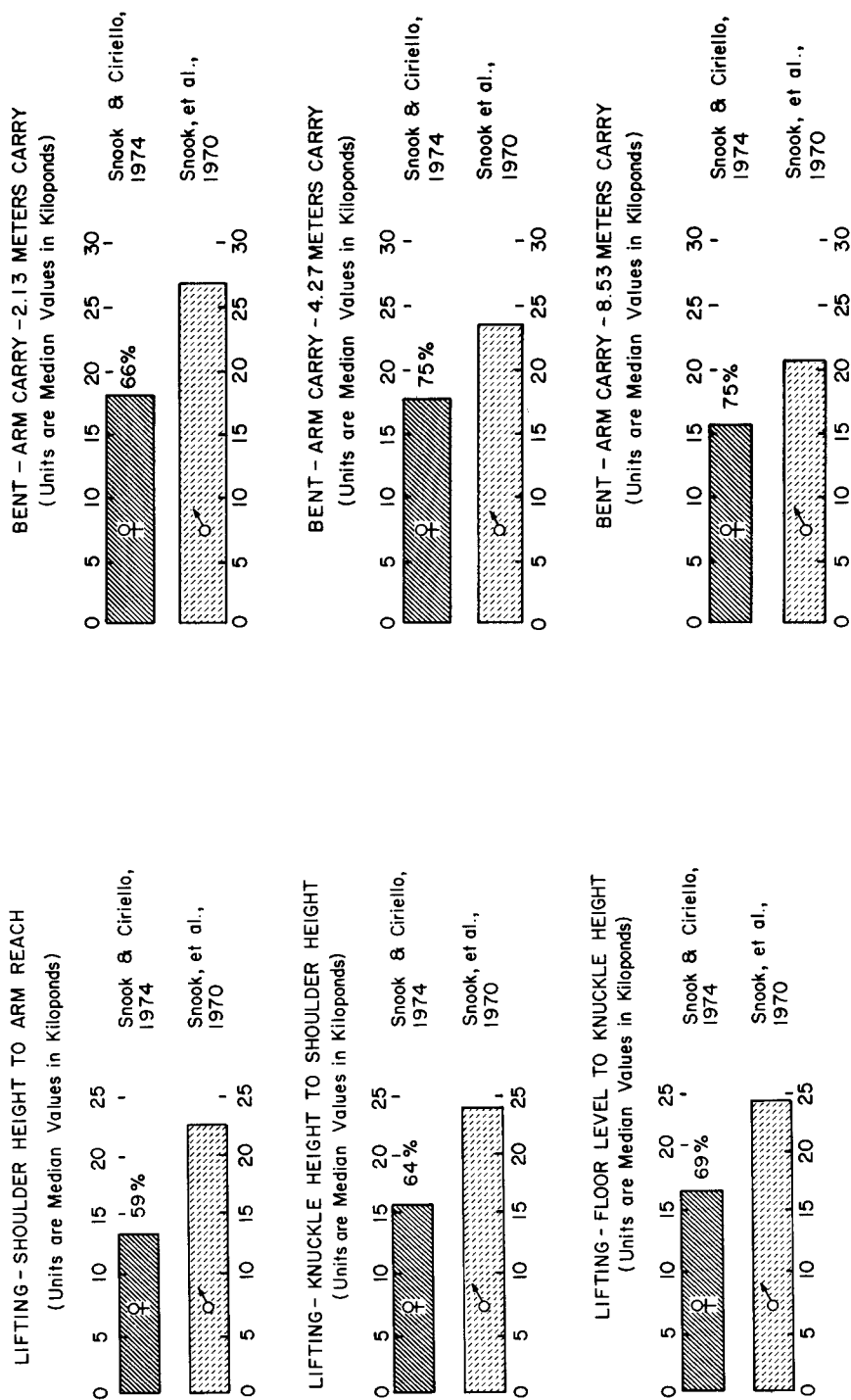


Figure 44. Female/male strength comparison: dynamic.

Figure 45. Female/male strength comparison: dynamic.

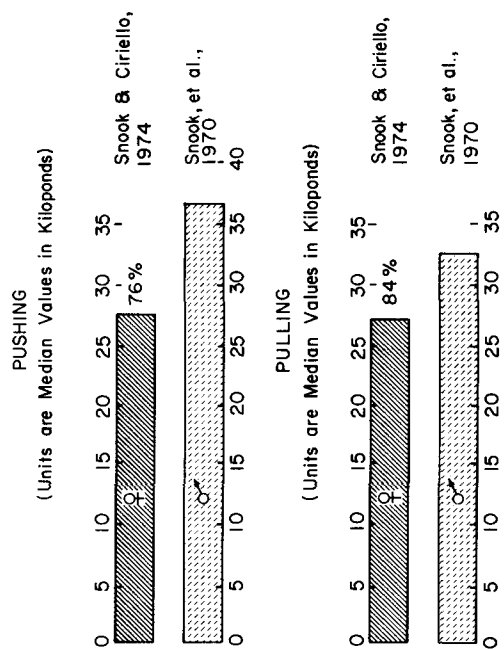


Figure 46. Female/male strength comparison: dynamic.

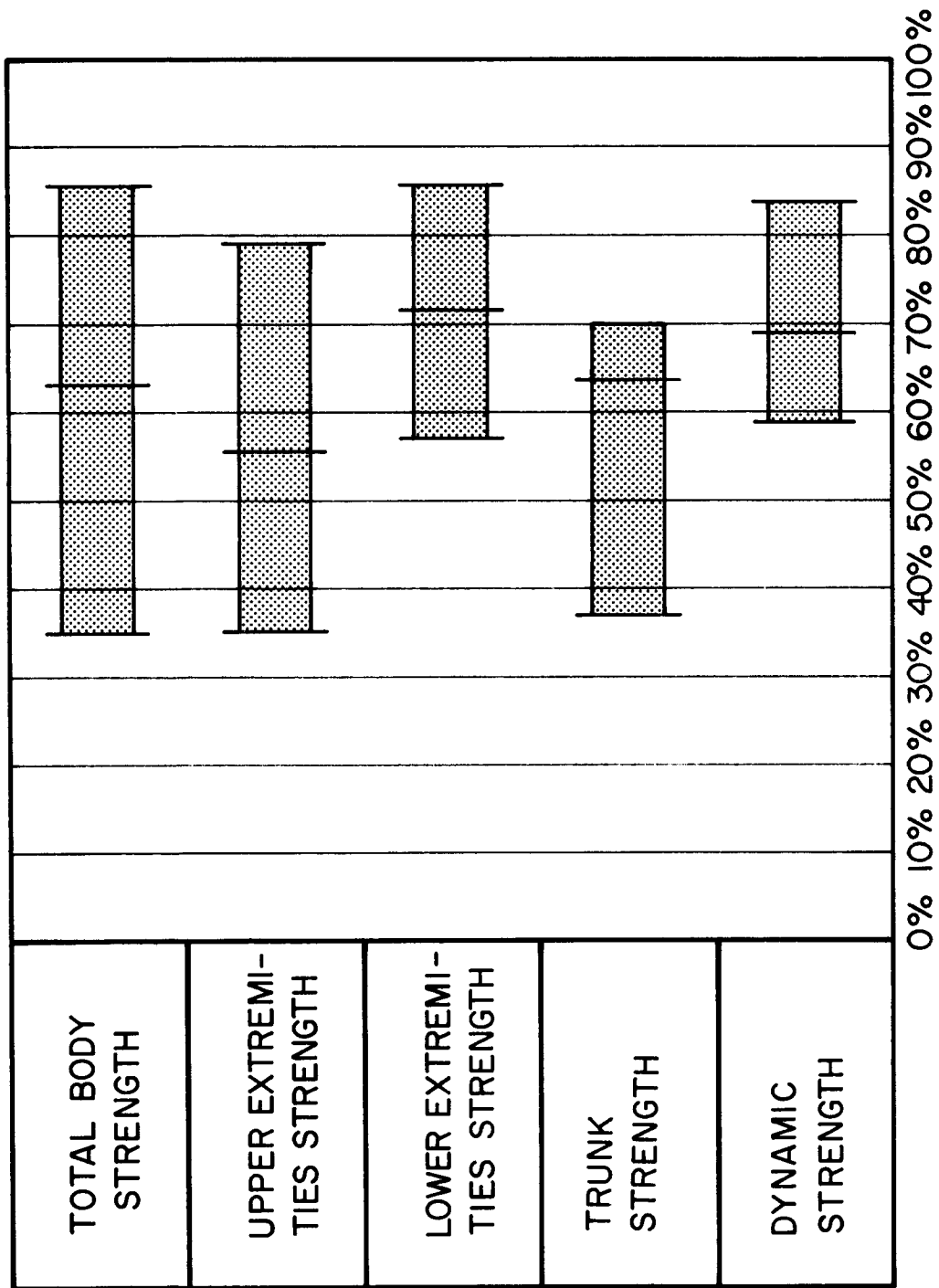


Figure 47. The range and average mean percentage differences in muscle strength characteristics between women and men.

strength data. The finding that the value obtained for a fifth percentile strength score for men in approximately fifty percent of the strength tests investigated in this research often exceeds that of the ninety-fifth percentile value for women is a precautionary reminder for engineers who often use 50th percentile values for design purposes.

In conclusion, our research would seem to substantiate that the mean percentage of women's total body strength is about 63.5% of men's total body strength. However, we believe that the emphasis should be re-focused on the broad range (from 35 to 86%) of mean percentage differences that were found to exist rather than on a single mean figure.

Because of the extreme variability in muscle strength measurements, ergonomists and design engineers should be careful in making extrapolations from muscle strength data. It is, of course, useless to suppose that such precautionary advice will prevent a designer from making estimates of female muscle strength from male data if no relevant information is available for females. To assist the designer in making such an estimate for females, Laubach (1976a) has suggested using the following statistical procedure for computing the often-used criteria of the fifth percentile:

- (1) Select a test item from Figures 23-46 that most closely approximates the strength movement for which you have available data, e.g., if the movement approximates a horizontal pull (Figure 26) measurements as described by Asmussen and Heeboll-Neilsen (1961), use the percentage difference of 63 in your calculations.
- (2) Assume that the data you have obtained from your sample of male subjects yield a mean value of 50 kiloponds (kp) with a standard deviation of 10 kiloponds.
- (3) To calculate the estimated fifth percentile value for men, multiply 1.65 times 10 kp (S.D.) to give 16.5 kp. Subtract 16.5 kp from 50 kp (mean) to give 33.5 kp for the estimated fifth percentile value for men.
- (4) Take the fifth percentile value for men, 33.5, and multiply by the percentile difference, 63, to give 21.1 kp for the estimated fifth percentile values for females.

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ADDITIONAL DATA SOURCES

The following documents are not readily available because of limited distribution (unpublished or preliminary data). However, copies/information may be obtained by contacting the author/source.

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