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MUSCULAR STRENGTH OF WOMEN AND MEN: A COMPARATIVE STUDY

UNIVERSITY OF DAYTON RESEARCH INSTITUTE
300 COLLEGE PARK AVENUE
DAYTON, OHIO 45469

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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NOTICES

TECHNICAL REVIEW AND APPROVAL

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments were conducted to measure static muscular strength characteristics of women subjects and compare these results with similar data previously reported for males. Twelve measures of static muscular strength, 22 body-size measurements, and the somatotypes of 31 female subjects were investigated. Selected reports in the literature that have dealt with the comparison of static and dynamic muscular strength of women and men are presented and discussed in some detail. The summary descriptive

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statistics for the strength measures were compared (tabularly and graphically) and percentage differences in strength between women and men reported. An analysis of the range and the average mean percentage difference in muscular strength capabilities is presented. The complete intercorrelation matrix for the 38 variables (including age) obtained in this research is shown.

PREFACE

This study was prepared for the University of Dayton Research Institute, 300 College Park Avenue, Dayton, Ohio under Air Force Contract No. F33615-74-C-5116 for the Human Engineering Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

Dr. Lloyd L. Laubach, Yellow Springs, Ohio served as the principal investigator for this research.

The author would like to thank the following people. Ms. Nancy Teepen contributed to the success of this investigation in her role of collecting the experimental portions of the data. Dr. K. H. E. Kroemer and Dr. J. T. McConville assisted in developing selected aspects of the research techniques. Dr. Paul Webb provided access to the research data and lent administrative support. Mr. C. E. Clauser served as the contract monitor and critically reviewed the manuscript.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF TABLES

SECTION I

INTRODUCTION

This report presents muscular strength data that was obtained from a group of young women. The data gathered in this study were compared with similar muscle strength data that had previously been obtained from a group of young men (Kroemer, 1969, and Laubach and McConville, 1969).

Selected reports in the literature that have dealt with the comparison of static and dynamic muscular strength of women and men are presented and discussed in some detail--both tabularly and graphically.

The primary purpose of this study is to present comparative muscular strength capabilities of women and men.

SECTION II

Methods and Procedures

Cable Tension and Hand Grip Strength Measurements.

The cable tension and hand grip strength measurements were selected to duplicate similar measurements on males reported by Laubach and McConville (1969). Five cable tension tests of body strength were conducted. These tests included the flexion of shoulder, elbow, hip, and trunk; and extension of the knee. The cable tension strength tests were administered with a calibrated cable tensiometer in accordance with the techniques described by Clarke and Clarke (1963). The reader requesting specific information about test techniques is referred to Clarke and Clarke (1963, pp. 73-96). Hand grip strength was measured with the Smedley adjustable hand dynamometer. The strength score used for the cable tension and hand grip strength measurements was the maximum amount of force (without jerking) that the subject could exert against the pulling assembly.*

Horizontal Push Forces Exertable in Common Standing Positions.

This portion of the study attempted to duplicate previously reported research on males conducted by Kroemer (1969). Kroemer conducted experiments to measure the maximum isometric horizontal push forces exertable in 65 common working positions. His subjects were 45 male college students who, while pushing horizontally, either anchored their feet against a footrest

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* The subjects were instructed to apply the maximum force possible using a constant pull. The observer noted the movement on the needle on the dial of the cable tensiometer and encouraged the subject to continue pulling until the obvious peak force had been achieved. The observer then instructed the subject to relax. The peak force was then recorded from the maximum reading indicator.

or braced themselves against a vertical wall.

The equipment, experimental conditions, and the procedures reported by Kroemer were used, with minor modifications, on our sample of 31 female college subjects. Readers desiring a more detailed explanation of the above are referred to Kromer (1969). The test positions chosen for this study are briefly described in the paragraphs below.

The first test position investigated in the horizontal push forces series was entitled Forward Push with Both Hands--Reaction Force Provided by Floor and Footrest. The height of the center of the push panel was adjusted to 70% of the subject's acromial height.* The horizontal distance between the push panel and the footrest was also adjusted to 70% of the subject's acromial height. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 12, Trial No. 1.7.

The second test position selected for study was entitled Lateral Push with the Shoulder--Reaction Force Provided by Floor and Footrest. The height of the center of the push panel was adjusted to 60% of the subject's acromial height. The horizontal distance between the push panel and the footrest was adjusted to 80% of the subject's acromial height. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 16, Trial No. 2.8.

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*The push panel was adjusted to <u>individual</u> body dimensions rather than to given absolute measures.

The third test position was entitled Forward Push with Both Hands--Reaction Force Provided by a Vertical Wall. The height of the center of the push panel was adjusted to 100% of the subject's acromial height. The horizontal distance between the push panel and the wall was adjusted to 80% of the subject's thumb-tip reach. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 20, Trial No. 3.4.

The fourth test position in this series was a Backward Push--Reaction Force Provided by a Vertical Wall. The height of the center of the push panel was adjusted to 40% of the subject's acromial height. The horizontal distance between the push panel and the wall was adjusted to 80% of the subject's thumb-tip reach. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 32, Trial No. 6.1.

The fifth test position was entitled Lateral Push with One Hand--Reaction Force Provided by a Vertical Wall. The height of the center of the push panel was adjusted to 100% of the subject's acromial height. The horizontal distance between the push panel and the wall was adjusted to 80% of the subject's lateral thumb-tip reach. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 40, Trial No. 8.4.

The sixth and final test position in the horizontal push force series was entitled Forward Push with One Hand--Reaction Force Provided by a Vertical Wall. The height of the center of the push panel was adjusted to 100% of the subject's acromial height. The horizontal distance between the push panel and the wall was adjusted to 80% of the subject's thumb-tip reach. For more specific information concerning this test position, the reader is referred to Kroemer (1969), p. 48, Trial No. 10.4.

Each subject was told to exert a maximum push force steadily over a period of 5 seconds and that short-time peak (jerking) forces were not desired. The strength score was obtained by calculating the mean of the forces applied over seconds 2, 3, and 4 of the exertion.

Review of Comparative Muscle Strength Related Literature.

In our survey of the literature we have chosen to report selected published studies that pertain to comparable muscle strength characteristics of women and men. Tables 4, 5, 6, and 7 along with Figures 13-53 summarize the results of these findings. Table 8 summarizes the age, height, and weight characteristics along with the number of subjects in each of the studies shown in Tables 2-7.

The testing techniques for measuring muscular strength varied somewhat between each of the reported studies. However, the direct comparative data for the women and the men (e.g., see Table 4 - Nordgren, 1972 and Backlund and Nordgren, 1968) were assessed using identical testing techniques. For the reader who is interested in the procedures used by each of the investigators, the complete bibliographical citation is listed in the References at the end of this report.

SECTION III

SUBJECTS

The 31 female subjects used in this study, all volunteers paid for their participation, were from either the University of Dayton, Dayton, Ohio (n=28) or the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio (n=3). Subjects suspected of a physical deformity and/or an organic deficiency were excluded from the study.

On each subject 21 direct anthropometric dimensions plus four derived anthropometric dimensions were obtained; also noted were age and handedness. The anthropometric dimensions were measured according to the techniques and methods described by Clauser, et al., 1972.

Table 1 lists the descriptions of the study sample as compared with the 1968 USAF anthropometric survey of Air Force Women (Clauser, et al., 1972).

TABLE 1

CHARACTERISTICS OF THE STUDY SAMPLE AS COMPARED WITH THE 1968 USAF SURVEY OF AIR FORCE WOMEN

		This Study n=31		1968 Air Force Women n=1905	
Dimension	Unit	Mean	S.D.	Mean	S.D.
Age	Years	20.7	1.9	23.4	6.5
Weight	kg	58.4	6.6	57.7	7.5
Stature	cm	165.0	6.0	162.1	6.0
Acromial Height	cm	134.4	5.2	131.9	5.5
Sitting Height	cm	86.9	2.8	85.6	3.2
Tibiale Height	cm	44.0	2.0	42.0	2.4
Lateral Malleolus Height	cm	6.5	0.5	6.8	0.6
Thumb-Tip Reach	cm	71.7	2.9	74.1	3.9
Lateral Thumb-Tip Reach	cm	96.7	3.8		
Acromiale-Radiale Length	cm	27.9	1.5	31.0	1.6
Radiale-Stylion Length	cm	20.6	1.2	23.4	1.4
Hand Length	cm	17.2	0.7	18.4	1.0
Biceps Circumference, Relaxed	cm	25.3	1.7	25.6	2.3
Biceps Circumference, Flexed	cm	26.3	1.5	26.8	2.3
Forearm Circumference, Relaxed	cm	23.2	1.1	23.5	1.4
Calf Circumference	cm	34.6	2.3	34.1	2.3
Humerus Breadth	cm	6.2	0.3	6.1	0.3
Femur Breadth	cm	8.8	0.4	8.1	0.5
Skinfold:Triceps	mm	16.3	3.9	19.0	5.4
Skinfold:Subscapular	mm	13.6	4.7	12.9	4.8
Skinfold:Suprailiac	mm	17.9	3.2	19.7	7.0
Skinfold:Medial Calf	mm	18.4	4.2	15.9	5.2
Endomorphy*		4.8	0.8		
Mesomorphy*		3.5	1.0		
Ectomorphy*		2.6	1.0		
Leg Length**	cm	78.1	4.2		
Handedness--Right	%	90		89	
--Left	%	10		9	

* The somatotype components of endomorphy, mesomorphy, and ectomorphy were computed using the procedure described by Heath and Carter, 1967.

** Leg length was derived by simply subtracting sitting height from stature.

SECTION IV

RESULTS

The major results of this study are presented in both tabular and graphical form. Table 2 presents selected descriptive statistics including the mean, standard deviation, coefficient of variation, skewness, kurtosis and the estimated fifth and ninety-fifth percentiles* for each of the five cable-tension muscle strength measurements plus hand grip strength. Following Table 2 are Figures 1-6 which graphically depict the data shown in Table 2. Also illustrated in Figures 1-6 are the percentage differences in muscular strength capabilities that were found to exist between women and men; e.g., Figure 1 the fifth percentile shoulder flexion strength value for women was 16.3 kiloponds while for men this value was 31.3 kiloponds or a percentage difference of 52%. Table 3 shows the same set of descriptive statistics as in Table 2 for the push force values obtained from women and men. Figures 7-12 graphically depict the data shown in Table 3 and are to be interpreted in the same manner as Figures 1-6. Table 4 is a summary table of static muscular strength data that have been located in the research literature that allow us to make comparisons of the strength of the upper extremities of women and men. Tables 4, 5 and 6 are identical in design and list the mean, standard deviation, the mean percentage difference of strength capabilities of women and men, and the reference as to where the data

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* See discussion on calculation of percentiles in Appendix II.

were obtained. Figures 13-26 graphically depict the data presented in Table 4. Also included in the appropriate Figures 13-26 are comparative data that have previously been presented in Table 2. Table 5 and Figures 27-36 are illustrations of static strength assessments of the lower limbs. Table 5 and Figures 27-36 are to be interpreted in the same manner as Table 4 and Figures 13-26. Table 6 and Figures 37-39 are examples of static strength measures of the trunk. Their interpretation is the same as Tables 3 and 4 and Figures 13-36. Table 7 and Figures 40-53 present dynamic strength measurements. Table 7 lists the <u>median</u> value instead of the mean value as has been previously shown in Tables 4, 5, and 6. Therein lies the only difference in interpreting Table 7 and Figures 40-53 from the previously presented data. Table 8 is a summary table of the subject characteristics that have been used for comparative purposes in developing Tables 4-7 and Figures 13-53.

The complete intercorrelation matrix for all the variables presented in Table 1 and the muscle strength measurements for women in Tables 2 and 3 is presented in Appendix I.

The computations of the statistical measures follow the procedures and techniques described by Churchill (Clauser, et al., 1972). Appendix II presents a brief discussion of the statistical procedures and the formulas used in this report.

TABLE 2

A COMPARISON OF CABLE TENSION STRENGTH VALUES OBTAINED FROM WOMEN AND MEN

Variable	Sex	Mean	S.D.	C.V.%	β_1	β_2	5%ile	95%ile
SHOULDER FLEXION	F	22.6	3.8	16.8	0.5	2.8	16.3	28.9
	M	50.1	11.4	22.8			31.3	68.9
ELBOW FLEXION	F	25.2	4.8	19.0	0.7	3.7	17.3	33.1
	M	57.2	11.6	20.3			38.1	76.3
HIP FLEXION	F	50.9	11.9	23.4	1.3	4.4	31.3	70.5
	M	62.6	16.3	26.0			35.7	89.5
KNEE EXTENSION	F	58.8	15.2	25.9	0.1	2.3	33.7	83.9
	M	102.8	25.7	25.0			60.4	145.2
TRUNK FLEXION	F	33.8	8.8	26.0	0.3	2.4	19.3	48.3
	M	90.9	24.3	26.7			50.8	131.0
GRIP STRENGTH	F	26.4	3.8	14.4	0.8	3.6	20.1	32.7
	M	50.4	8.8	17.5			35.9	64.9

The data reported for the females were obtained in this study. The comparative data for males came from Laubach and McConville, 1969. Strength values are reported in kiloponds. Grip Strength was measured with the Smedley hand dynamometer.

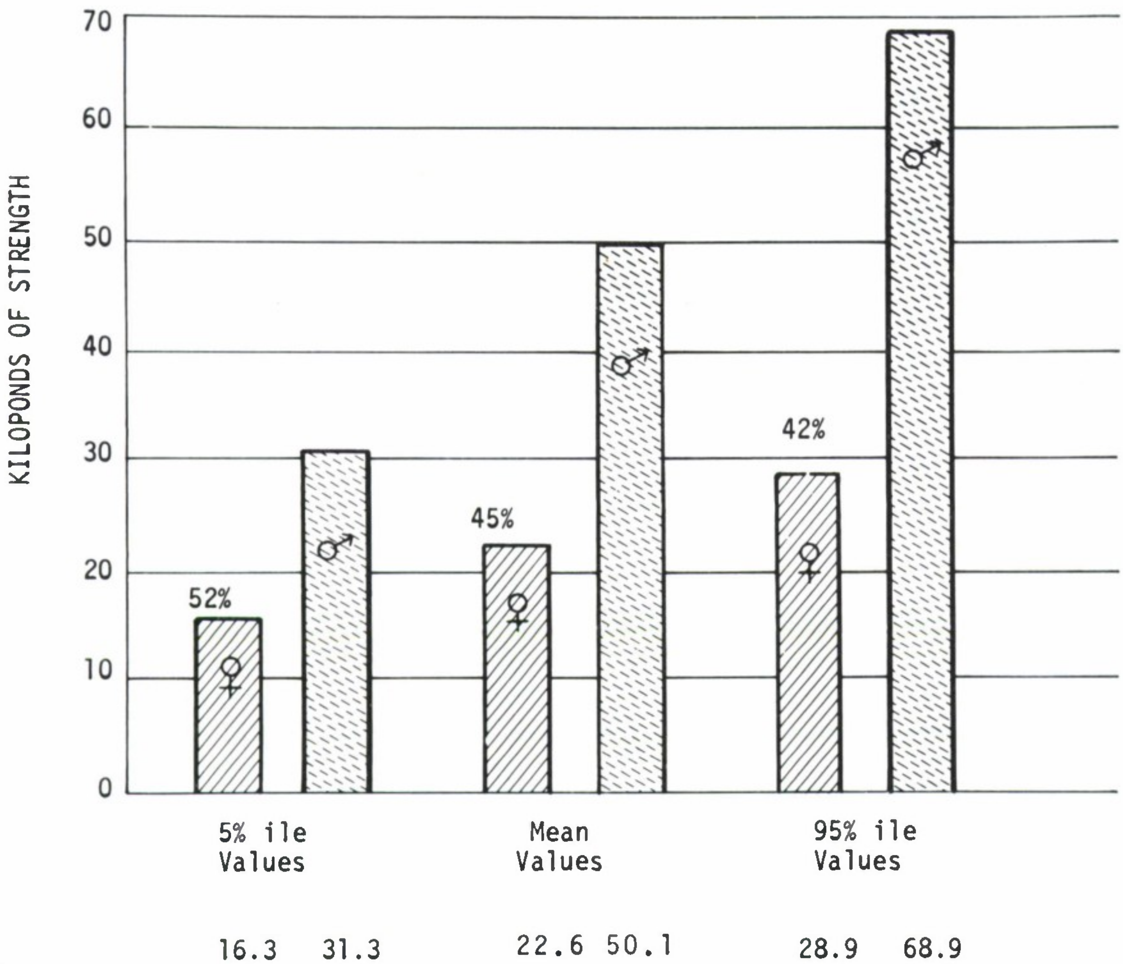


Figure 1. SHOULDER FLEXION

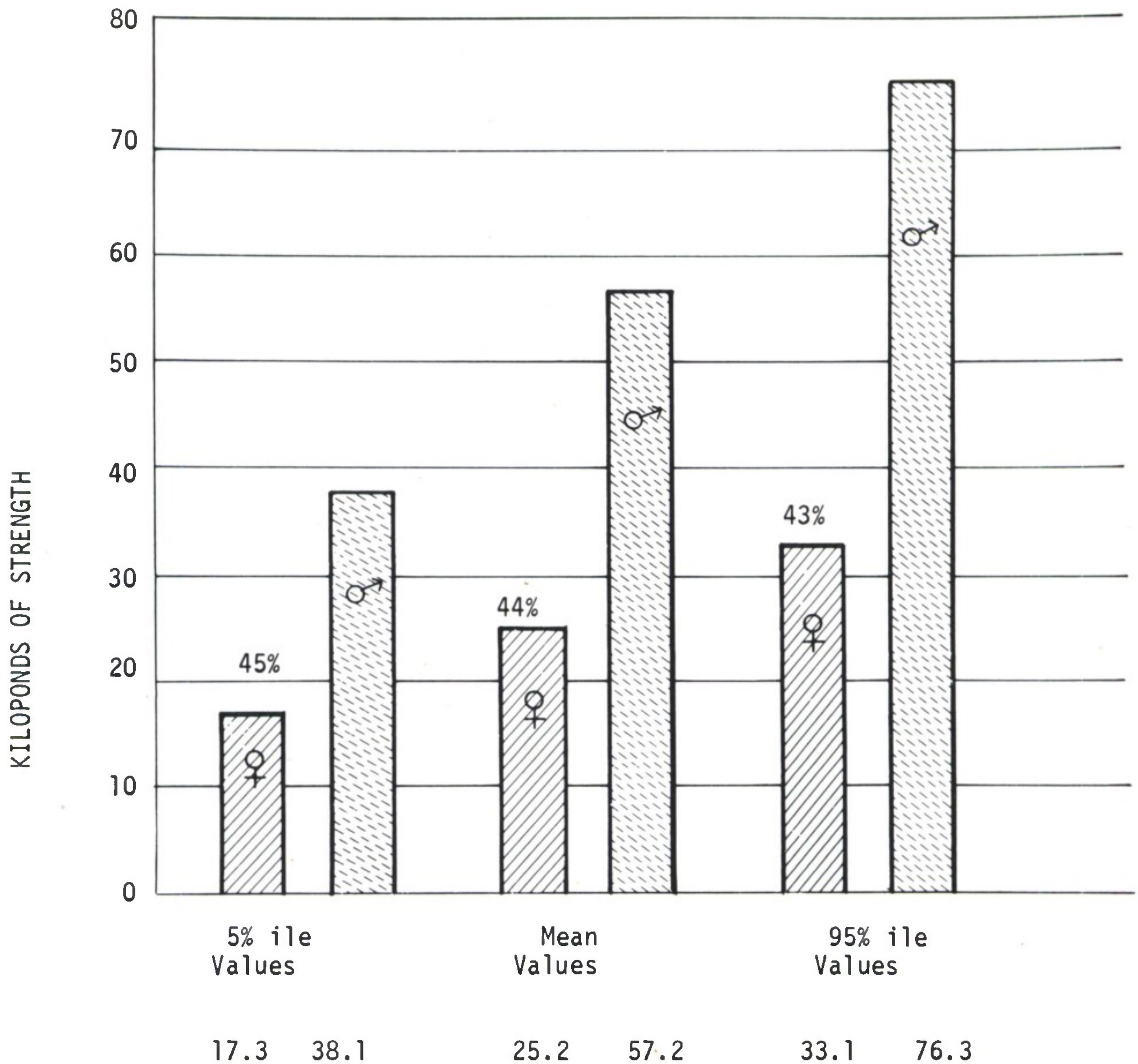


Figure 2. ELBOW FLEXION

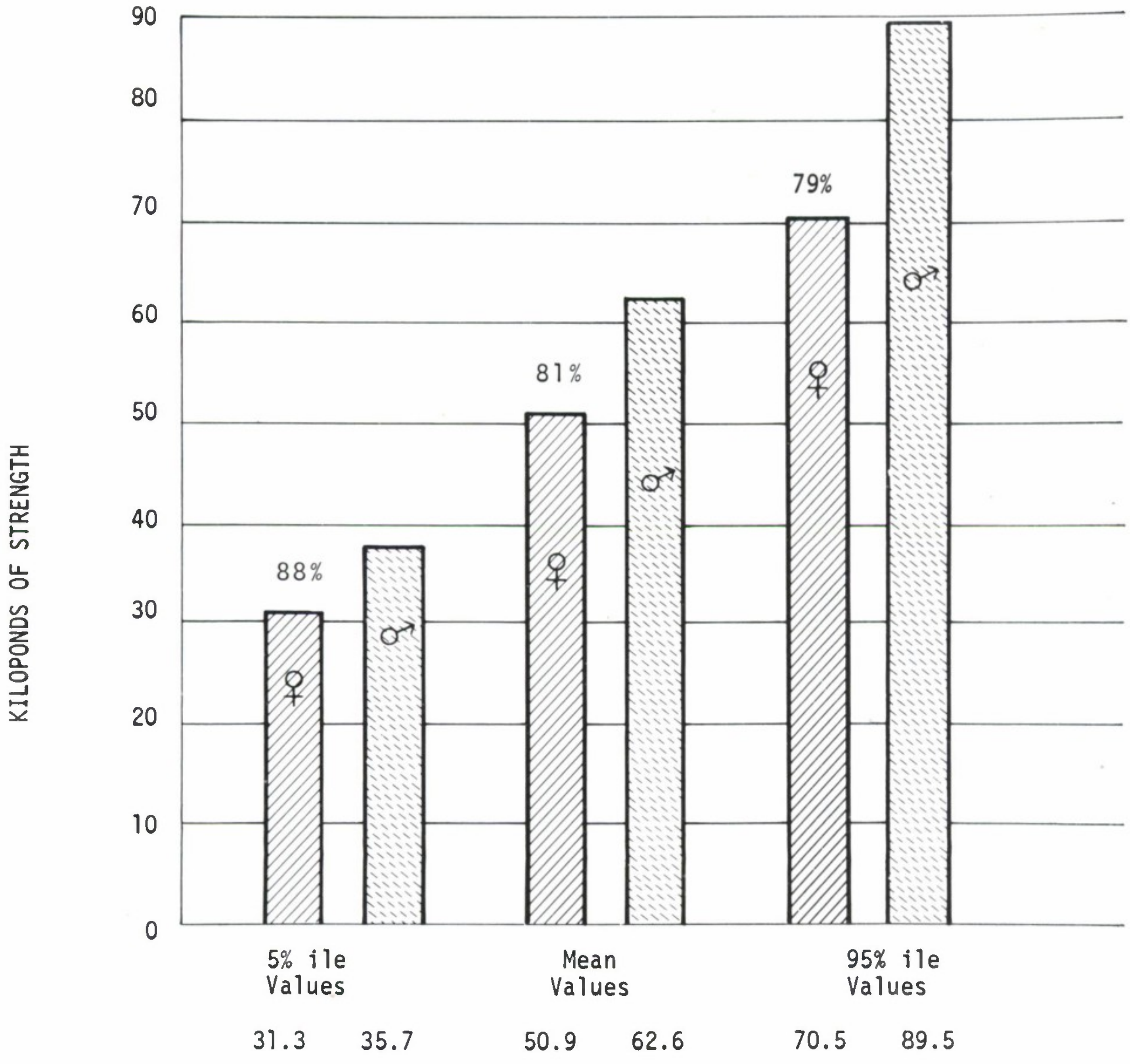


Figure 3. HIP FLEXION

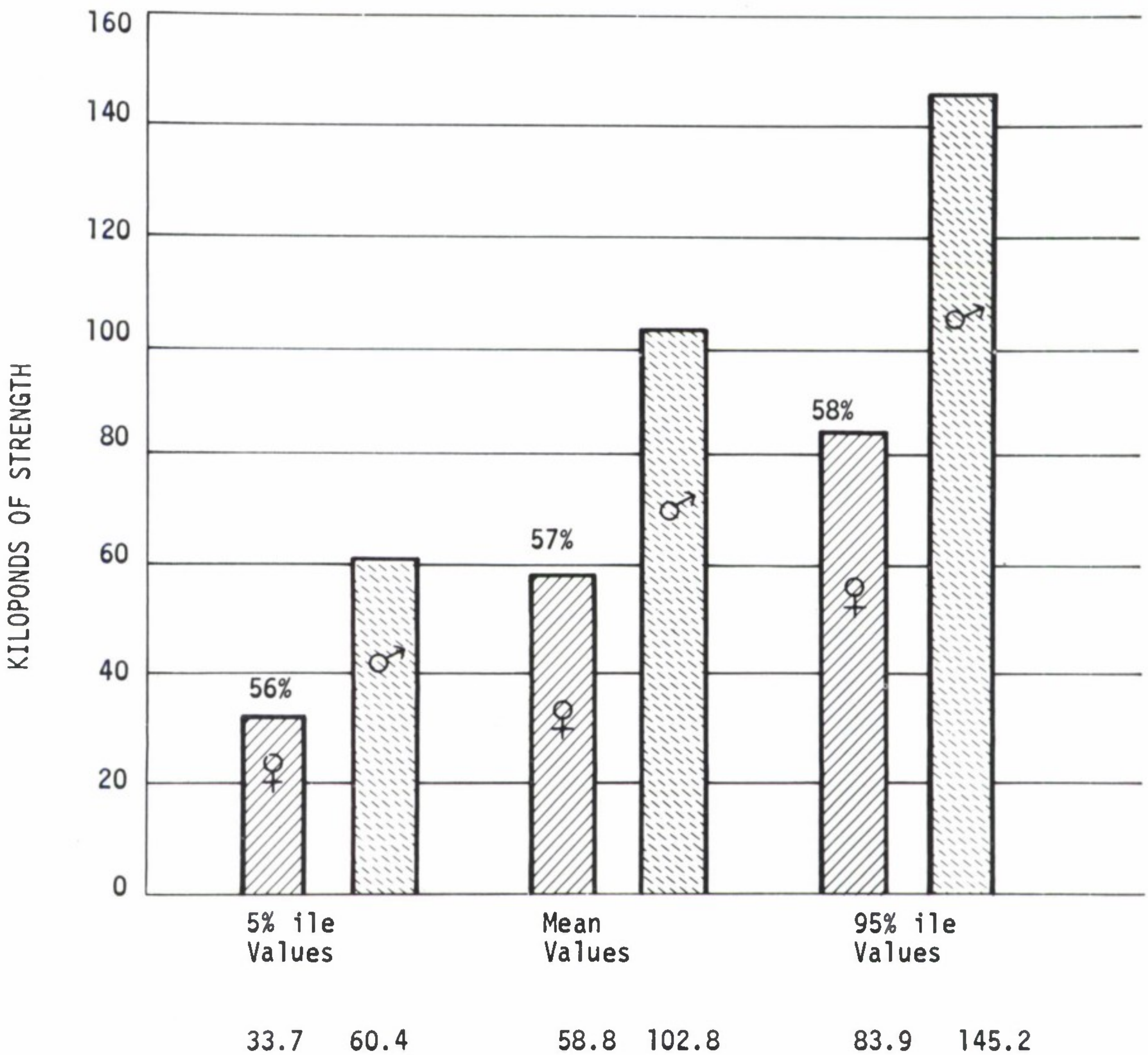


Figure 4. KNEE EXTENSION

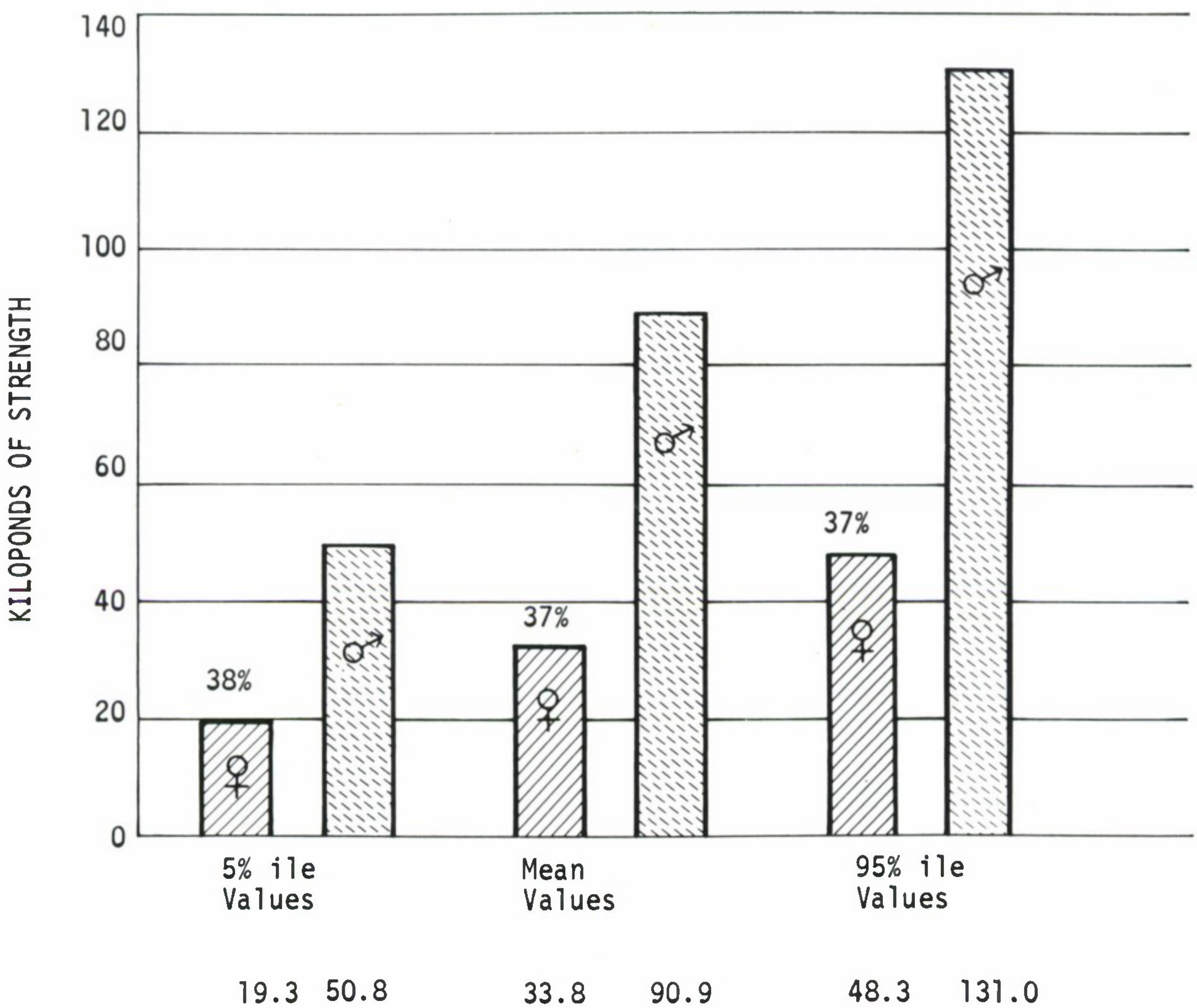


Figure 5. TRUNK FLEXION

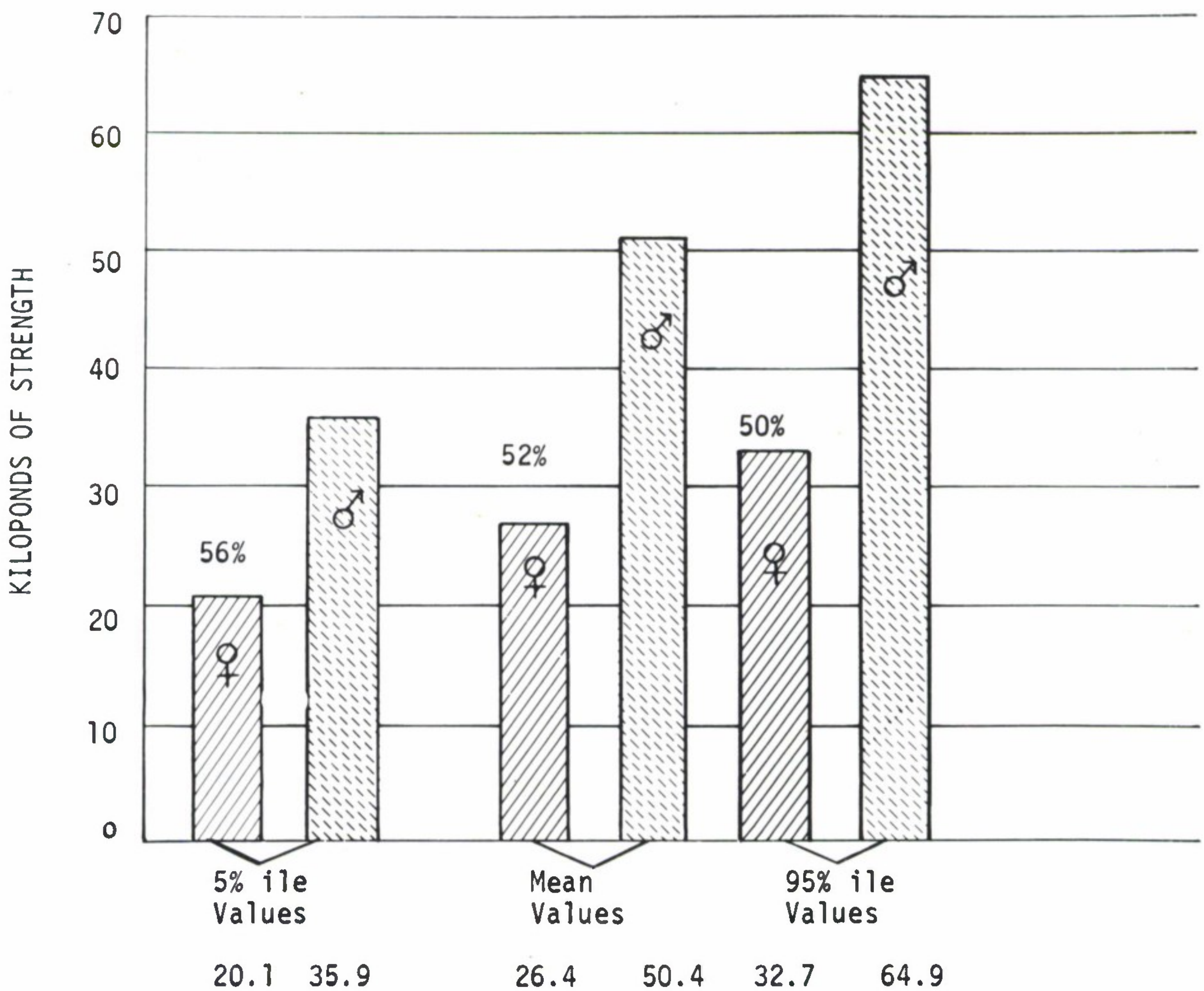


Figure 6. GRIP STRENGTH

TABLE 3

A COMPARISON OF PUSH FORCE VALUES OBTAINED FROM WOMEN AND MEN

Variable	Sex	Mean	S.D.	C.V.%	β_1	β_2	5%ile	95%ile
FORWARD PUSH WITH BOTH HANDS--Reaction Force Provided by Floor and Footrest	F	23.9	7.2	30.1	1.9	8.1	12.0	35.8
	M	63.6	15.0	23.6			38.9	88.4
LATERAL PUSH WITH THE SHOULDER--Reaction Force Provided by Floor and Footrest	F	38.8	11.2	28.9	-0.2	2.3	20.3	57.3
	M	87.1	18.0	20.7			57.4	116.8
FORWARD PUSH WITH BOTH HANDS--Reaction Force Provided by a Vertical Wall	F	56.1	18.7	33.3	0.6	2.4	25.2	87.0
	M	130.9	40.6	31.0			63.9	197.9
BACKWARD PUSH--Reaction Force Provided by a Vertical Wall	F	68.8	25.3	36.8	0.8	3.3	27.1	110.5
	M	194.0	75.5	38.9			69.4	318.6
LATERAL PUSH WITH ONE HAND--Reaction Force Provided by a Vertical Wall	F	32.5	13.0	40.0	0.6	2.3	11.1	54.0
	M	76.0	19.4	25.5			44.0	108.0
FORWARD PUSH WITH ONE HAND--Reaction Force Provided by a Vertical Wall	F	25.0	7.6	30.4	0.8	4.1	12.5	37.5
	M	53.1	14.6	27.5			29.0	77.2

The data reported for the females were obtained in this study. The comparative data for males came from Kroemer, 1969. Strength values are reported in kiloponds.

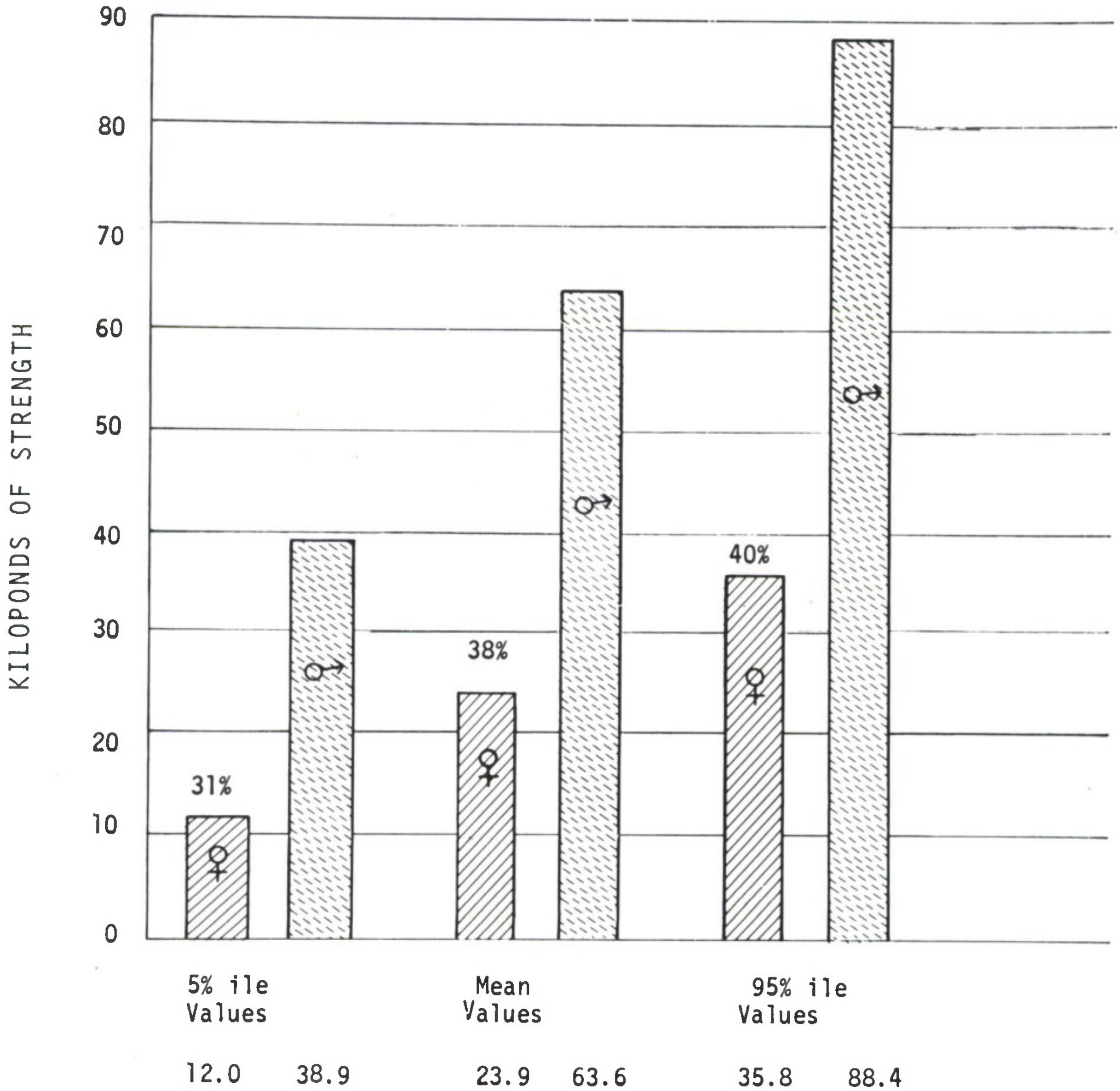
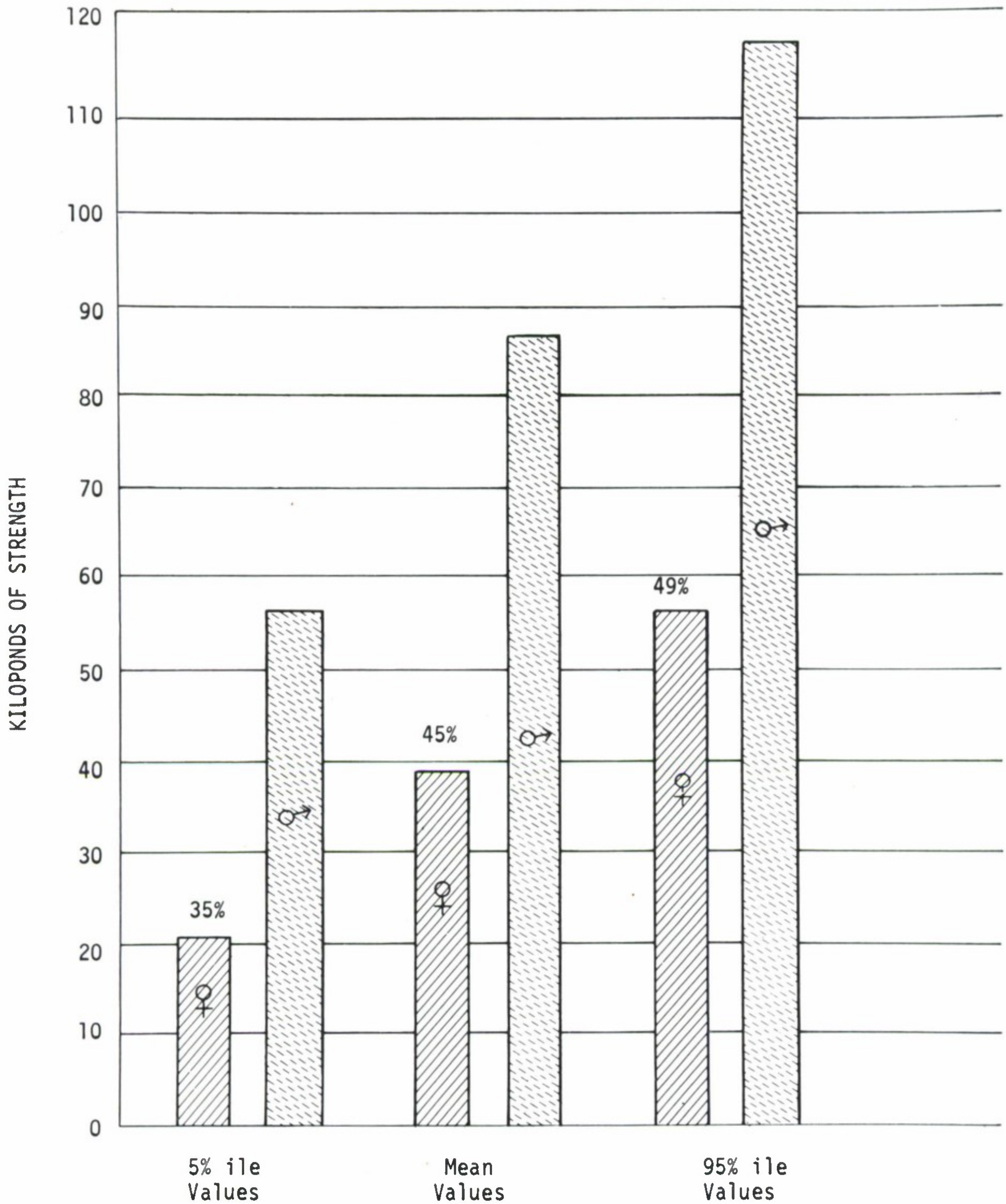


Figure 7. FORWARD PUSH WITH BOTH HANDS--REACTION FORCE PROVIDED BY FLOOR AND FOOTREST.



20.3 57.4 38.8 87.1 57.3 116.8

Figure 8. LATERAL PUSH WITH THE SHOULDER--REACTION FORCE PROVIDED BY FLOOR AND FOOTREST.

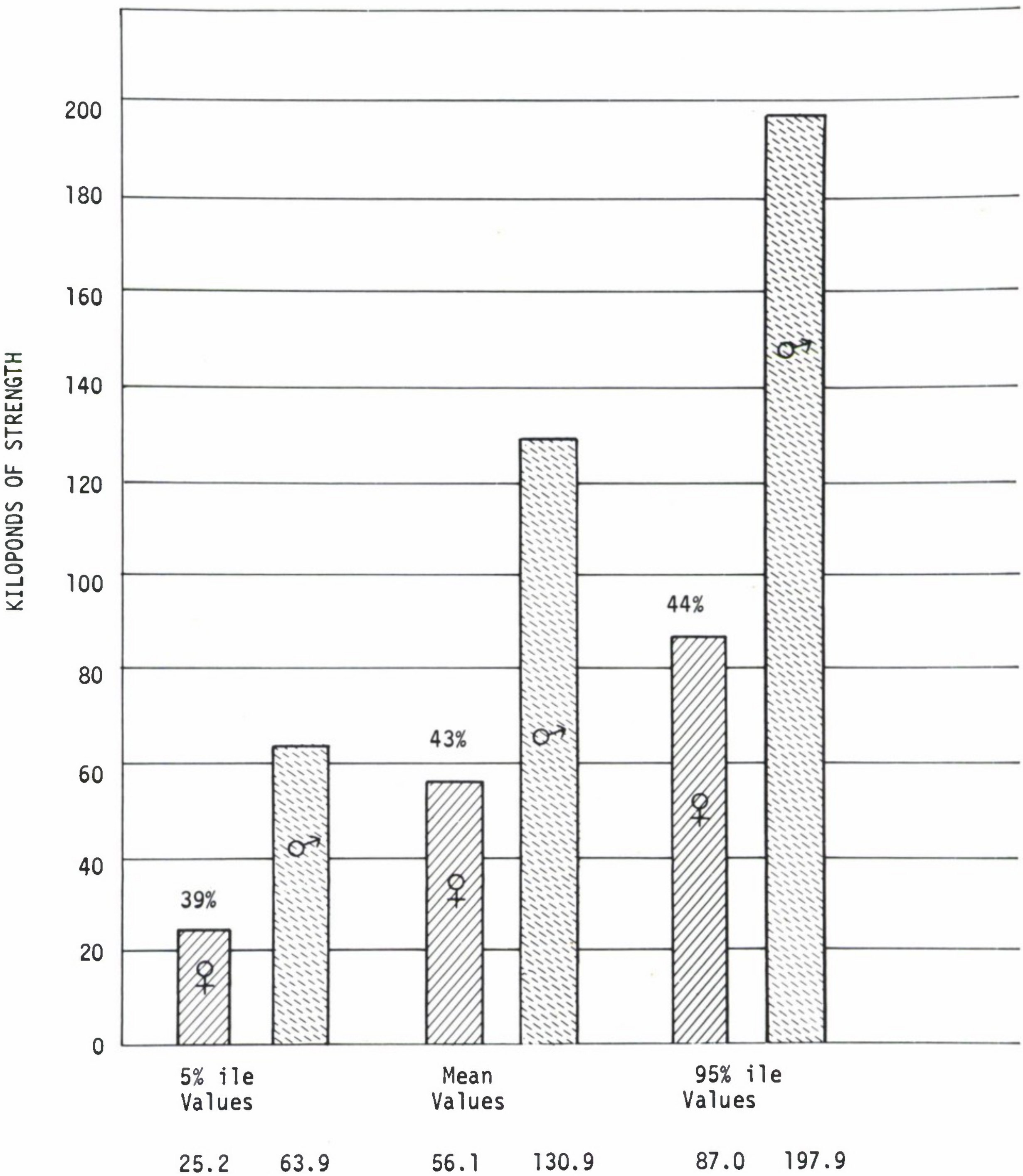


Figure 9. FORWARD PUSH WITH BOTH HANDS--REACTION FORCE PROVIDED BY A VERTICAL WALL.

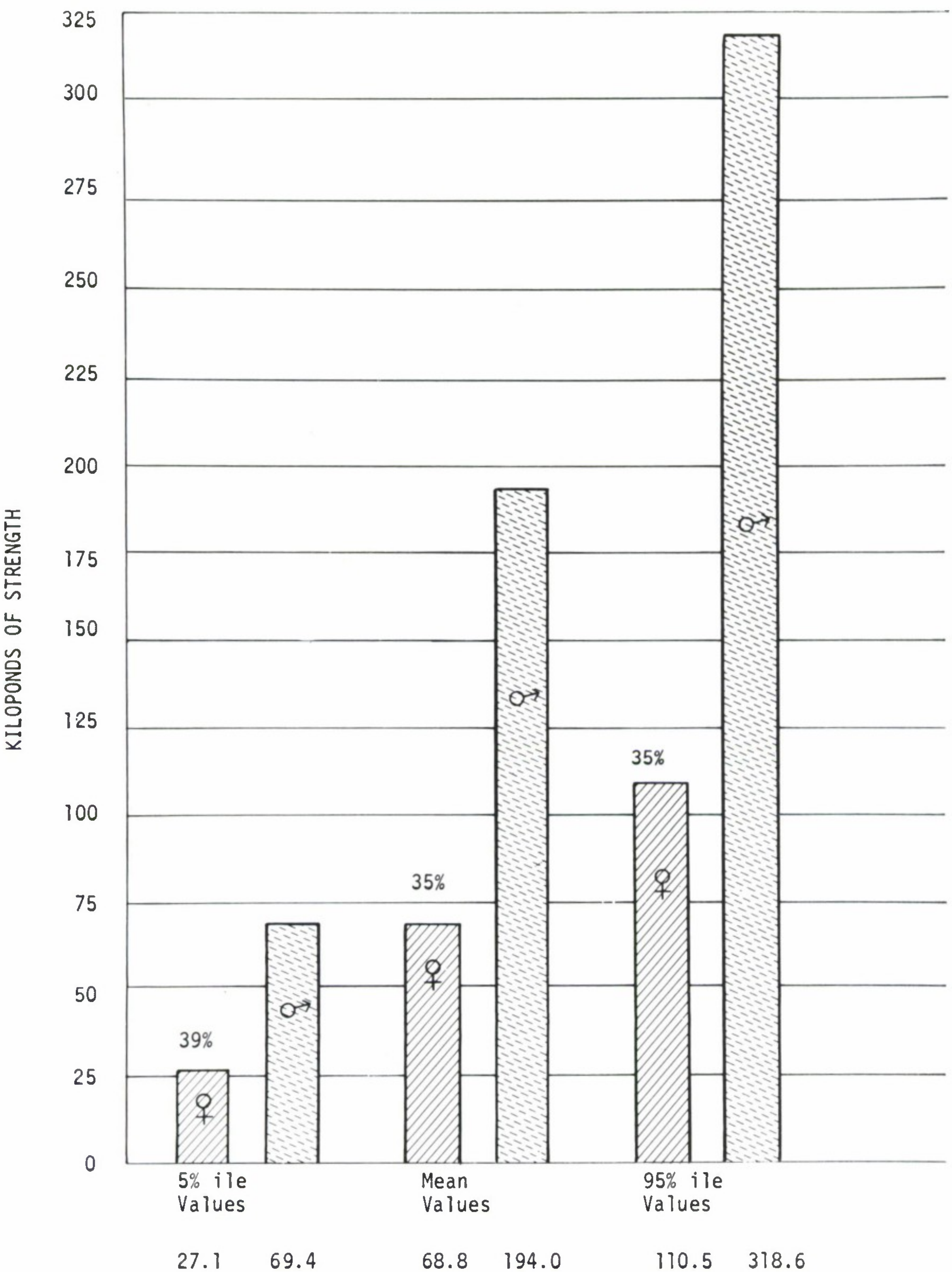


Figure 10. BACKWARD PUSH--REACTION FORCE PROVIDED BY A VERTICAL WALL.

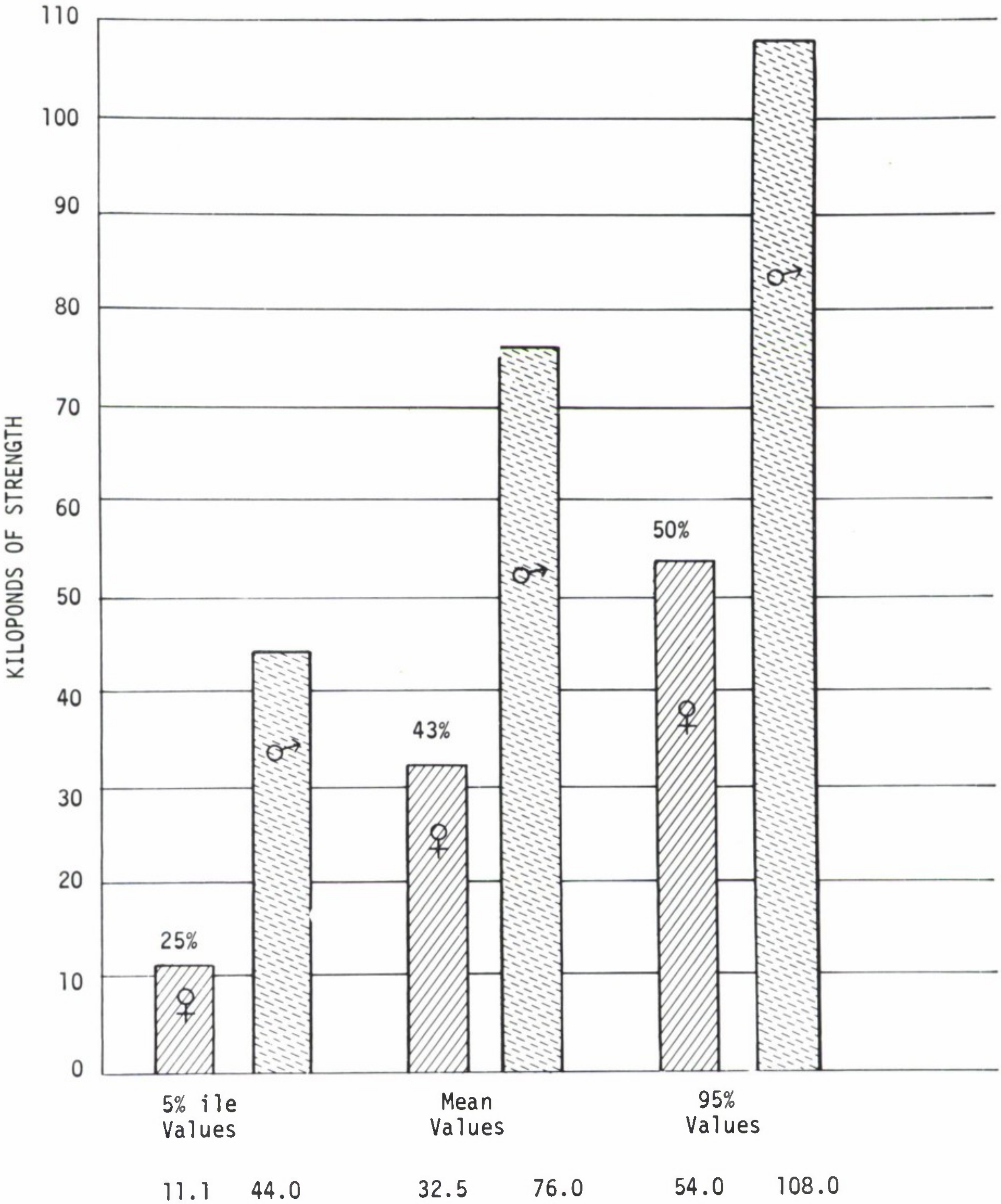


Figure 11. LATERAL PUSH WITH ONE HAND--REACTION FORCE PROVIDED BY A VERTICAL WALL.

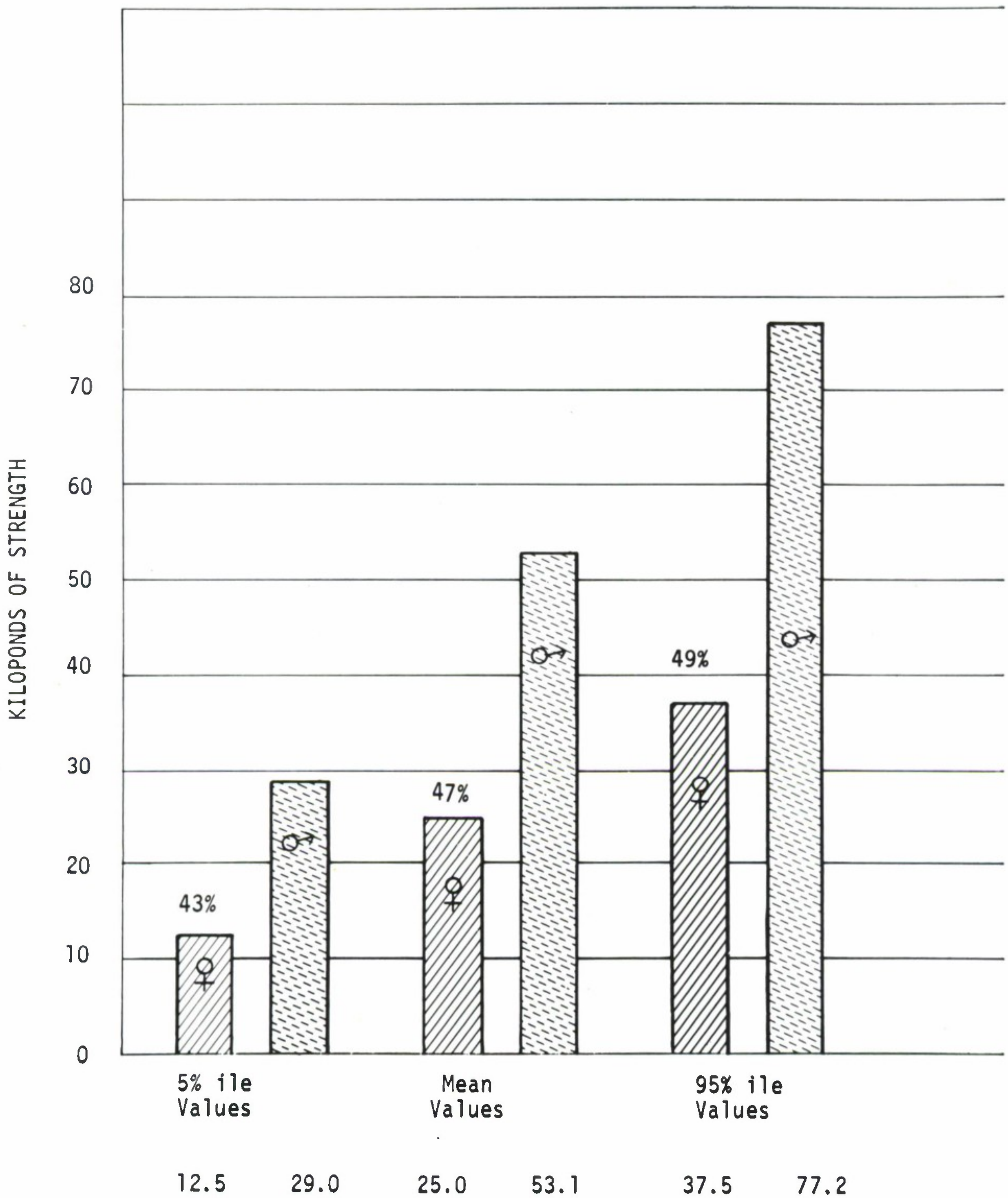


Figure 12. FORWARD PUSH WITH ONE HAND--REACTION FORCE PROVIDED BY A VERTICAL WALL.

TABLE 4

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Upper Extremities)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Handgrip (kp)	F	29.8	6.0	54	Nordgren, 1972
	M	55.0	8.6		Backlund & Nordgren, 1968
	F	37.5	5.9	67	Asmussen & Heeboll-Nielsen, 1961
	M	55.9	9.0		
Horizontal Pull (kp)	F	25.0	3.0	61	Nordgren, 1972
	M	41.1	5.1		Backlund & Nordgren, 1968
	F	29.3	4.0	63	Asmussen & Heeboll-Nielsen, 1961
	M	46.5	6.3		
Horizontal Push (kp)	F	20.7	3.2	64	Asmussen & Heeboll-Nielsen, 1961
	M	32.1	6.5		
	F	18.7	2.8	50	Nordgren, 1972
	M	37.3	5.5		Backlund & Nordgren, 1968
Vertical Pull Downwards (kp)	F	35.3	5.0	62	Asmussen & Heeboll-Nielsen, 1961
	M	56.8	7.6		
	F	27.8	3.9	54	Nordgren, 1972
	M	51.6	6.1		Backlund & Nordgren, 1968
Vertical Push Upwards (kp)	F	13.8	2.0	58	Nordgren, 1972
	M	23.7	4.1		Backlund & Nordgren, 1968
Neck Flexion Forwards (kp)	F	8.4	3.5	61	Nordgren, 1972
	M	13.8	4.0		Backlund & Nordgren, 1968

TABLE 4

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Upper Extremities)

(continued)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Elbow Flexion (kp)	F	16.4	2.4	54	Nordgren, 1972
	M	30.1	4.7		Backlund & Nordgren, 1968
Elbow Extension (kp)	F	10.0	2.4	52	Nordgren, 1972
	M	19.2	3.0		Backlund & Nordgren, 1968
Hand Volar Flexion (kp cm)	F	56.4	9.5	69	Asmussen & Heeboll-Nielsen, 1961
	M	81.4	16.1		
	F	54.1	9.5	69	Nordgren, 1972
	M	78.6	24.9		Backlund & Nordgren, 1968
Hand Dorsal Extension (kp cm)	F	70.5	12.3	68	Asmussen & Heeboll-Nielsen, 1961
	M	103.6	22.3		
	F	62.5	15.0	57	Nordgren, 1972
	M	109.4	51.3		Backlund & Nordgren, 1968
Handle Pronation (kp cm)	F	87.4	16.5	61	Asmussen & Heeboll-Nielsen, 1961
	M	144.1	31.6		
	F	66.5	21.1	47	Nordgren, 1972
	M	142.0	32.4		Backlund & Nordgren, 1968
Handle Supination (kp cm)	F	88.3	15.6	58	Asmussen & Heeboll-Nielsen, 1961
	M	152.7	27.6		
	F	58.2	16.5	45	Nordgren, 1972
	M	128.0	63.5		Backlund & Nordgren, 1968

TABLE 4

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Upper Extremities)

(continued)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Key Pronation (kp cm)	F	32.3	5.1	77	Asmussen & Heeboll-Nielsen, 1961
	M	41.8	6.5		
	F	17.4	4.5	64	Nordgren, 1972
	M	27.4	8.7		Backlund & Nordgren, 1968
Key Supination (kp cm)	F	33.9	5.2	79	Asmussen & Heeboll-Nielsen, 1961
	M	42.9	6.9		
	F	14.1	3.6	56	Nordgren, 1972
	M	25.1	6.2		

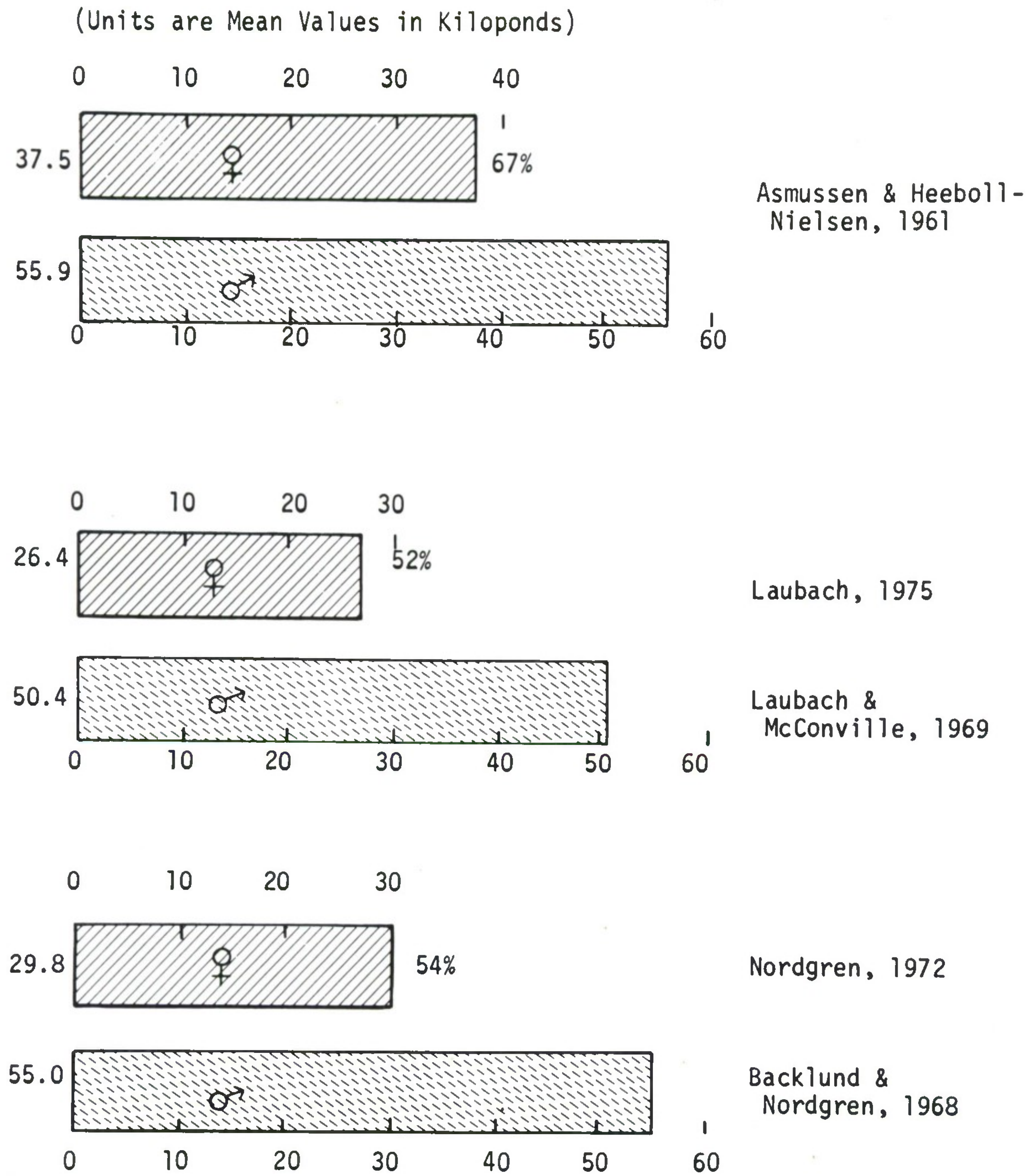


Figure 13. HANDGRIP STRENGTH

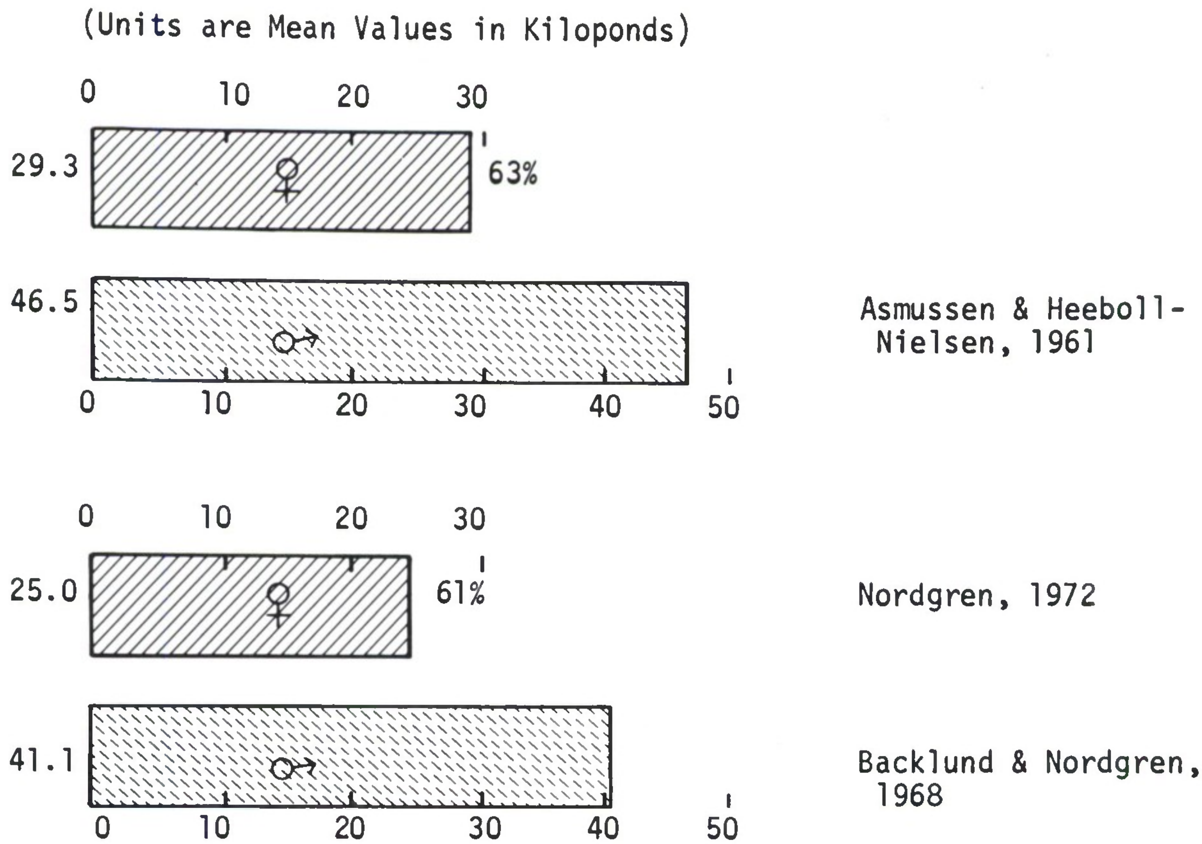


Figure 14. HORIZONTAL PULL

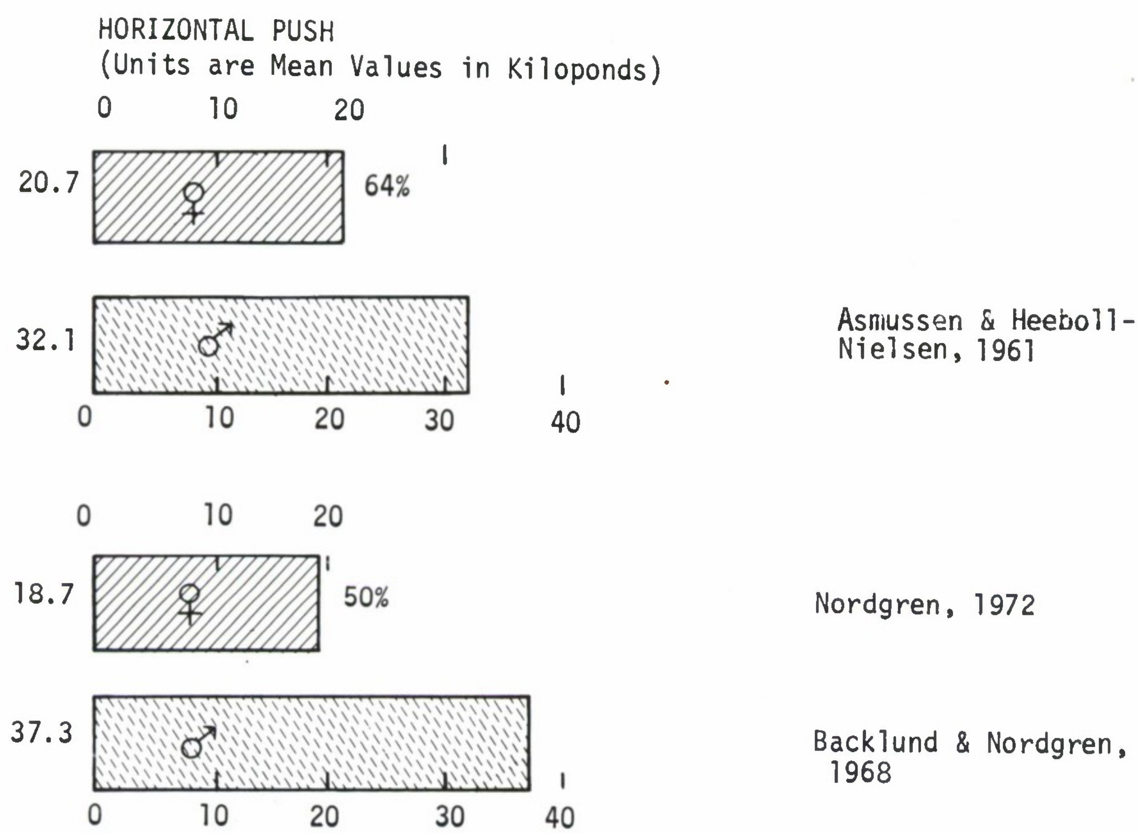


Figure 15. HORIZONTAL PUSH

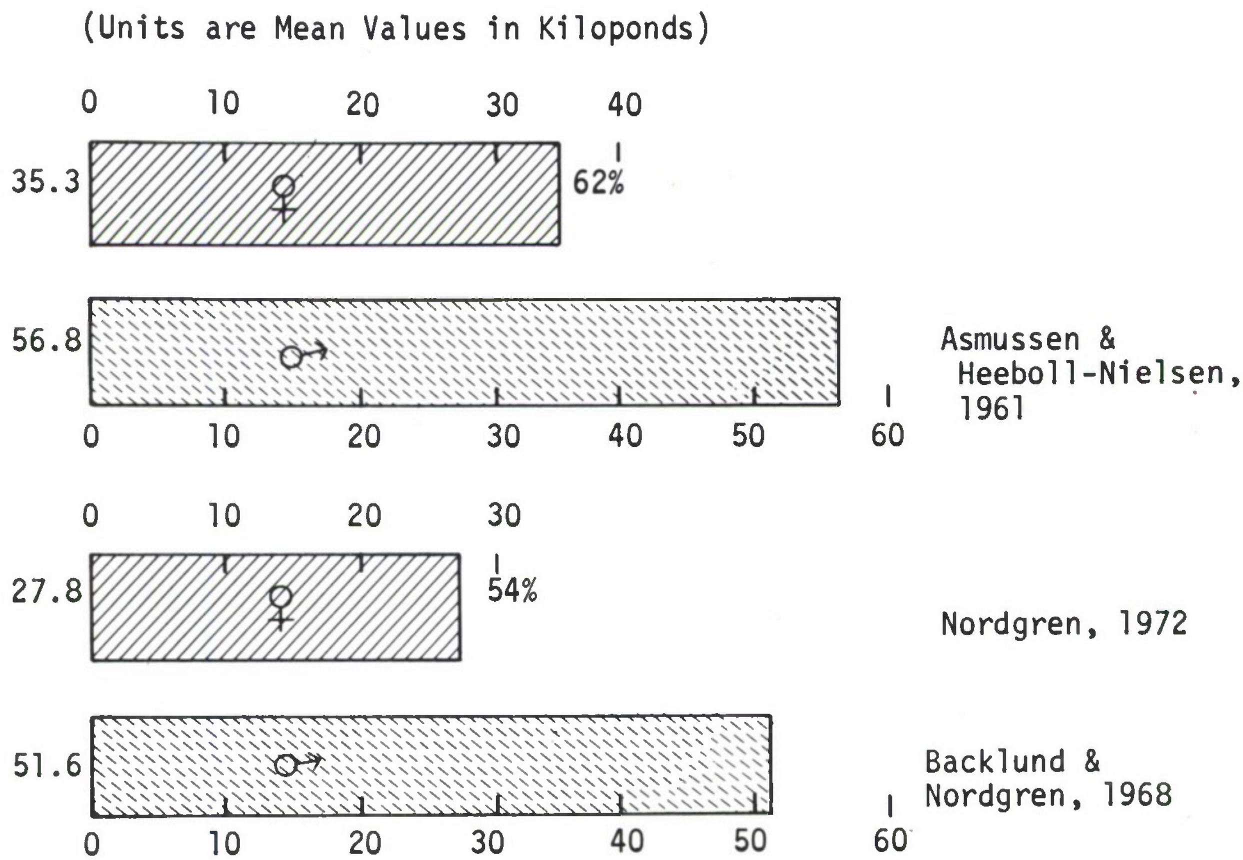


Figure 16. VERTICAL PULL DOWNWARDS

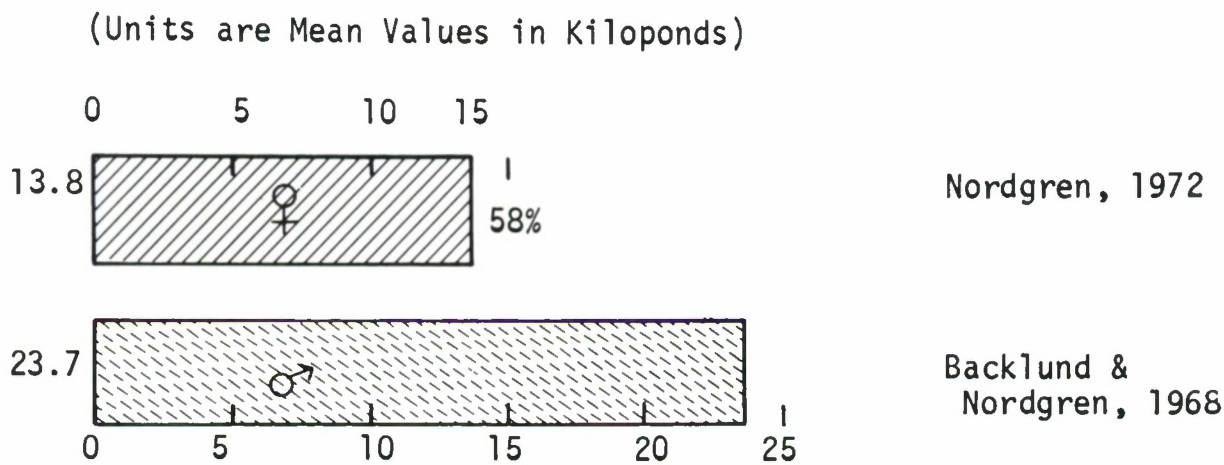


Figure 17. VERTICAL PUSH UPWARDS

(Units are Mean Values in Kiloponds)

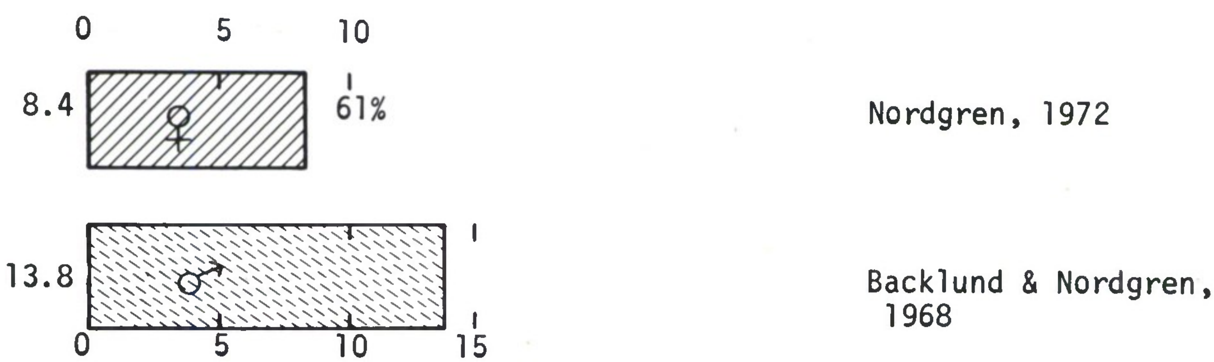


Figure 18. NECK FLEXION FORWARDS

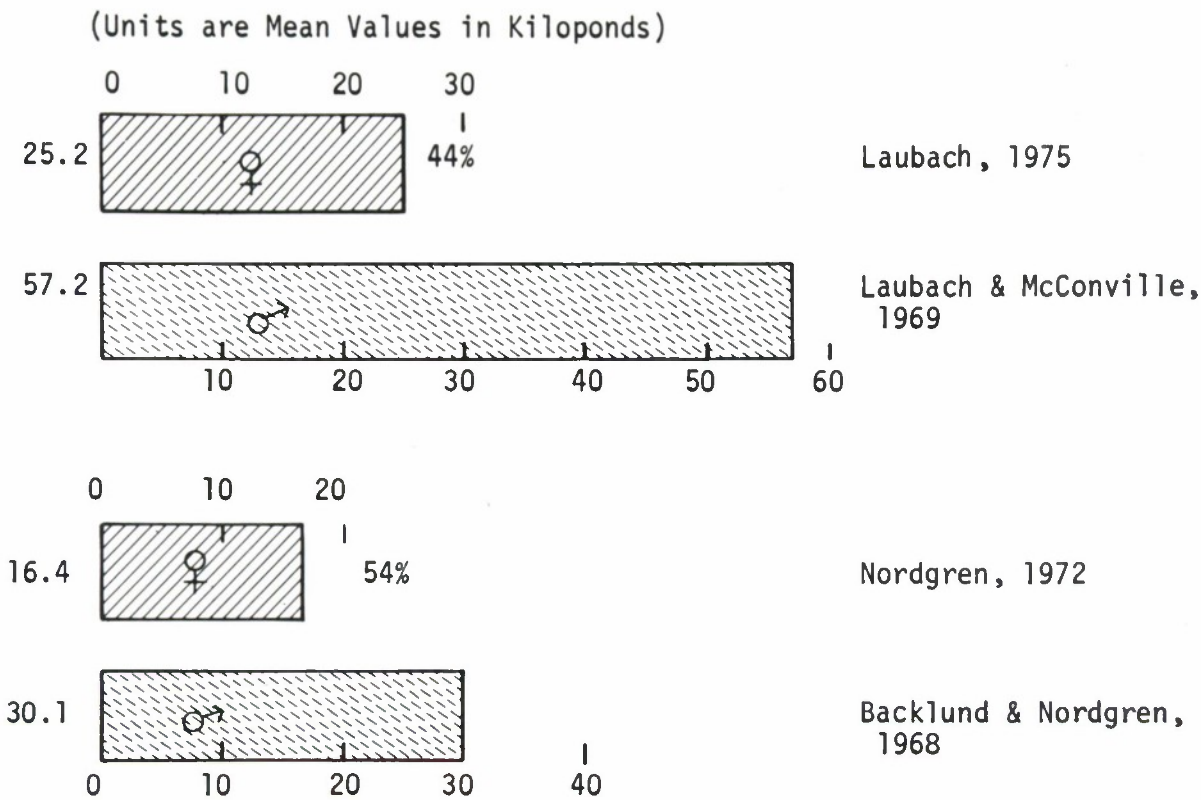


Figure 19. ELBOW FLEXION

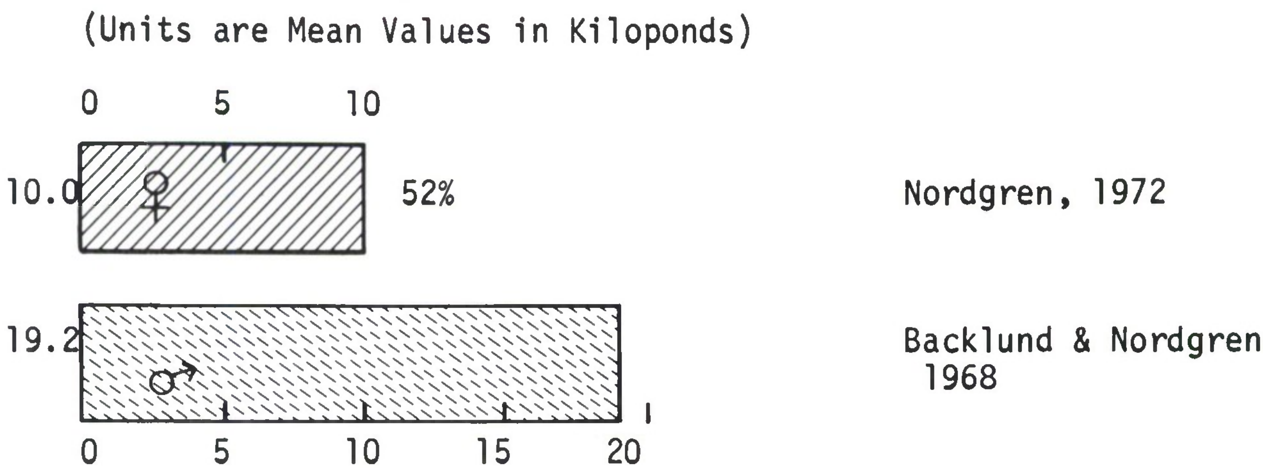


Figure 20. ELBOW EXTENSION

(Units are Mean Values in Kilopond Centimeters)

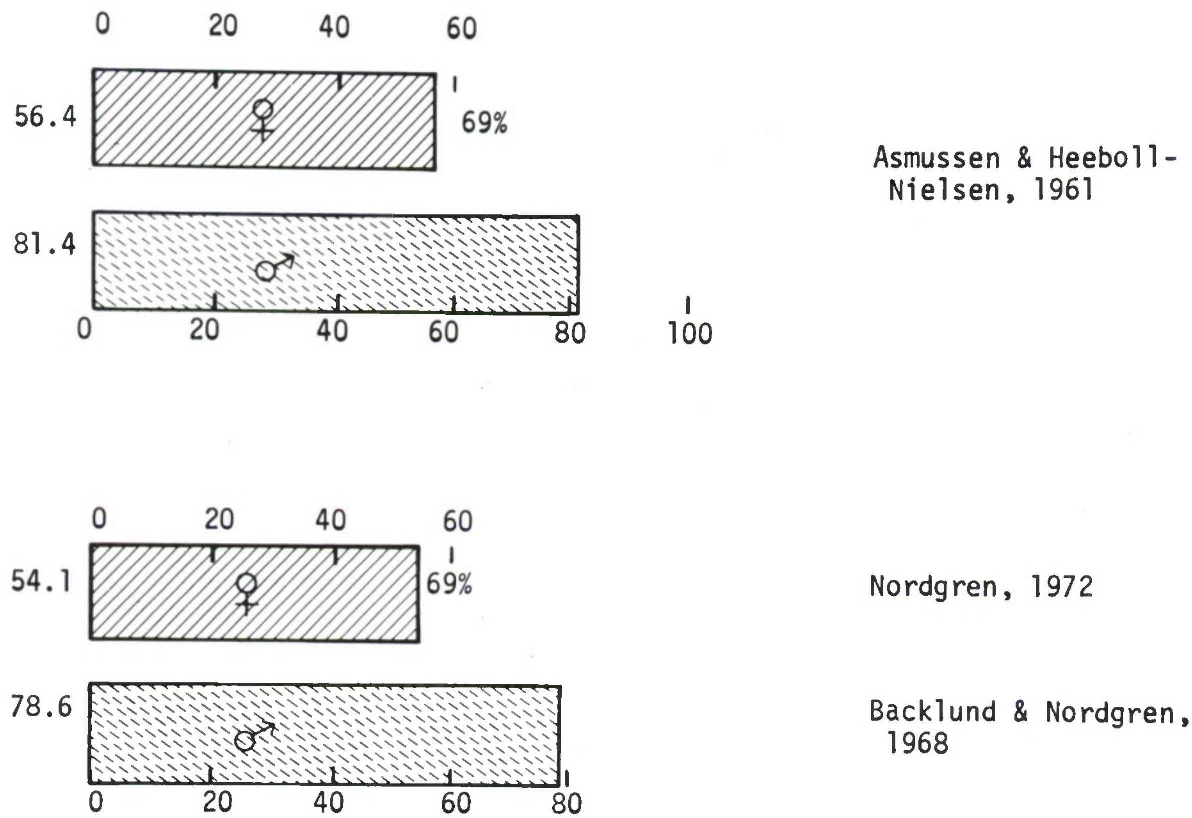


Figure 21. HAND VOLAR FLEXION

(Units are Mean Values in Kilopond Centimeters)

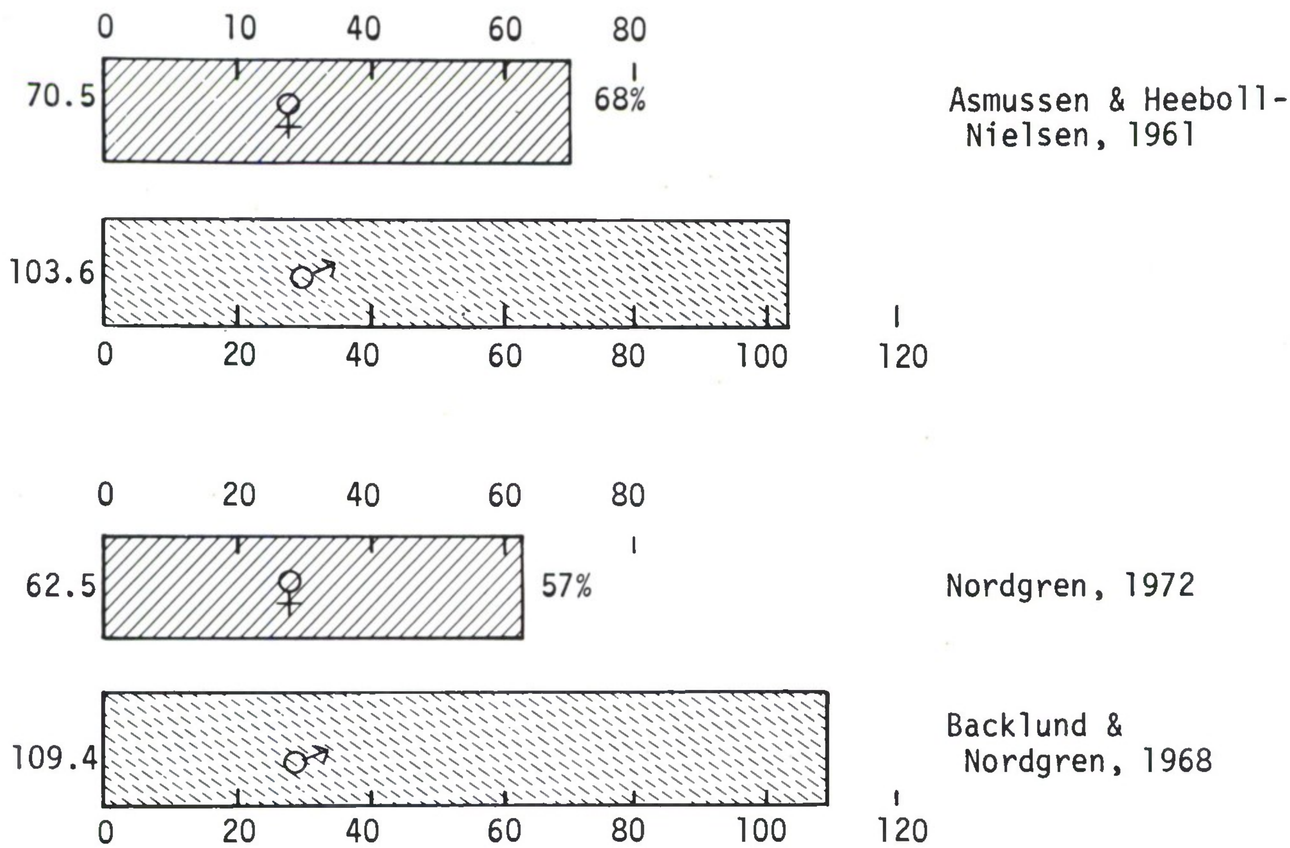


Figure 22. HAND DORSAL EXTENSION

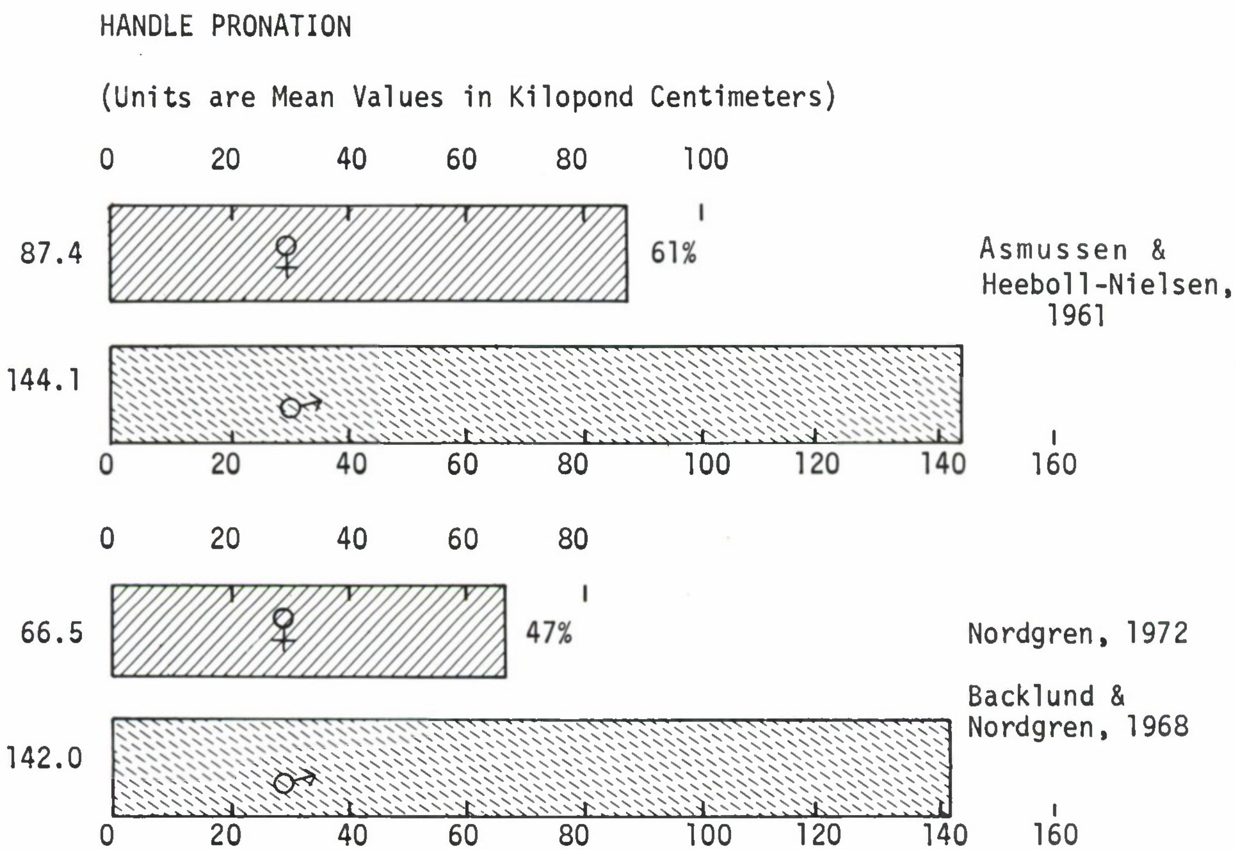


Figure 23. HANDLE PRONATION

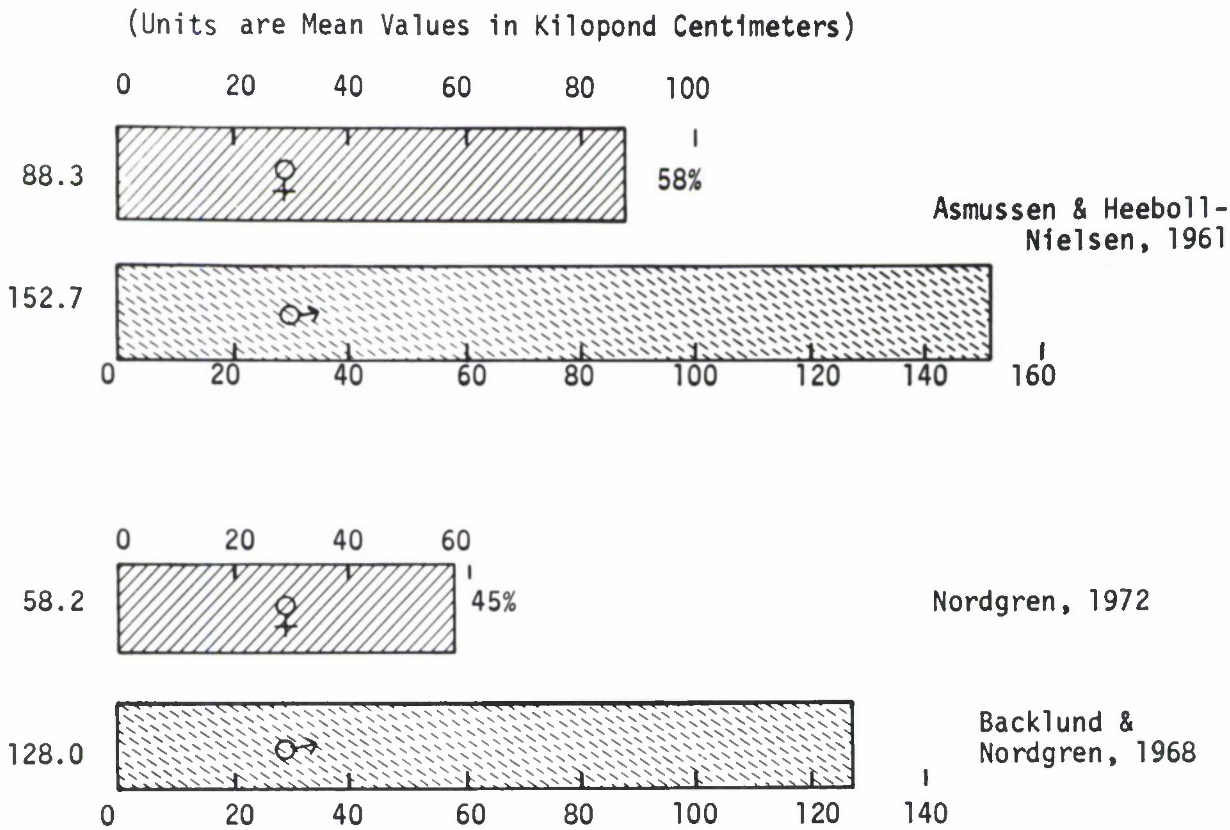


Figure 24. HANDLE SUPINATION

KEY PRONATION

(Units are Mean Values in Kilopond Centimeters)

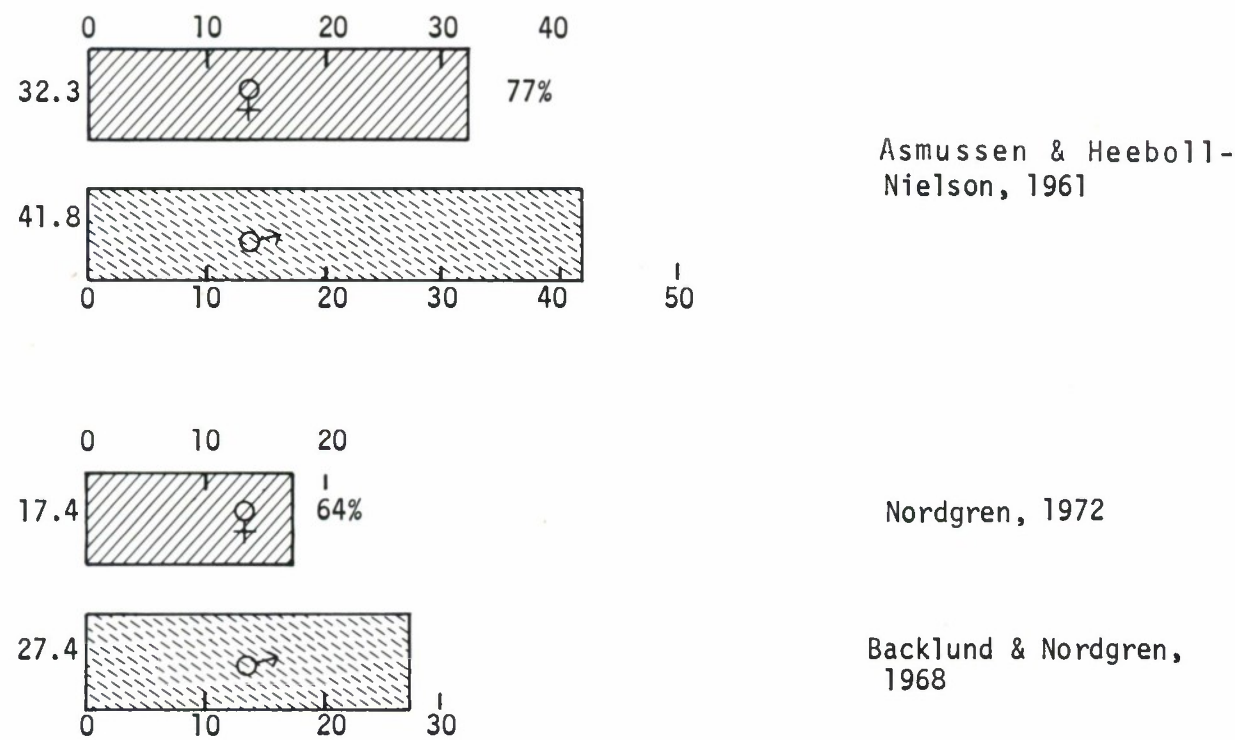


Figure 25. KEY PRONATION

KEY SUPINATION

(Units are Mean Values in Kilopond Centimeters)

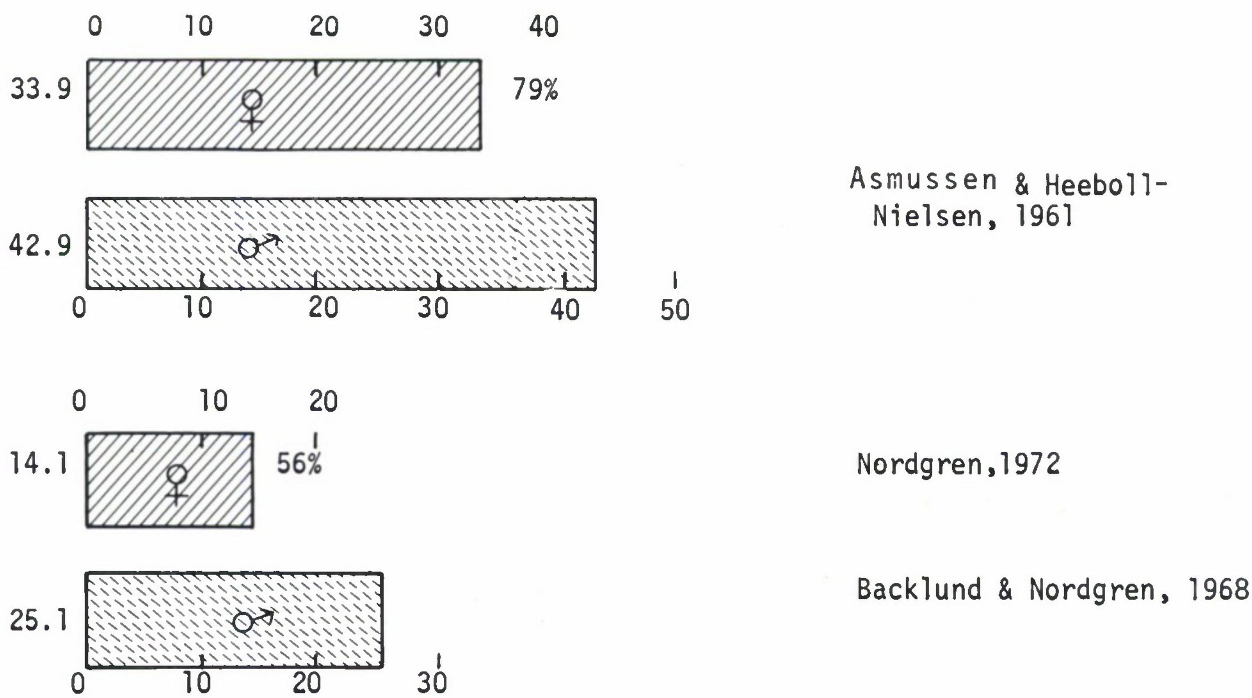


Figure 26. KEY SUPINATION

TABLE 5

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Lower Extremities)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Hip Abduction (kp)	F	32.6	5.9	75	Asmussen & Heeboll-Nielsen, 1961
	M	43.4	6.9		
	F	28.9	6.5	69	Nordgren, 1972
	M	41.8	7.8		Backlund & Nordgren, 1968
Hip Adduction (kp)	F	35.3	7.1	67	Asmussen & Heeboll-Nielsen, 1961
	M	52.7	8.6		
	F	29.3	5.9	63	Nordgren, 1972
	M	46.7	10.9		Backlund & Nordgren, 1968
Hip Flexion (kp)	F	44.2	6.8	71	Asmussen & Heeboll-Nielsen, 1961
	M	62.3	10.7		
	F	37.4	6.7	67	Nordgren, 1972
	M	55.7	8.5		Backlund & Nordgren, 1968
Hip Extension (kp)	F	34.2	6.2	71	Asmussen & Heeboll-Nielsen, 1961
	M	48.4	9.7		
	F	40.1	8.4	73	Nordgren, 1972
	M	55.0	9.7		Backlund & Nordgren, 1968
Knee Flexion (kp cm)	F	972	154.5	77	Asmussen & Heeboll-Nielsen, 1961
	M	1266	200.0		
(kp)	F	18.3	2.9	64	Nordgren, 1972
	M	28.5	4.9		Backlund & Nordgren, 1968

TABLE 5

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Lower Extremities)

(continued)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Knee Extension (kp cm)	F	1212	244.8	78	Asmussen & Heeboll-Nielsen, 1961
	M	1557	281.8		
(kp)	F	50.3	11.0	78	Nordgren, 1972
	M	64.5	19.3		Backlund & Nordgren, 1968
Ankle Plantar Flexion (kp cm)	F	959	179.3	86	Asmussen & Heeboll-Nielsen, 1961
	M	1119	188.0		
(kp)	F	98.0	25.9	79	Nordgren, 1972
	M	124.0	23.9		Backlund & Nordgren, 1968
Ankle Dorsi Flexion (kp cm)	F	385	49	73	Asmussen & Heeboll-Nielsen, 1961
	M	531	79		
(kp)	F	14.9	5.0	70	Nordgren, 1972
	M	21.4	3.4		Backlund & Nordgren, 1968
Leg Extension (kp)	F	214	42.2	73	Asmussen & Heeboll-Nielsen, 1961
	M	294	50.9		
	F	127.6	30.3	63	Nordgren, 1972
	M	202.3	49.8		Backlund & Nordgren, 1968
Leg Extension (Both Legs) (kp)	F	388	89.6	74	Asmussen & Heeboll-Nielsen, 1961
	M	523	102.0		

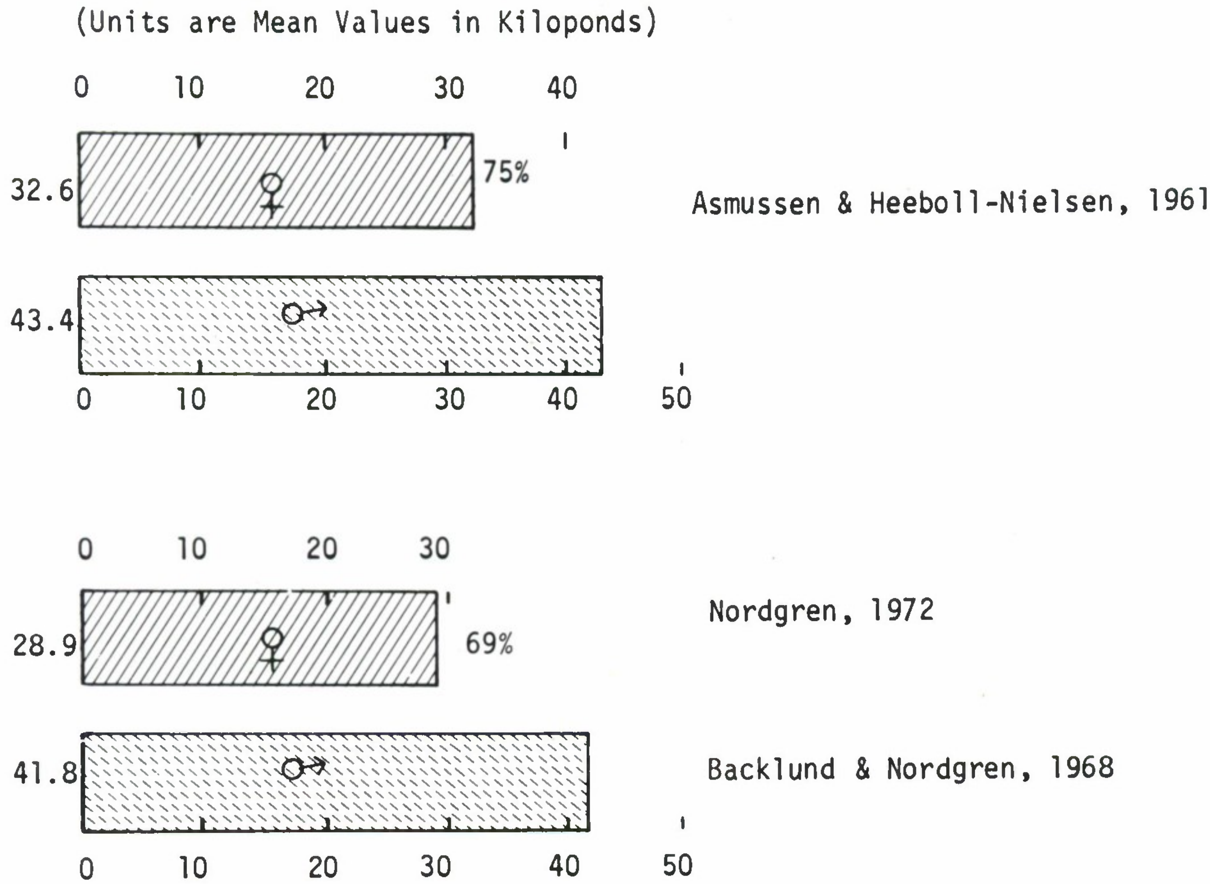


Figure 27. HIP ABDUCTION

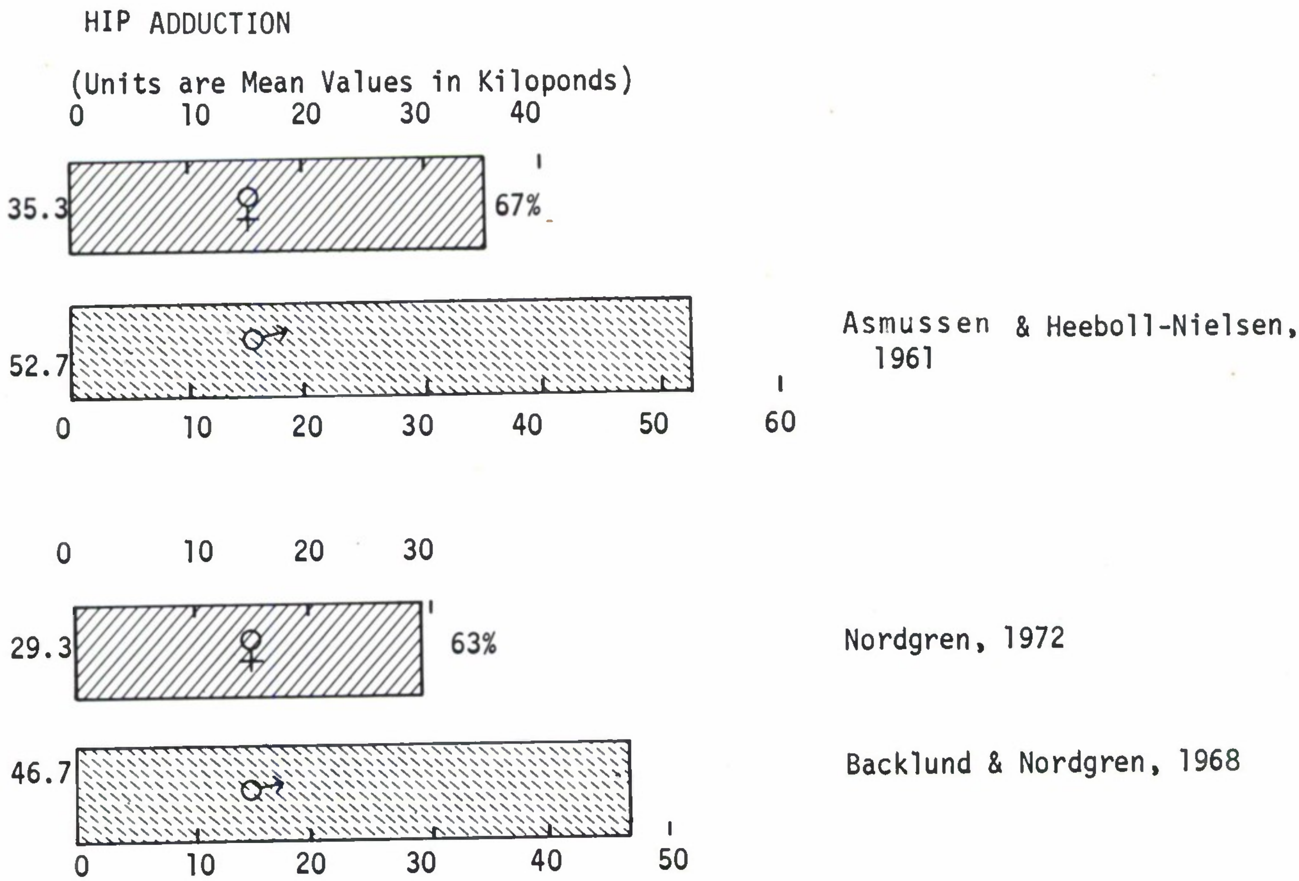


Figure 28. HIP ADDUCTION

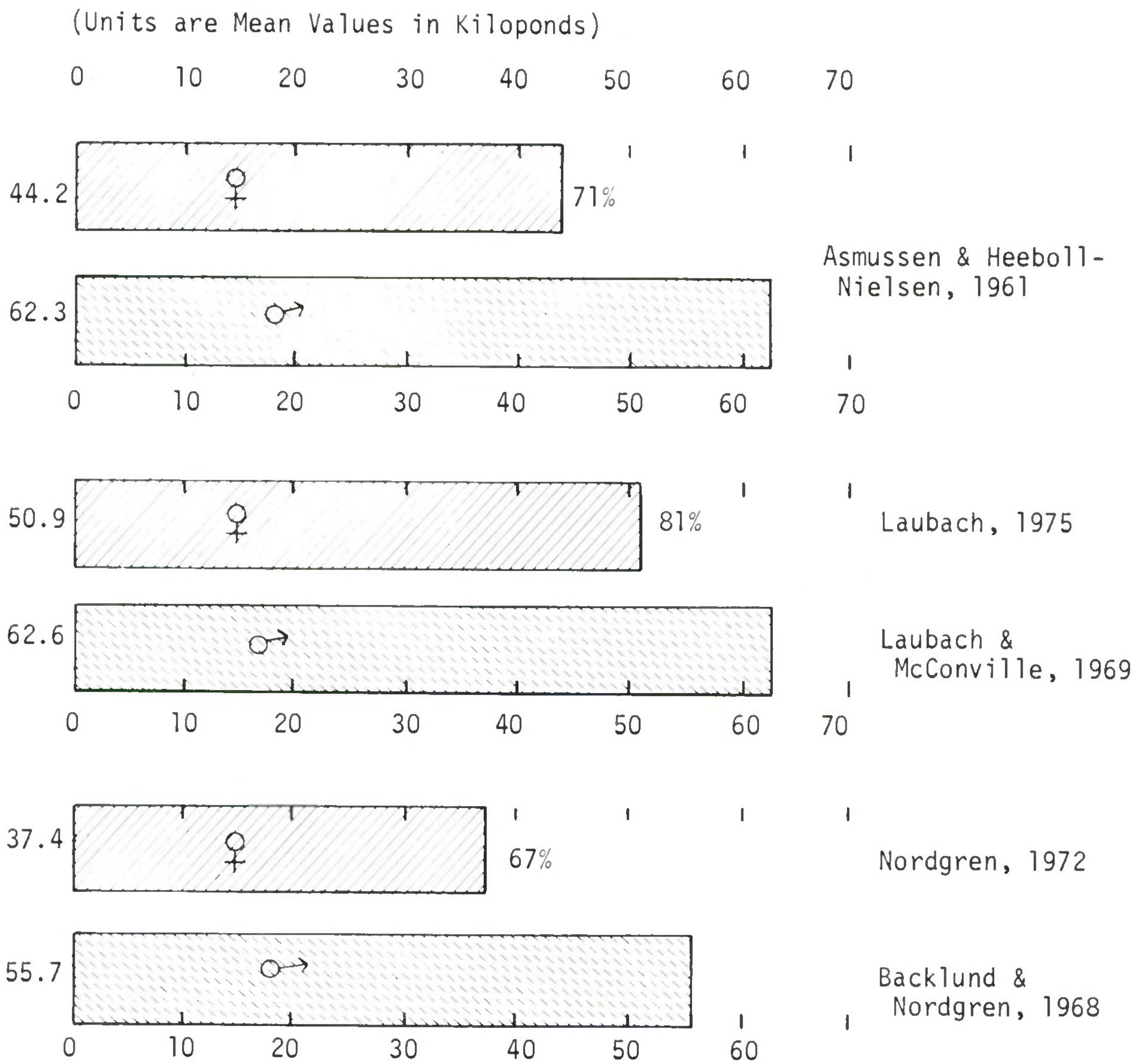


Figure 29. HIP FLEXION

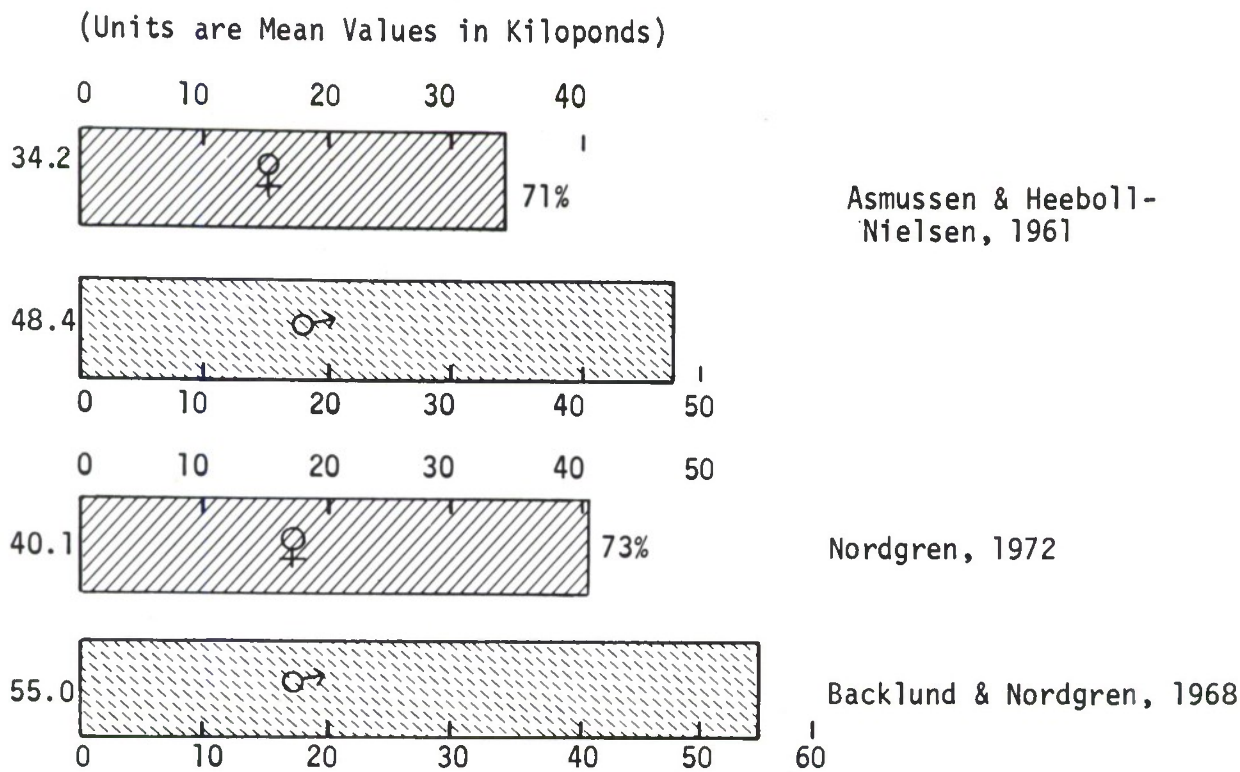
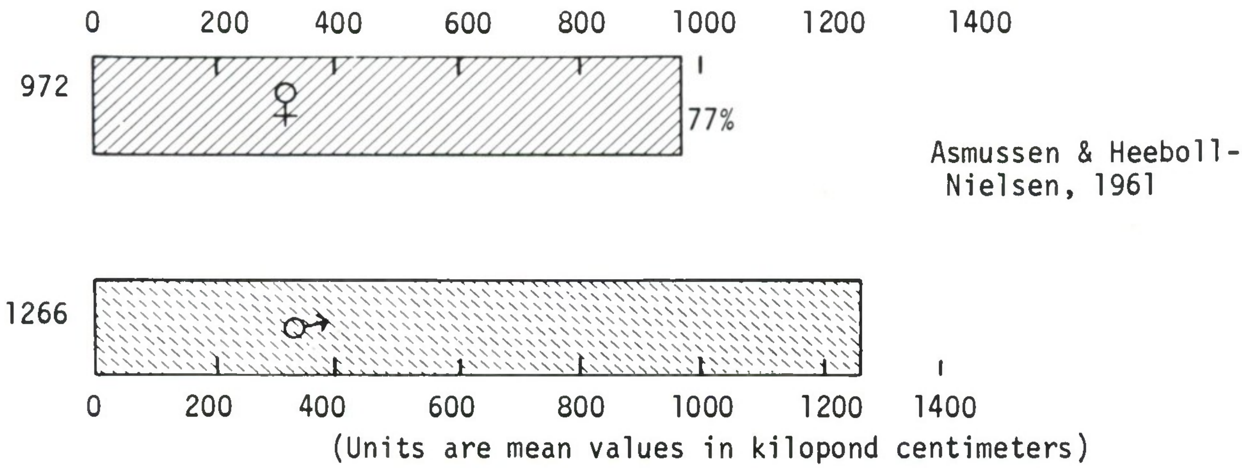


Figure 30. HIP EXTENSION



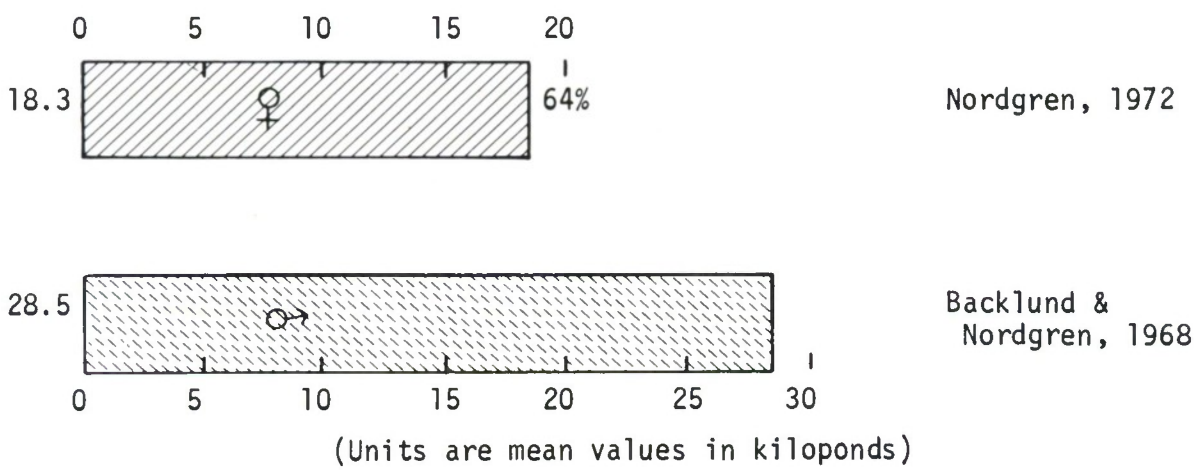


Figure 31. KNEE FLEXION

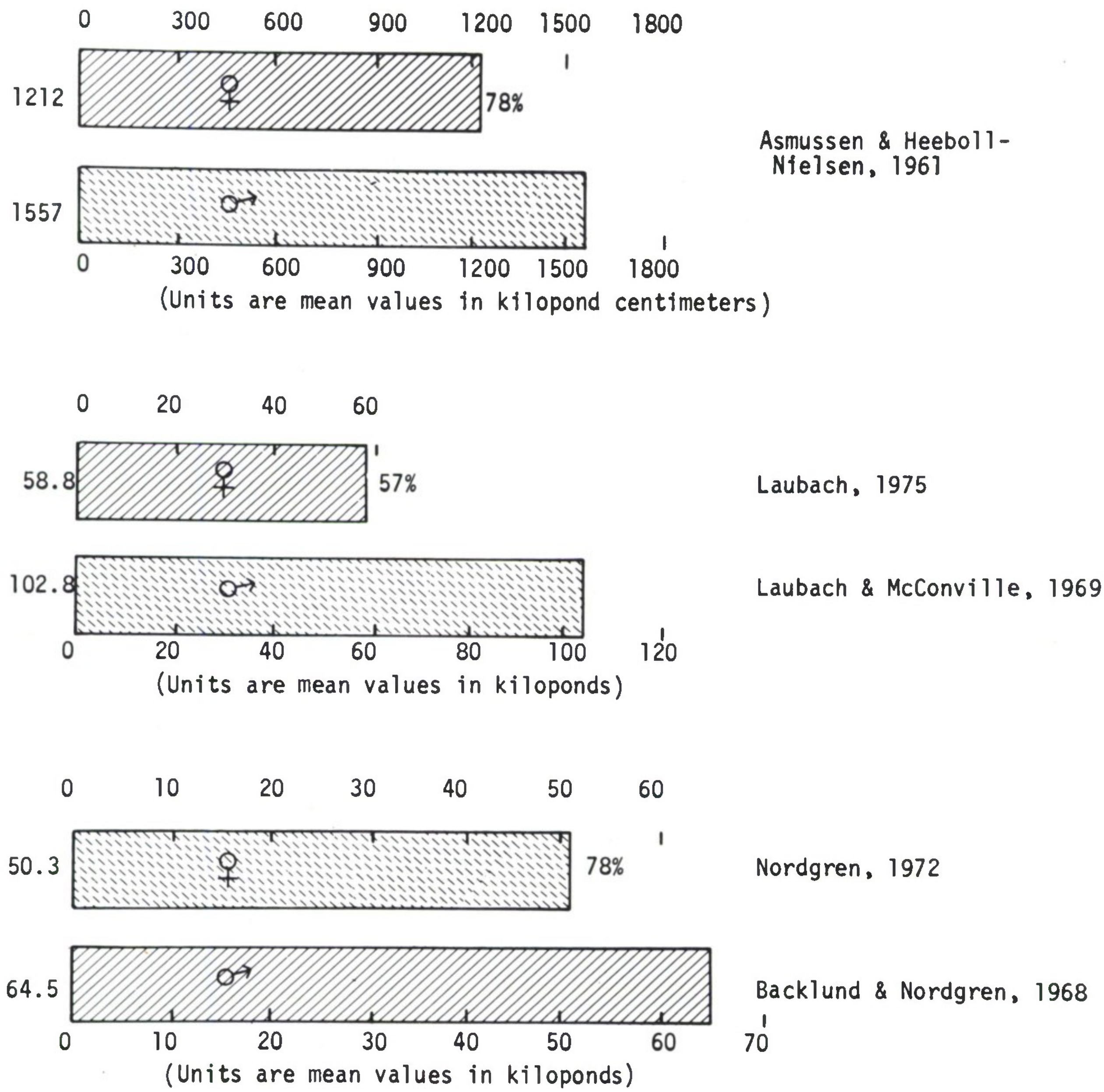


Figure 32. KNEE EXTENSION

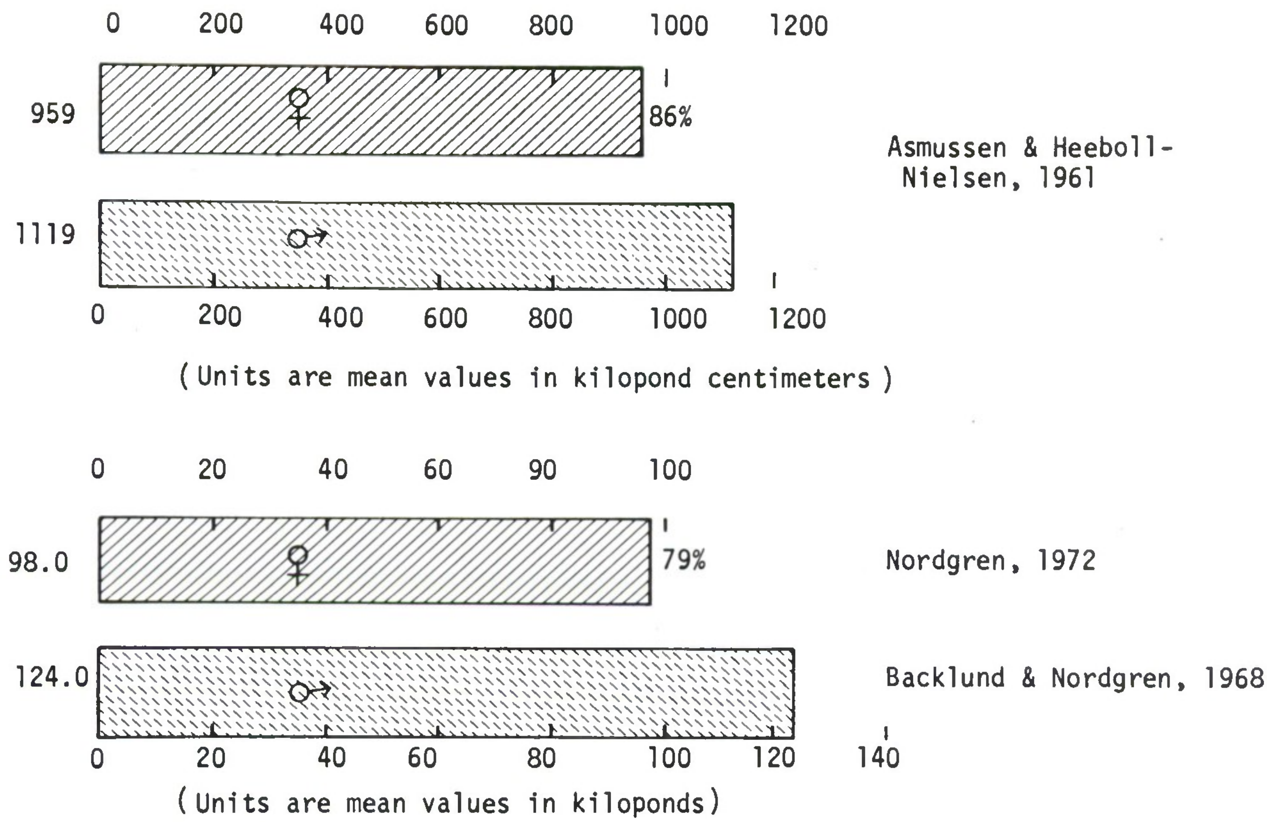


Figure 33. ANKLE PLANTAR FLEXION

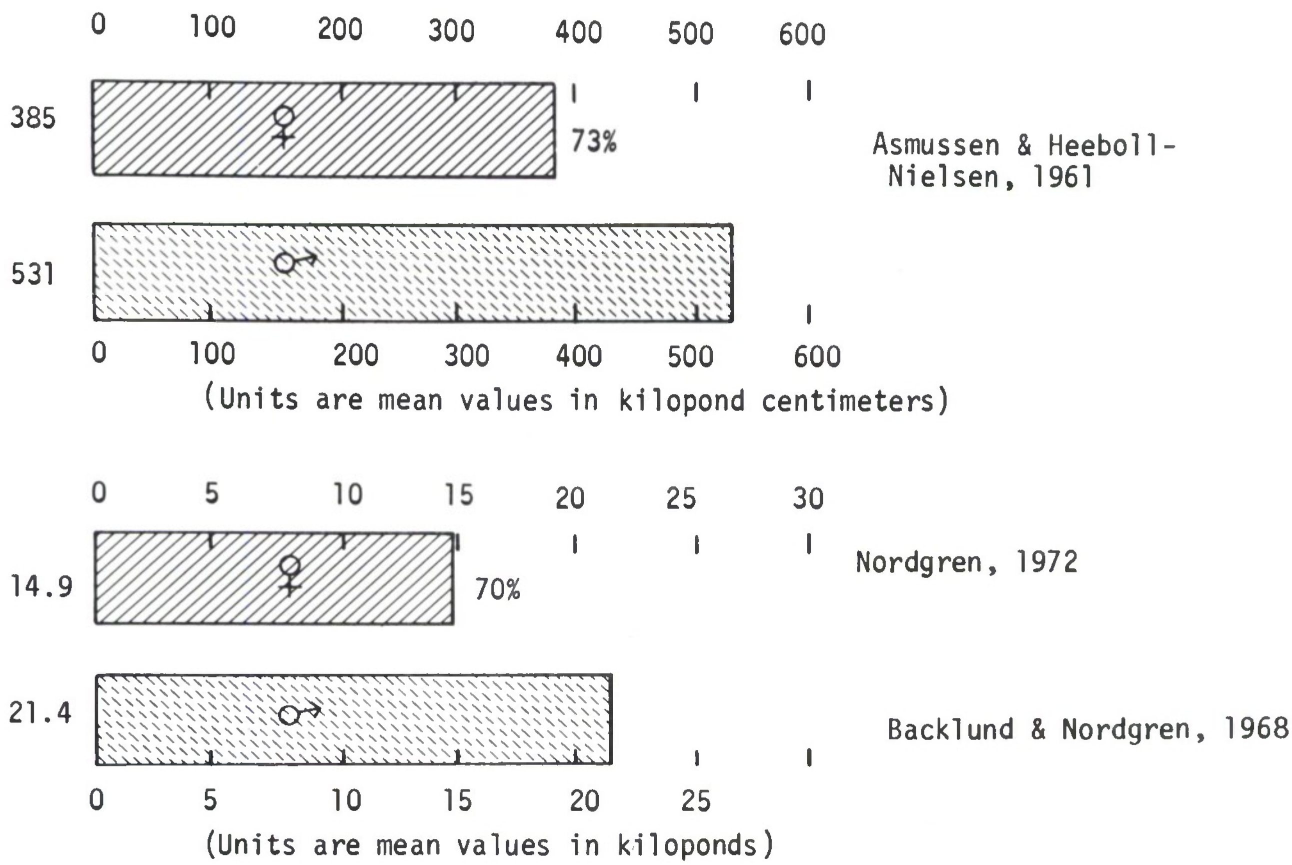


Figure 34. ANKLE DORSI FLEXION

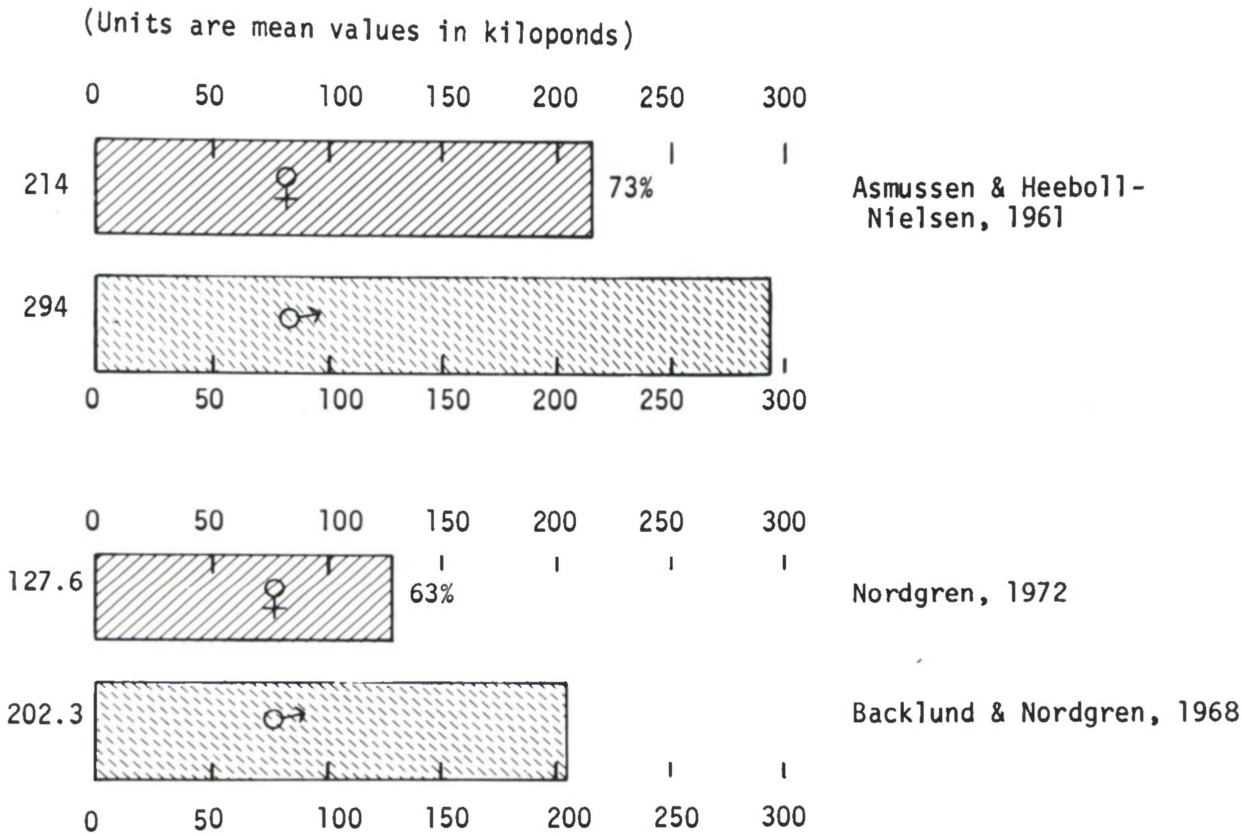
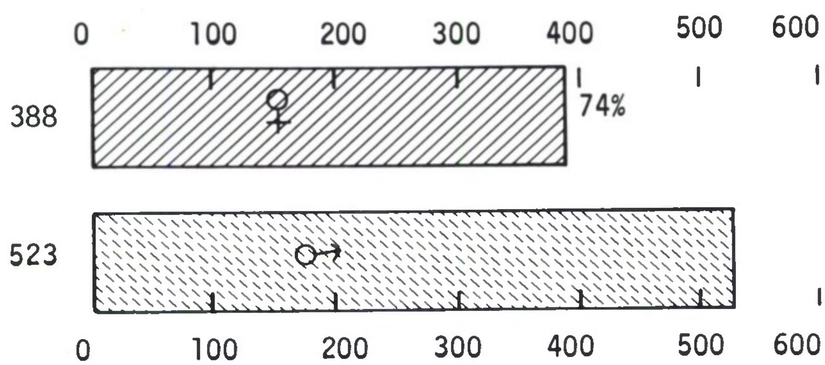


Figure 35. LEG EXTENSION

(Units are mean values in kiloponds)



Asmussen & Heeboll-Nielsen, 1961

Figure 36. LEG EXTENSION (BOTH LEGS)

TABLE 6

SUMMARY TABLE OF STATIC STRENGTH RELATED LITERATURE
(Trunk)

Variable	Sex	Mean	S.D.	% Diff.	Reference
Trunk Forward Flexion (kp)	F	40.9	7.6	67	Asmussen & Heeboll-Nielsen, 1961
	M	60.6	9.5		
	F	39.7	8.6	62	Nordgren, 1972
	M	63.8	10.9		Backlund & Nordgren, 1968
Trunk Flexor Force, Standing (kp)	F	47.0	10.4	63	Troup & Chapman, 1969
	M	75.0	13.0		
Trunk Flexor Force, Sitting (kp)	F	44.0	8.2	68	Troup & Chapman, 1969
	M	65.0	10.2		
Trunk Backward Extension (kp)	F	56.6	10.0	69	Asmussen & Heeboll-Nielsen, 1961
	M	81.6	11.8		
	F	52.3	9.1	70	Nordgren, 1972
	M	74.9	10.7		Backlund & Nordgren, 1968
Trunk Extensor Force, Standing (kp)	F	66.0	12.9	67	Troup & Chapman, 1969
	M	98.0	17.8		
Trunk Extensor Force, Sitting (kp)	F	85.0	15.6	64	Troup & Chapman, 1969
	M	132.0	22.3		
Trunkbending Sideways (kp)	F	35.5	6.6	67	Asmussen & Heeboll-Nielsen, 1961
	M	53.1	9.0		
Trunk Bending, Right Side (kp)	F	39.4	8.7	66	Nordgren, 1972
	M	59.8	11.5		Backlund & Nordgren, 1968
Trunk Bending, Left Side (kp)	F	39.8	6.9	65	Nordgren, 1972
	M	61.7	12.3		Backlund & Nordgren, 1968

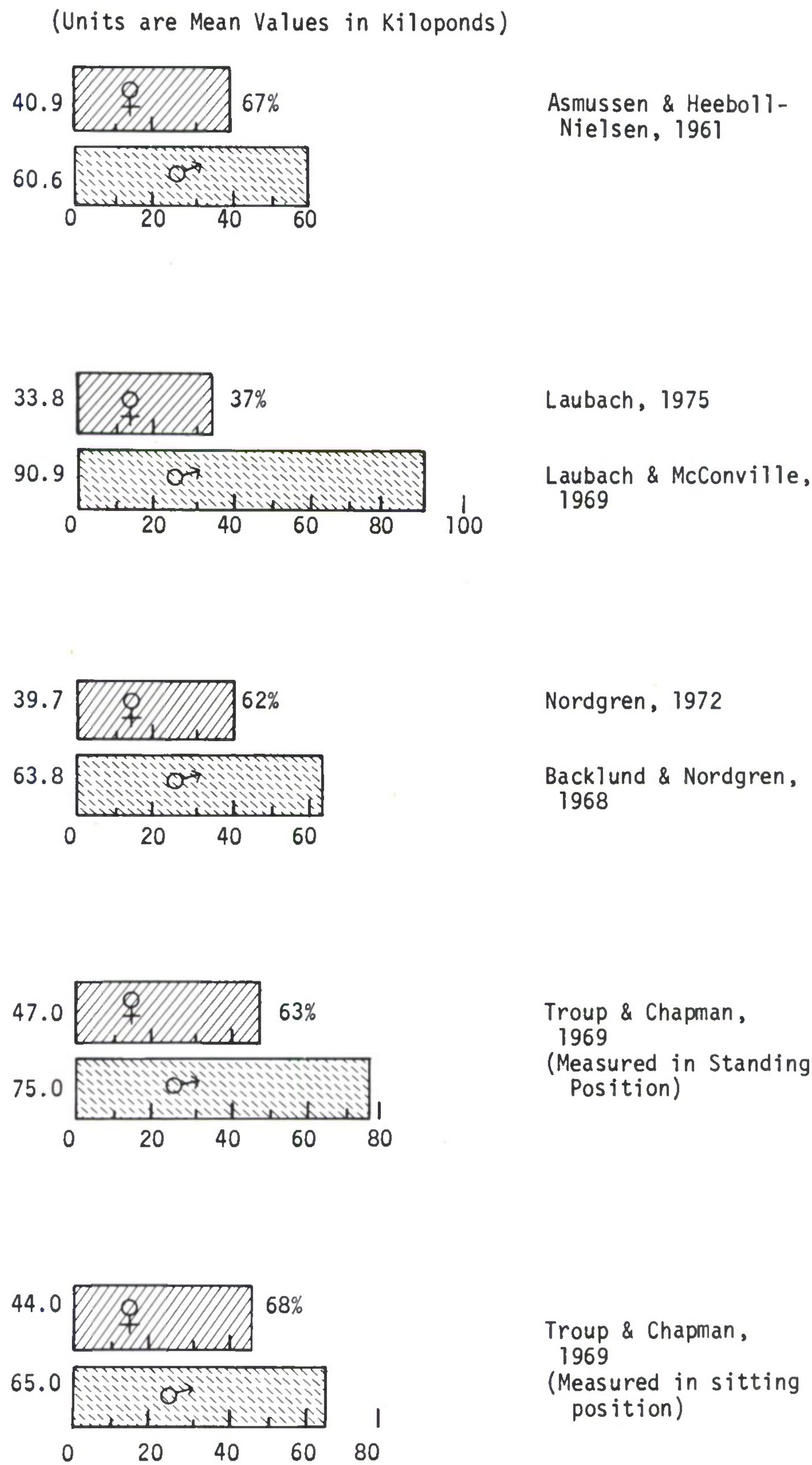


Figure 37. TRUNK FLEXION STRENGTH

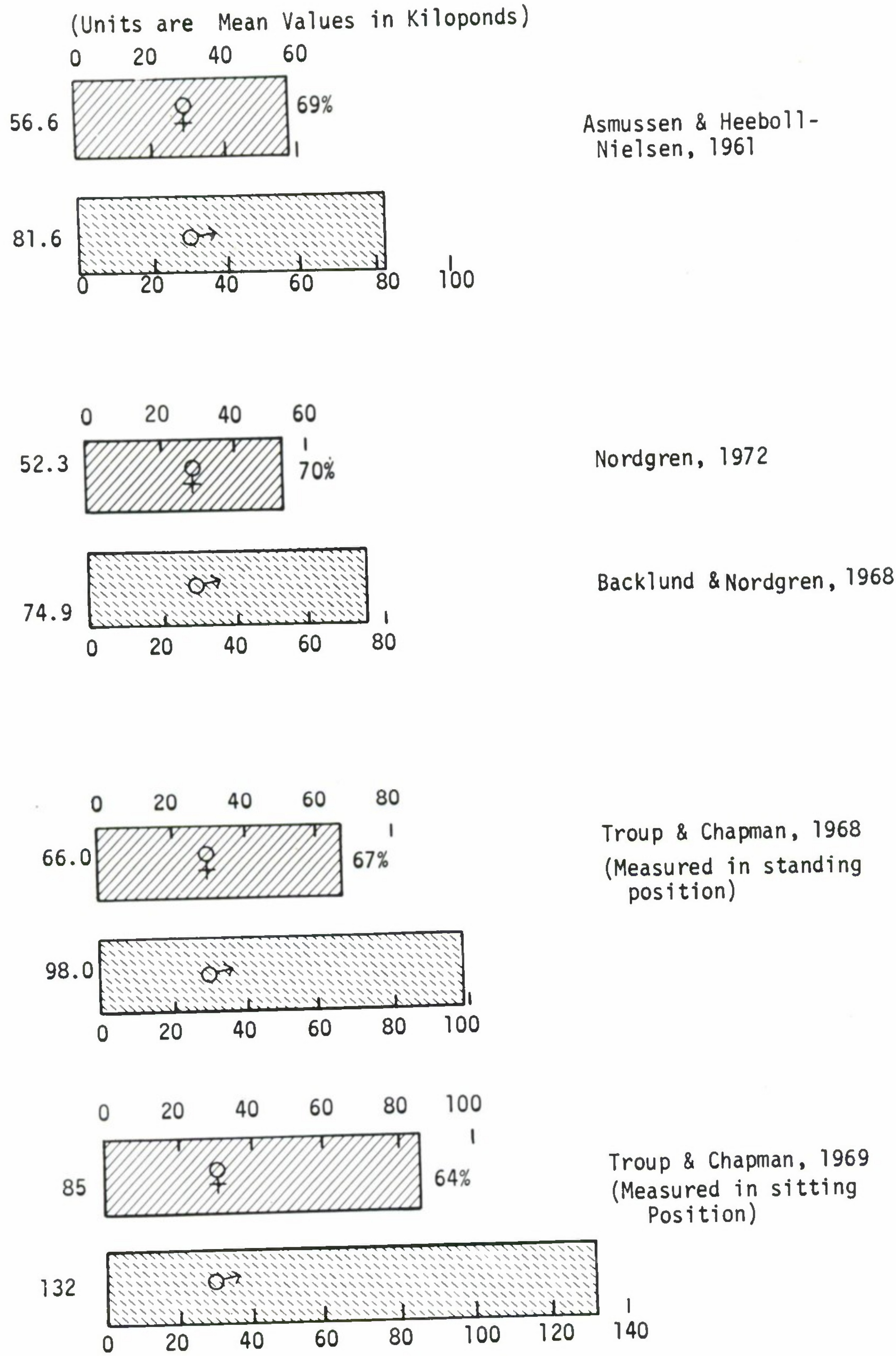


Figure 38. TRUNK EXTENSION STRENGTH

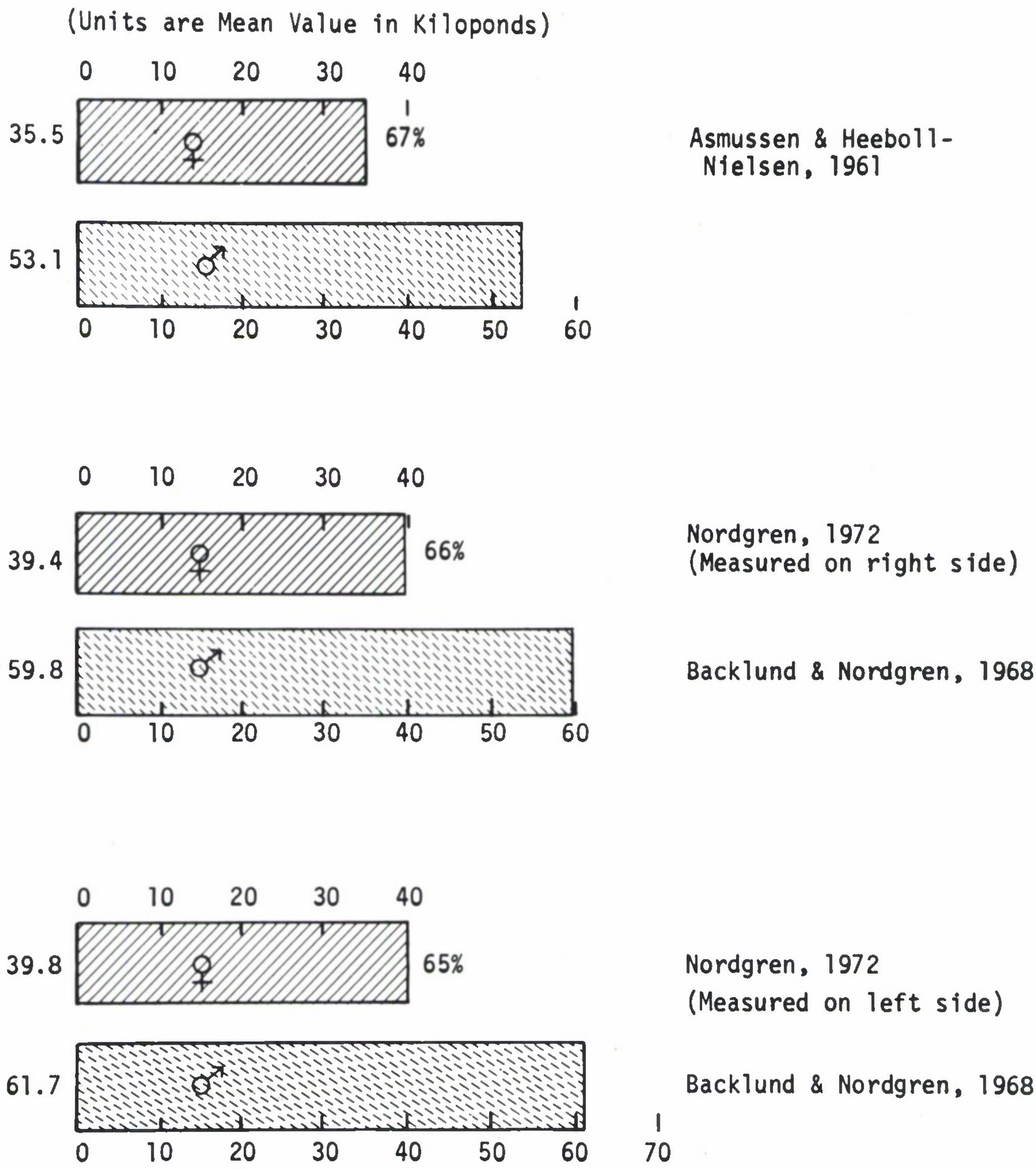


Figure 39. TRUNK BENDING SIDEWAYS STRENGTH

TABLE 7

SUMMARY TABLE OF DYNAMIC STRENGTH RELATED LITERATURE

Variable	Sex	Median	% Diff.	Reference
Maximum Weights (kg) Acceptable While Lifting a 48.3 x 34.3 x 14.0 cm. Tote Box				
Shoulder Height	F	13.2		Snook & Ciriello, 1974
to			59	
Arm Reach	M	22.2		Snook, et al., 1970
Knuckle Height	F	15.4		Snook & Ciriello, 1974
to			64	
Shoulder Height	M	24.1		Snook, et al., 1970
Floor Level	F	16.8		Snook & Ciriello, 1974
to			69	
Knuckle Height	M	24.5		Snook, et al., 1970
Maximum Weights (kg) Acceptable While Lowering a 48.3 x 34.3 x 14.0 cm. Tote Box				
Arm Reach	F	13.6		Snook & Ciriello, 1974
to			68	
Shoulder Height	M	20.0		Snook, et al., 1970
Shoulder Height	F	15.9		Snook & Ciriello, 1974
to			64	
Knuckle Height	M	25.0		Snook, et al., 1970
Knuckle Height	F	17.3		Snook & Ciriello, 1974
to			62	
Floor Level	M	28.1		Snook, et al., 1970

TABLE 7

SUMMARY TABLE OF DYNAMIC STRENGTH RELATED LITERATURE

(continued)

Variable	Sex	Median	% Diff.	Reference
Maximum Initial Forces (kp) Acceptable While Pushing and Pulling Against a Bar Set Midway Between Knuckle Height and Elbow Height				
Push	F	27.7	76	Snook & Ciriello, 1974
	M	36.3		Snook, et al., 1970
Pull	F	26.8	84	Snook & Ciriello, 1974
	M	31.8		Snook, et al., 1970
Maximum Weight (kg) Acceptable While Carrying a 48.3 x 34.3 x 14.0 cm. Tote Box at Knuckle Height (Straight-Arm Carry)				
2.13 Meters Carry	F	20.4	63	Snook & Ciriello, 1974
	M	32.2		Snook, et al., 1970
4.27 Meters Carry	F	18.6	65	Snook & Ciriello, 1974
	M	28.6		Snook, et al., 1970
8.53 Meters Carry	F	19.1	70	Snook & Ciriello, 1974
	M	27.2		Snook, et al., 1970

TABLE 7

SUMMARY TABLE OF DYNAMIC STRENGTH RELATED LITERATURE
(continued)

Variable	Sex	Median	% Diff.	Reference
Maximum Weight (kg) Acceptable While Carrying a 48.3 x 34.3 x 14.0 cm. Tote Box at Elbow Height (Bent-Arm Carry)				
2.13 Meters Carry	F	17.3	66	Snook & Ciriello, 1974
	M	26.3		Snook, et al., 1970
4.27 Meters Carry	F	17.3	75	Snook & Ciriello, 1974
	M	23.2		Snook, et al., 1970
8.53 Meters Carry	F	15.4	75	Snook & Ciriello, 1974
	M	20.4		Snook, et al., 1970

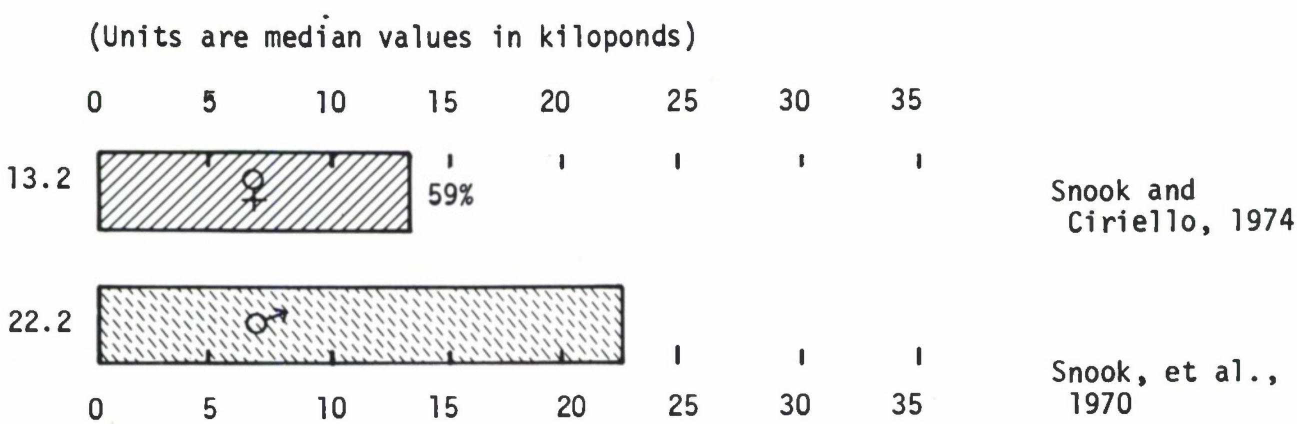


Figure 40. LIFTING - SHOULDER HEIGHT TO ARM REACH

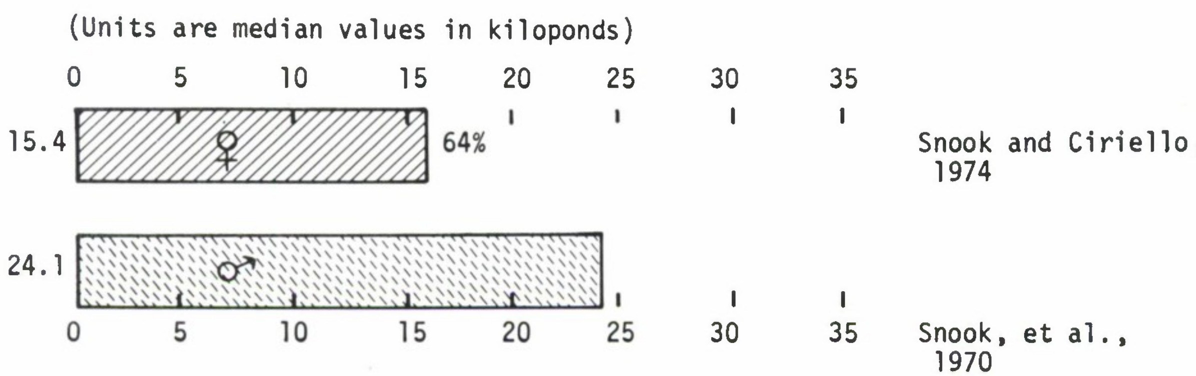


Figure 41. LIFTING - KNUCKLE HEIGHT TO SHOULDER HEIGHT

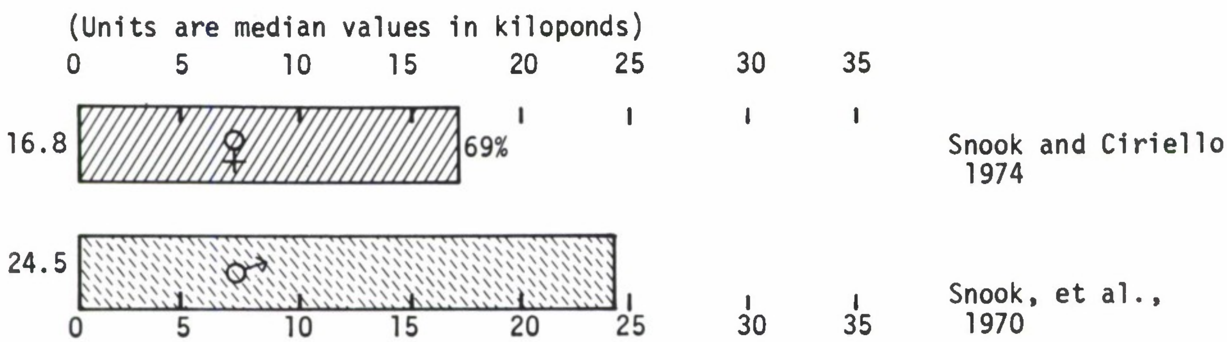


Figure 42. LIFTING - FLOOR LEVEL TO KNUCKLE HEIGHT

(Units are median values in kiloponds)

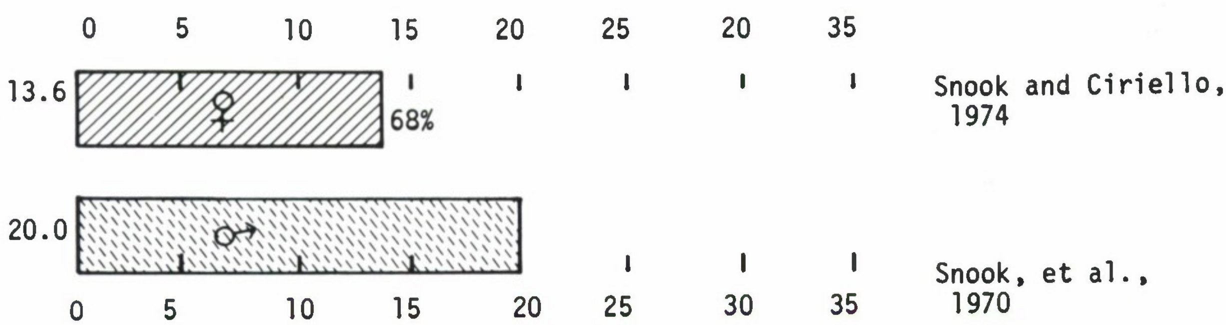


Figure 43. LOWERING - ARM REACH TO SHOULDER HEIGHT

(Units are median values in kiloponds)

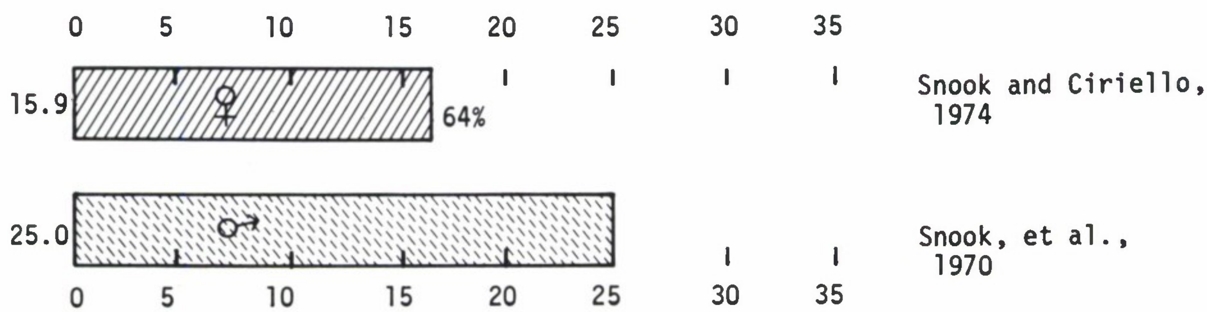


Figure 44. LOWERING - SHOULDER HEIGHT TO KNUCKLE HEIGHT

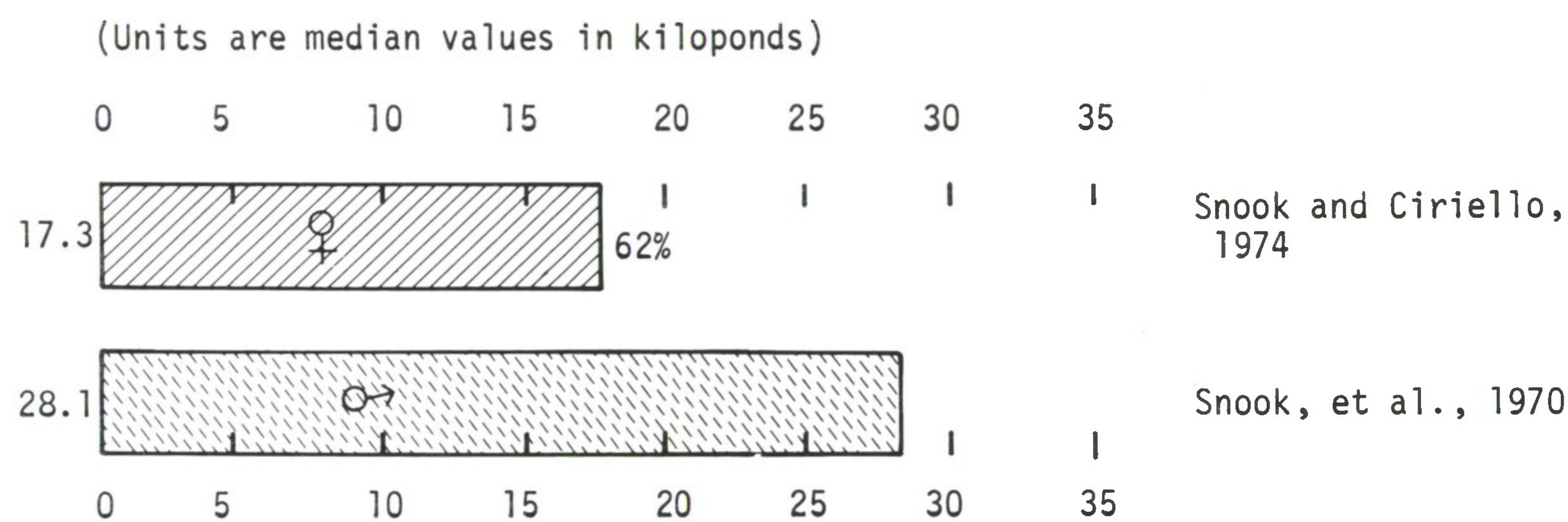


Figure 45. LOWERING - KNUCKLE HEIGHT TO FLOOR LEVEL

(Units are median values in kiloponds)

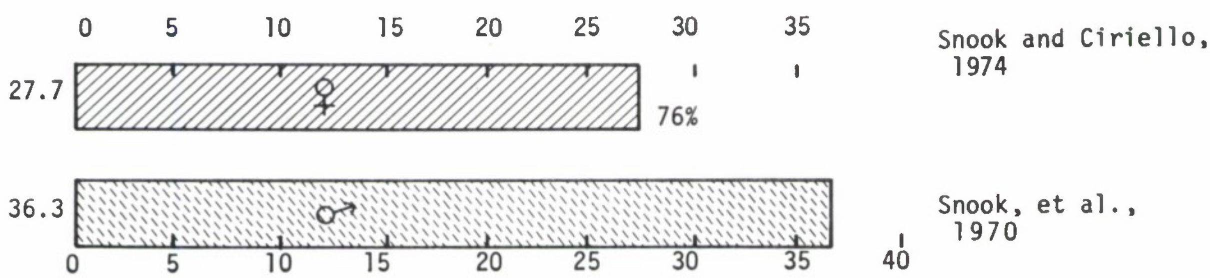


Figure 46. PUSHING

(Units are median values in kiloponds)

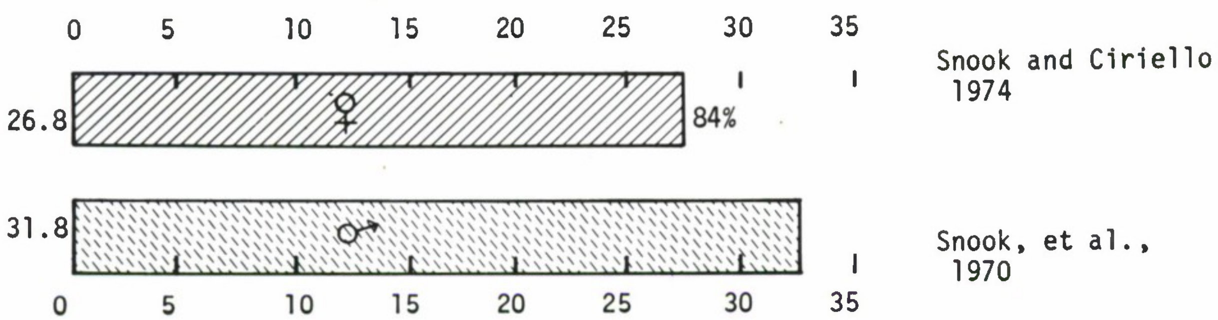


Figure 47. PULLING

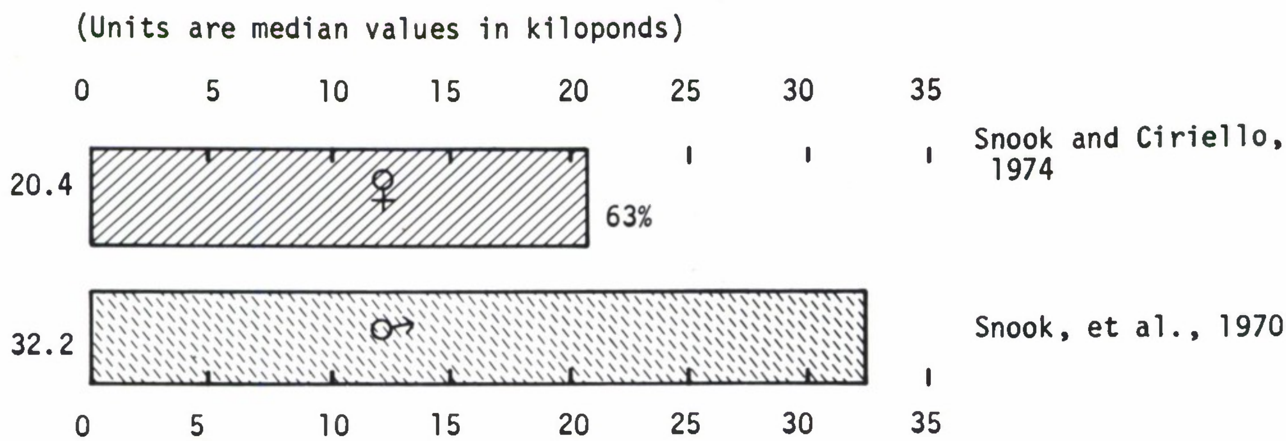


Figure 48. STRAIGHT-ARM CARRY - 2.13 METERS CARRY

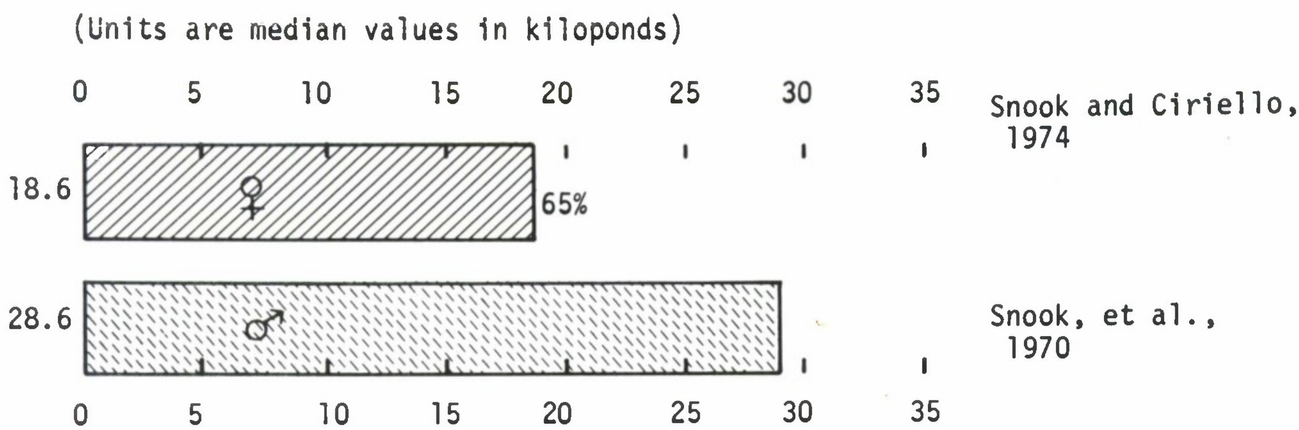


Figure 49. STRAIGHT-ARM CARRY - 4.27 METERS CARRY

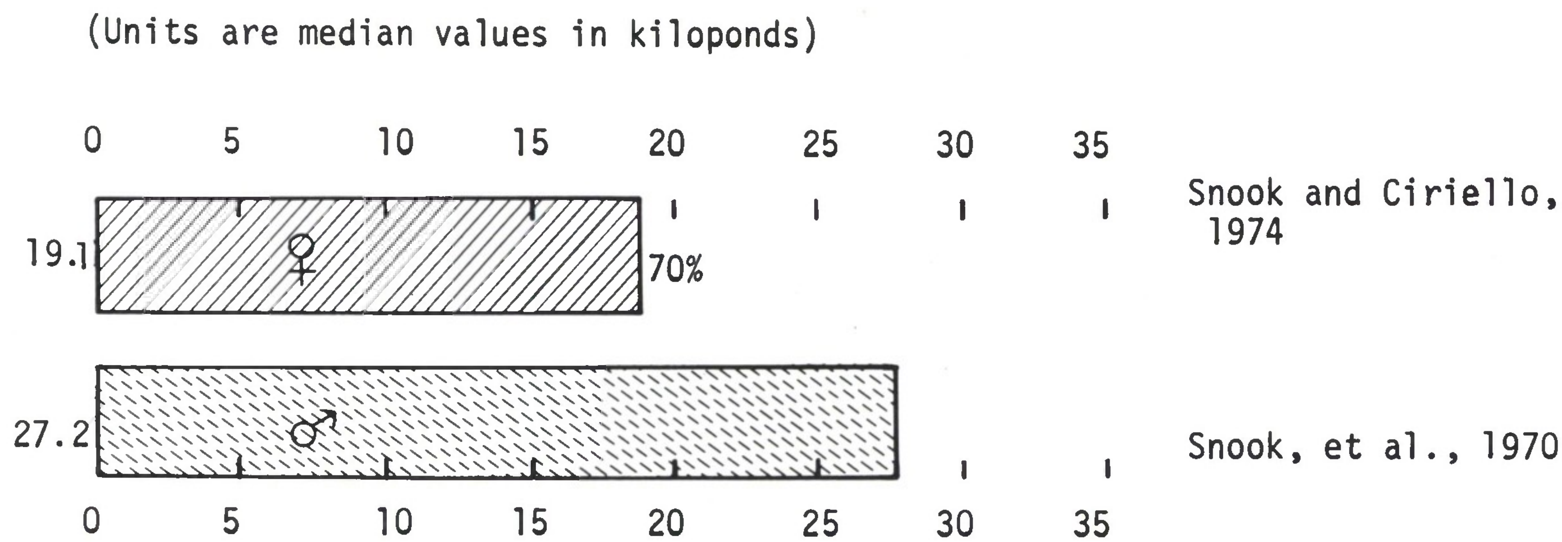


Figure 50. STRAIGHT-ARM CARRY - 8.53 METERS CARRY

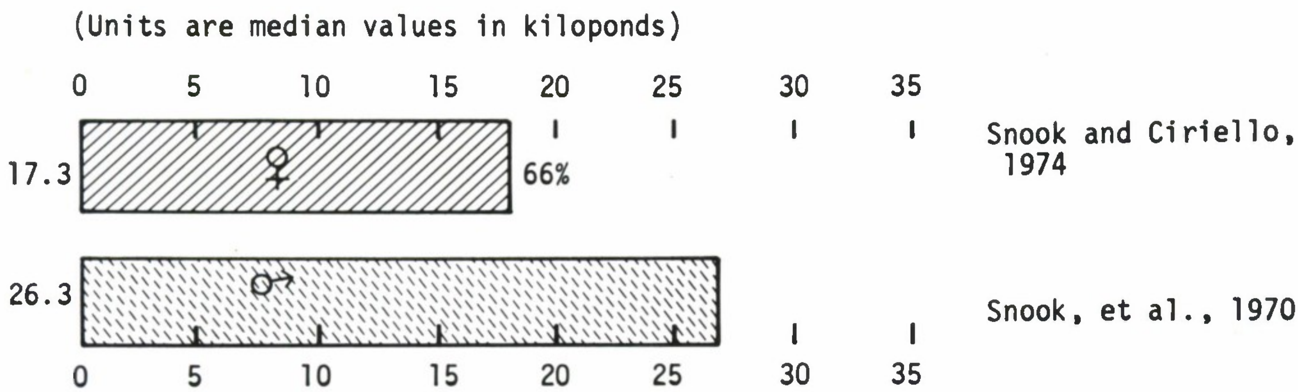


Figure 51. BENT-ARM CARRY - 2.13 METER CARRY

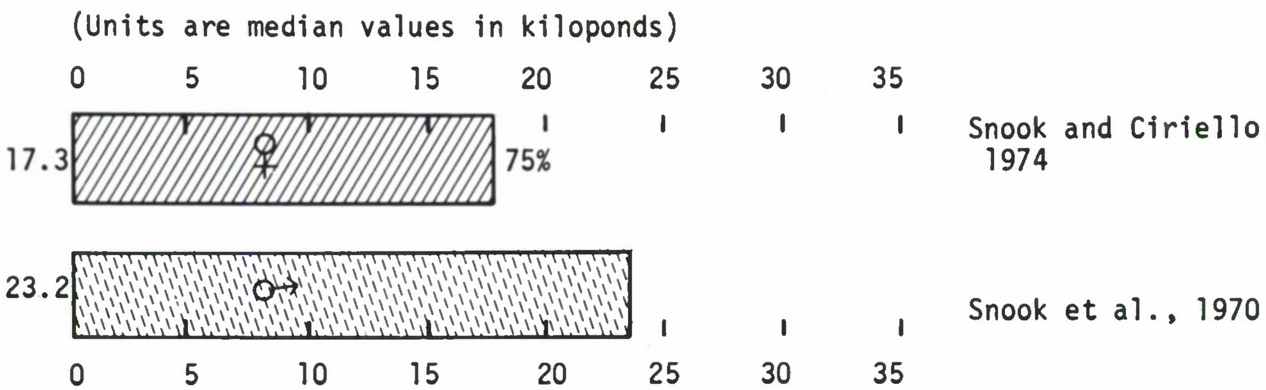


Figure 52. BENT-ARM CARRY - 4.27 METER CARRY

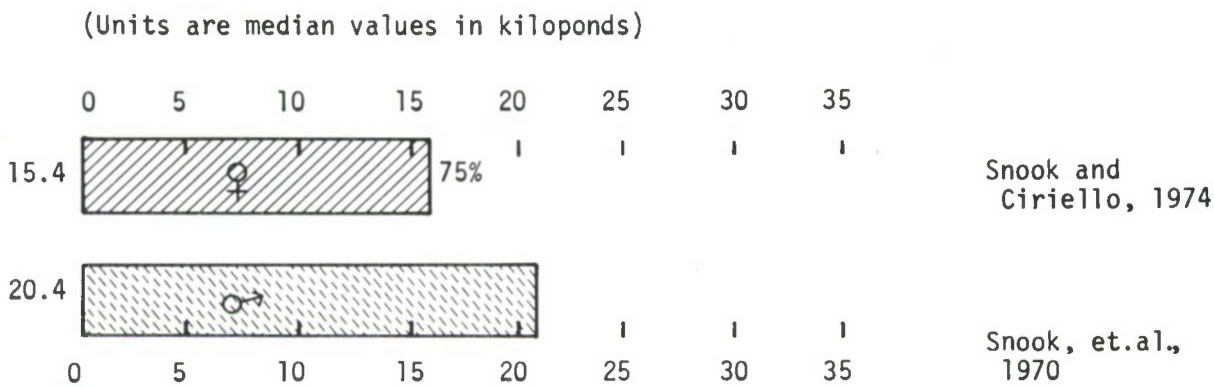


Figure 53. BENT-ARM CARRY - 8.53 METER CARRY

TABLE 8

SUMMARY TABLE OF SUBJECT CHARACTERISTICS
USED FOR COMPARATIVE PURPOSES

Variable	Sex	Mean	S.D.		Reference
Age (years)	F	20			Asmussen & Heeboll-Nielsen, 1961
	M	20			Asmussen & Heeboll-Nielsen, 1961
Height (cm.)	F	165			Asmussen & Heeboll-Nielsen, 1961
	M	175			Asmussen & Heeboll-Nielsen, 1961
Weight* (kg.)	F	58			Asmussen & Heeboll-Nielsen, 1961
	M	72			Asmussen & Heeboll-Nielsen, 1961
Number of Subjects	F			81	Asmussen & Heeboll-Nielsen, 1961
	M			96	Asmussen & Heeboll-Nielsen, 1961

****

Variable	Sex	Mean	S.D.		Reference
Age (years)	F	20			Nordgren, 1972
	M	22.3	2.3		Backlund & Nordgren, 1968
Height (cm.)	F	165.6	5.0		Nordgren, 1972
	M	183	6.2		Backlund & Nordgren, 1968
Weight (kg.)	F	57.2	6.5		Nordgren, 1972
	M	70.3	8.0		Backlund & Nordgren, 1968
Number of Subjects	F			23	Nordgren, 1972
	M			25	Backlund & Nordgren, 1968

---

*Weight was extrapolated from the average height (female = 165 cm; male = 175 cm) in relation to their age (20 yrs). The strength values that were used from Asmussen and Heeboll-Nielsen were those presented for 20 year old females with an average height of 165 cm and 20 year old males with an average height of 175 cm.

TABLE 8
(continued)

SUMMARY TABLE OF SUBJECT CHARACTERISTICS
USED FOR COMPARATIVE PURPOSES

Variable	Sex	Mean	S.D.		Reference
Age (years)	F	18.9			Troup & Chapman, 1969
	M	21.3			Troup & Chapman, 1969
Height (cm.)	F	164	5.6		Troup & Chapman, 1969
	M	176	5.7		Troup & Chapman, 1969
Weight (kg.)	F	61	5.7		Troup & Chapman, 1969
	M	73	8.6		Troup & Chapman, 1969
Number of Subjects	F			132	Troup & Chapman, 1969
	M			98	Troup & Chapman, 1969
**					
Age (years)	F	38.5			Snook & Ciriello, 1974
	M	39.9			Snook, et al., 1970
Height (cm.)	F	160.9	3.8		Snook & Ciriello, 1974
	M	170.1	6.2		Snook, et al., 1970
Weight (kg.)	F	65.6	16.2		Snook & Ciriello, 1974
	M	74.6	9.8		Snook, et al., 1970
Number of Subjects	F			15	Snook & Ciriello, 1974
	M			28	Snook, et al., 1970

TABLE 8

(continued)

SUMMARY TABLE OF SUBJECT CHARACTERISTICS USED FOR COMPARATIVE PURPOSES

Variable	Sex	Mean	S.D.		Reference
Age (years)	F	20.7	1.9		This Study
	M	20.7	1.7		Kroemer, 1969
Height (cm.)	F	165.0	6.0		This Study
	M	177.4	5.1		Kroemer, 1969
Weight (kg.)	F	58.4	6.6		This Study
	M	76.5	11.1		Kroemer, 1969
Number of Subjects	F			31	This Study
	M			45	Kroemer, 1969
**					
Age (years)	F	20.7	1.9		This Study
	M	21.1	4.5		Laubach & McConville, 1969
Height (cm.)	F	165.0	6.0		This Study
	M	175.7	6.5		Laubach & McConville, 1969
Weight (kg.)	F	58.4	6.6		This Study
	M	71.2	9.9		Laubach & McConville, 1969
Number of Subjects	F			31	This Study
	M			77	Laubach & McConville, 1969

SECTION V

DISCUSSION OF RESULTS

The primary purpose of this study was to present comparable muscle strength capabilities of women and men. This has been accomplished in a series of tables and graphical presentations that are shown in the previous section of this report.

It is interesting to note in Tables 2 and 3 that the fifth percentile value for a particular strength measurement for men often exceeds the ninety-fifth percentile value for women; e.g., the fifth percentile value for men in shoulder flexion is 31.3 kiloponds while the ninety-fifth percentile value for women for shoulder flexion is 28.9 kiloponds. This, obviously, is not the case in all situations; e.g., see hip flexion, but is true in four of the cable tension strength items and two of the six push force measurements. 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 fifth percentile values for design purposes.

In reviewing the muscle strength related literature to about 1961, Hettinger (1961) has substantiated the statement "that general muscle strength in women is about two-thirds that of men." Hettinger points out that this is only an average figure which should be used only for general calculations and does not apply to all muscle groups. A summarization of the data reported in this study and the related materials reports in the literature tend to confirm Hettinger's thesis; i.e., the "overall" muscle strength of women is about 63.5% that of men. However, we want to elaborate on this subject in more detail as follows. For the static strength measurements of the upper extremities (Table 4), we have found an average mean percentage difference of 59.5%* between women and men. However, this mean percentage difference in the upper extremities ranges from 44% to 79%. The strength in the lower extremities of women compared to men averages 71.9% with a range of 57% to 86% (Table 5). Trunk strength differences of 63.8% were found to exist between women and men with a range of 37% to 70% (Table 6). The indicators of dynamic strength (Table 7) which included primarily measures of lifting, lowering, pulling, and pushing revealed median percentage differences that averaged 68.6% and ranged in magnitude from 59% to 84%.

Table 9 is a summarization of the averaged mean percentage differences and the range of mean percentage differences that were found to exist in muscle strength capabilities of women and men. The major objective of this table is to emphasize the broad range of mean percentage differences that were found to exist in selected muscle strength dimensions. The reported mean percentage differences shown in Table 9 should be used

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*This value was obtained by simply summing the mean percentage difference values in Table 4 and finding their arithmetic average.

only for general informational purposes; if more "exacting" information is desired, the reader should refer to the more specific information presented in Tables 2, 3, 4, 5, 6, and 7.

TABLE 9

AVERAGE MEAN PERCENTAGE DIFFERENCES OF MUSCLE STRENGTH OF WOMEN AND MEN

	Mean Percentage Difference	Range
Total Body Strength*	63.5%	35% - 86%
Upper Extremities**	59.5%	44% - 79%
Lower Extremities**	71.9%	57% - 86%
Trunk**	63.8%	37% - 70%
Dynamic***	68.6%	59% - 84%

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* Includes static and dynamic measurements.

** Static muscle strength.

*** Primarily muscle strength measurements involving lifting, lowering, pulling, and pushing. These values are median percentage differences.

For the designer who needs an estimate of female muscle strength (we are assuming that the strength data are available for males but not for females) we recommend the following:

(1) Select a test item from Tables 2-7 that most closely approximates the strength movement which you have available data for; e.g., if the movement approximates the Horizontal Pull as described by Nordgren (1972) and Backlund and Nordgren (1968), use the percentage difference of 61 in your calculations.

(2) Assume that the data you have obtained from your sample of male subjects yield a mean value of 50 units with a standard deviation of 10 units.

(3) To calculate the estimated fifth percentile value for men multiply 1.65 times 10 units (S.D.) to give 16.5 units. Subtract 16.5 units from 50 units (Mean) to give 33.5 units for the estimated fifth percentile value for men.

(4) Take the fifth percentile value for men (33.5) and multiply by the percentage difference (61%)* to give 20.4 units for the estimated fifth percentile value for females.

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*It was shown in Figures 1-12 that the percentage differences between female and male strength were, in general, similar at the 5%ile, mean, and 95%ile values; e.g., Figure 2 - Elbow Flexion - the percentage difference between female and male strength is 45%, 44%, and 43%, at the 5%ile, mean, and 95%ile values, respectively.

Correlations Among Measurements

The complete intercorrelation matrix for the 26 anthropometric and 12 muscle strength measurements studied in this research is shown in Appendix I. In general, the correlations between the strength exertions and the anthropometric dimensions were rather low. None of the correlation coefficients among the strength and the anthropometric measurements reached 0.70. This was not an unexpected finding as it has been well documented in previous research pertaining to men (Laubach and McConville, 1969; and Laubach, Kroemer, and Thordsen, 1972) that measures of body size, composition, and physique are not effective predictors of muscle strength. The actual correlation coefficients among the anthropometric and strength variables for the women were somewhat greater (i.e., in terms of statistical differences) than those of the men. Table 10 is a summarization of the correlation coefficients among the anthropometric and strength variables for women and men. The comparative data for men comes from Laubach and McConville, 1969.

TABLE 10

SELECTED CORRELATION COEFFICIENTS AMONG ANTHROPOMETRIC AND STRENGTH VARIABLES FOR WOMEN AND MEN

	Sex	Hip Flexion	Trunk Flexion	Elbow Flexion	Shoulder Flexion	Knee Extension	Grip Strength
Weight	F	.33	.54	.28	.33	.45	.55
	M	.30	.39	.50	.40	.19	.41
Stature	F	.41	.54	.41	.48	.56	.59
	M	.17	.13	.29	.17	.00	.31
SKF:Triceps	F	.05	.03	-.04	-.13	-.13	.08
	M	.06	.07	.00	-.01	-.04	-.03
SKF:Subscapular	F	-.13	.22	-.08	.01	.05	.18
	M	-.06	.05	.00	.00	-.08	-.06
SKF:Suprailiac	F	-.14	.14	-.05	-.18	-.07	-.08
	M	-.09	.11	.10	-.05	-.09	-.09

The number of subjects in the women's data was 31. A correlation coefficient of 0.36 is statistically greater than zero at the 0.05 level of confidence for n=31.

The number of subjects in the men's data was 77. A correlation coefficient of 0.22 is statistically greater than zero at 0.05 level of confidence for n=77.

SECTION VI

SUMMARY AND CONCLUSIONS

This report contains experimental data on the maximal static strength that female subjects (n=31) could exert in twelve different test positions. These reported values are directly compared with muscular strength test scores obtained from two groups of male subjects. Also shown in this report is an extensive review of the muscle strength literature that compares strength capabilities of women and men.

The data show that the "overall" total body strength of women as compared to men is about 63.5%; however, this value may range from 35 to 86%. Static strength in the upper extremities of women was found to be 59.5% that of men, ranging from 44 to 79%. Strength of the lower extremities of women was found to be 71.9% that of men with a range of 57 to 86%. Women's trunk strength was found to be 63.8% that of men with a range of 37 to 70%. The dynamic strength characteristics, which included lifting, lowering, pushing, and pulling tasks, of women was found to average 68.6% that of men, ranging from 59 to 84%.

The correlations between the strength values and the anthropometric dimensions were generally too low to have practical predictive value. The same type of finding has also been well documented in research on men.

Tables 2 - 7 and Figures 1 - 53 show in detail selected descriptive statistics for each of the muscle strength measurements that were compared between the women and men. These data should be of value for researchers working in design engineering, biomechanics, industrial engineering, sports medicine, and ergonomics to name a few.

APPENDIX I

INTERCORRELATION MATRIX FOR THE ANTHROPOMETRIC AND MUSCLE STRENGTH MEASUREMENTS

The intercorrelation matrix shown on the following pages lists the correlation coefficients between the 26 anthropometric and 12 muscle strength measurements. The legend for the intercorrelation matrix lists the variable number and the variable name for each of the 38 dimensions.

The intercorrelation matrix is read as follows: The correlation coefficient between variable 1 (Age) and variable 2 (Weight) is -.41, between variable 1 (Age) and variable 3 (Height) is -.35 and so on.

A correlation coefficient of 0.36 is statistically greater than zero at the 0.05 level of confidence for n=31.

LEGEND FOR INTERCORRELATION MATRIX

Variable Number	Variable Name	Variable Number	Variable Name
1.	AGE	27.	SHOULDER FLEXION
2.	WEIGHT	28.	ELBOW FLEXION
3.	STATURE	29.	HIP FLEXION
4.	ACROMIAL HEIGHT	30.	KNEE EXTENSION
5.	SITTING HEIGHT	31.	TRUNK FLEXION
6.	ACROMIALE-RADIALE LENGTH	32.	GRIP STRENGTH
7.	RADIALE-STYLION LENGTH		
8.	TIBIALE HEIGHT	33.	FORWARD PUSH WITH BOTH HANDS--Reaction Force Provided by Floor and Footrest
9.	LATERAL MALLEOLUS HEIGHT		
10.	THUMB-TIP REACH		
11.	LATERAL THUMB-TIP REACH		
12.	BICEPS CIRCUMFERENCE, RELAXED	34.	LATERAL PUSH WITH THE SHOULDER--Reaction Force Provided by Floor and Footrest
13.	BICEPS CIRCUMFERENCE, FLEXED		
14.	FOREARM CIRCUMFERENCE, RELAXED		
15.	CALF CIRCUMFERENCE	35.	FORWARD PUSH WITH BOTH HANDS--Reaction Force Provided by a Vertical Wall
16.	HAND LENGTH		
17.	HUMERUS BREADTH		
18.	FEMUR BREADTH		
19.	SKINFOLD:TRICEPS	36.	BACKWARD PUSH--Reaction Force Provided by a Vertical Wall
20.	SKINFOLD:SUBSCAPULAR		
21.	SKINFOLD:SUPRAILIAC		
22.	SKINFOLD:MEDIAL CALF	37.	LATERAL PUSH WITH ONE HAND--Reaction Force Provided by a Vertical Wall
23.	ENDOMORPHY		
24.	MESOMORPHY		
25.	ECTOMORPHY	38.	FORWARD PUSH WITH ONE HAND--Reaction Force Provided a Vertical Wall
26.	LEG LENGTH		

INTERCORRELATION MATRIX

Variable Number	1	2	3	4	5	6	7	8	9	10
1	1.00	-.41	-.35	-.33	-.42	-.11	-.13	-.05	-.25	-.33
2	-.41	1.00	.58	.53	.54	.53	.42	.45	.33	.38
3	-.35	.58	1.00	.98	.77	.74	.59	.81	.63	.47
4	-.33	.53	.98	1.00	.72	.73	.57	.83	.62	.46
5	-.42	.54	.77	.72	1.00	.33	.22	.43	.42	.13
6	-.11	.53	.74	.73	.33	1.00	.70	.77	.37	.59
7	-.13	.42	.59	.57	.22	.70	1.00	.58	.34	.50
8	-.05	.45	.81	.83	.43	.77	.58	1.00	.56	.49
9	-.25	.33	.63	.62	.42	.37	.34	.56	1.00	.31
10	-.33	.38	.47	.46	.13	.59	.50	.49	.31	1.00
11	-.23	.62	.77	.74	.35	.85	.76	.83	.45	.69
12	-.04	.61	.01	-.04	.18	.01	.08	-.03	.03	-.26
13	.01	.54	.02	-.04	.15	.03	.14	.01	-.02	-.27
14	-.30	.79	.27	.21	.28	.29	.35	.19	.29	.08
15	-.28	.75	.18	.13	.34	.20	.12	.09	.18	.06
16	-.12	.55	.62	.61	.20	.69	.54	.71	.56	.65
17	-.32	.75	.66	.62	.47	.60	.46	.56	.52	.37
18	-.32	.60	.41	.37	.30	.31	.22	.40	.59	.15
19	.12	.43	-.17	-.20	-.01	-.05	-.09	-.06	-.17	-.03
20	.14	.50	-.03	-.11	-.02	.20	.12	-.02	-.16	.06
21	-.10	.49	-.06	-.08	-.05	.11	.09	-.05	-.17	.24
22	-.07	.24	-.26	-.29	-.11	-.13	-.05	-.18	-.01	-.20
23	.02	.54	-.09	-.13	-.04	.12	.08	-.02	-.18	.16
24	.11	.29	-.48	-.53	-.24	-.31	-.25	-.42	-.21	-.41
25	.10	-.51	.40	.42	.19	.20	.19	.34	.32	.12

INTERCORRELATION MATRIX
(Continued)

Variable Number	1	2	3	4	5	6	7	8	9	10
26	-.21	.46	.90	.91	.42	.82	.70	.87	.61	.59
27	.01	.33	.48	.44	.42	.41	.44	.50	.17	.24
28	-.11	.28	.41	.42	.38	.32	.28	.23	.08	.13
29	-.30	.33	.41	.36	.45	.28	.26	.26	.04	.22
30	-.17	.45	.56	.52	.50	.39	.52	.48	.40	.35
31	-.28	.54	.54	.50	.36	.48	.54	.59	.32	.47
32	-.15	.55	.59	.54	.45	.54	.36	.56	.36	.41
33	-.18	.43	.48	.48	.61	.20	.18	.30	.24	.03
34	-.07	.38	.42	.40	.33	.37	.31	.51	.27	.13
35	-.07	.14	.32	.25	.41	.08	.22	.21	.29	-.07
36	-.16	.24	.58	.58	.55	.40	.34	.45	.33	.22
37	-.10	.36	.39	.37	.51	.23	.24	.29	.18	-.07
38	.02	-.03	.12	.06	.18	-.07	-.05	.10	.27	-.11

INTERCORRELATION MATRIX
(Continued)

Variable Number	11	12	13	14	15	16	17	18	19	20
1	-.23	-.04	.01	-.30	-.28	-.12	-.32	-.32	.12	.14
2	.62	.61	.54	.79	.75	.55	.75	.60	.43	.50
3	.77	.01	.02	.27	.18	.62	.66	.41	-.17	-.03
4	.74	-.04	-.04	.21	.13	.61	.62	.37	-.20	-.11
5	.35	.18	.15	.28	.34	.20	.47	.30	-.01	-.02
6	.85	.01	.03	.29	.20	.69	.60	.31	-.05	.20
7	.76	.08	.14	.35	.12	.54	.46	.22	-.09	.12
8	.83	-.03	.01	.19	.09	.71	.56	.40	-.06	-.02
9	.45	.03	-.02	.29	.18	.56	.52	.59	-.17	-.16
10	.69	-.26	-.27	.08	.06	.65	.37	.15	-.03	.06
11	1.00	.06	.09	.36	.17	.77	.60	.42	-.09	.21
12	.06	1.00	.97	.85	.67	.05	.33	.41	.55	.59
13	.09	.97	1.00	.81	.59	.02	.28	.36	.55	.56
14	.36	.85	.81	1.00	.76	.30	.67	.64	.46	.53
15	.17	.67	.59	.76	1.00	.23	.62	.63	.58	.29
16	.77	.05	.02	.30	.23	1.00	.57	.56	-.05	.13
17	.60	.33	.28	.67	.62	.57	1.00	.65	.19	.13
18	.42	.41	.36	.64	.63	.56	.65	1.00	.17	.08
19	-.09	.55	.55	.46	.58	-.05	.19	.17	1.00	.49
20	.21	.59	.56	.53	.29	.13	.13	.08	.49	1.00
21	.11	.34	.30	.35	.42	.13	.11	.01	.59	.68
22	-.15	.38	.38	.40	.48	-.20	.20	.17	.68	.31
23	.13	.52	.49	.48	.45	.13	.12	.10	.76	.85
24	-.31	.74	.70	.60	.67	-.16	.14	.37	.58	.39
25	.13	-.66	-.58	-.56	-.63	.07	-.12	-.21	-.63	-.58

INTERCORRELATION MATRIX
(Continued)

Variable Number	11	12	13	14	15	16	17	18	19	20
26	.86	-.10	-.08	.19	.02	.75	.62	.38	-.24	-.03
27	.47	.17	.17	.24	.13	.36	.36	.13	-.13	.01
28	.19	.07	.06	.11	.02	.23	.24	-.04	-.04	-.08
29	.31	.12	.16	.20	.23	.29	.41	.13	.05	-.13
30	.54	.06	.02	.24	.21	.44	.50	.25	-.13	.05
31	.68	.28	.29	.35	.22	.54	.35	.24	.03	.22
32	.61	.25	.26	.41	.25	.51	.57	.28	.08	.18
33	.23	.24	.18	.34	.30	.01	.50	.12	.11	.05
34	.44	.18	.18	.33	.21	.28	.53	.20	.08	.10
35	.16	.00	-.05	.13	.15	-.06	.38	.14	-.14	-.06
36	.39	-.09	-.10	.06	.10	.31	.41	.19	-.11	-.30
37	.15	.23	.19	.33	.38	-.04	.55	.18	.27	.00
38	-.02	.05	.00	.07	.01	-.21	.17	.05	-.04	.04

INTERCORRELATION MATRIX
(Continued)

Variable Number	21	22	23	24	25	26	27	28	29	30
1	-.10	-.07	.02	.11	.10	-.21	.01	-.11	-.30	-.17
2	.49	.24	.54	.29	-.51	.46	.33	.28	.33	.45
3	-.06	-.26	-.09	-.48	.40	.90	.48	.41	.41	.56
4	-.08	-.29	-.13	-.53	.42	.91	.44	.42	.36	.52
5	-.05	-.11	-.04	-.24	.19	.42	.42	.38	.45	.50
6	.11	-.13	.12	-.31	.20	.82	.41	.32	.28	.39
7	.09	-.05	.08	-.25	.19	.70	.44	.28	.26	.52
8	-.05	-.18	-.02	-.42	.34	.87	.50	.23	.26	.48
9	-.17	-.01	-.18	-.21	.32	.61	.17	.08	.04	.40
10	.24	-.20	.16	-.41	.12	.59	.24	.13	.22	.35
11	.11	-.15	.13	-.31	.13	.86	.47	.19	.31	.54
12	.34	.38	.52	.74	-.66	-.10	.17	.07	.12	.06
13	.30	.38	.49	.70	-.58	-.08	.17	.06	.16	.02
14	.35	.40	.48	.60	-.56	.19	.24	.11	.20	.24
15	.42	.49	.45	.67	-.63	.02	.13	.02	.23	.21
16	.13	-.20	.13	-.16	.07	.75	.36	.23	.29	.44
17	.11	.20	.12	.14	-.12	.62	.36	.24	.41	.50
18	.01	.17	.10	.37	-.21	.38	.13	-.04	.13	.25
19	.59	.68	.76	.58	-.63	-.24	-.13	-.04	.05	-.13
20	.68	.31	.85	.39	-.58	-.03	.01	-.08	-.13	.05
21	1.00	.48	.70	.32	-.57	-.05	-.18	-.05	-.14	-.07
22	.48	1.00	.55	.56	-.51	-.30	-.44	-.32	-.17	-.22
23	.90	.55	1.00	.43	-.67	-.10	-.16	-.09	-.10	-.05
24	.32	.56	.43	1.00	-.80	-.52	-.14	-.18	-.08	-.17
25	-.57	-.51	-.67	-.80	1.00	.44	.13	.13	.07	.08

INTERCORRELATION MATRIX
(Continued)

Variable Number	21	22	23	24	25	26	27	28	29	30
26	-.05	-.30	-.10	-.52	.44	1.00	.40	.32	.28	.46
27	-.18	-.44	-.16	-.14	.13	.40	1.00	.54	.45	.69
28	-.05	-.32	-.09	-.18	.13	.32	.54	1.00	.46	.36
29	-.14	-.17	-.10	-.08	.07	.28	.45	.46	1.00	.44
30	-.07	-.22	-.05	-.17	.08	.46	.69	.36	.44	1.00
31	.14	-.18	.19	-.17	-.04	.52	.63	.25	.53	.57
32	-.08	-.27	.03	-.10	.00	.53	.70	.45	.68	.61
33	.04	.01	.01	-.03	.02	.27	.58	.52	.34	.54
34	-.05	-.01	.03	-.02	.03	.37	.58	.39	.61	.57
35	-.21	.07	-.18	-.07	.17	.18	.37	.12	.19	.60
36	-.35	-.21	-.30	-.29	.36	.45	.42	.58	.68	.51
37	-.05	.24	.03	.08	.01	.21	.41	.41	.35	.45
38	-.16	.08	-.09	-.03	.17	.05	.20	.01	-.17	.30

INTERCORRELATION MATRIX

(Continued)

Variable Number	31	32	33	34	35	36	37	38
1	-.28	-.15	-.18	-.07	-.07	-.16	-.10	.02
2	.54	.55	.43	.38	.14	.24	.36	-.03
3	.54	.59	.48	.42	.32	.58	.39	.12
4	.50	.54	.48	.40	.25	.58	.37	.06
5	.36	.45	.61	.33	.41	.55	.51	.18
6	.48	.54	.20	.37	.08	.40	.23	-.07
7	.54	.36	.18	.31	.22	.34	.24	-.05
8	.59	.56	.30	.51	.21	.45	.29	.10
9	.32	.36	.24	.27	.29	.33	.18	.27
10	.47	.41	.03	.13	-.07	.22	-.07	-.11
11	.68	.61	.23	.44	.16	.39	.15	-.02
12	.28	.25	.24	.18	.00	-.09	.23	.05
13	.29	.26	.18	.18	-.05	-.10	.19	.00
14	.35	.41	.34	.33	.13	.06	.33	.07
15	.22	.25	.30	.21	.15	.10	.38	.01
16	.54	.51	.01	.28	-.06	.31	-.04	-.21
17	.35	.57	.50	.53	.38	.41	.55	.17
18	.24	.28	.12	.20	.14	.19	.18	.05
19	.03	.08	.11	.08	-.14	-.11	.27	-.04
20	.22	.18	.05	.10	-.06	-.30	.00	.04
21	.14	-.08	.04	-.05	-.21	-.35	-.05	-.16
22	-.18	-.27	.01	-.01	.07	-.21	.24	.08
23	.19	.03	.01	.03	-.18	-.30	.03	-.09
24	-.17	-.10	-.03	-.02	-.07	-.29	.08	-.03
25	-.04	.00	.02	.03	.17	.36	.01	.17

INTERCORRELATION MATRIX
(Continued)

Variable Number	31	32	33	34	35	36	37	38
26	.52	.53	.27	.37	.18	.45	.21	.05
27	.63	.70	.58	.58	.37	.42	.41	.20
28	.25	.45	.52	.39	.12	.58	.41	.01
29	.53	.68	.34	.61	.19	.68	.35	-.17
30	.57	.61	.54	.57	.60	.51	.45	.30
31	1.00	.71	.29	.53	.12	.30	.14	.01
32	.71	1.00	.50	.74	.24	.58	.33	.06
33	.29	.50	1.00	.66	.60	.52	.79	.44
34	.53	.74	.66	1.00	.53	.64	.65	.29
35	.12	.24	.60	.53	1.00	.49	.72	.78
36	.30	.58	.52	.64	.49	1.00	.60	.19
37	.14	.33	.79	.65	.72	.60	1.00	.56
38	.01	.06	.44	.29	.78	.19	.56	1.00

APPENDIX II

STATISTICAL PROCEDURES AND TERMINOLOGY

The statistical measures selected to summarize the experimental data were chosen as the ones which we hope will provide most potential users with the maximum of useful information.

Briefly described, these statistics are:

The arithmetic mean. This is the most common of the averages and is computed as the sum of the values divided by the number of values. In formula, the mean equals

$$\bar{x} = \frac{\Sigma x}{n}$$

where Σ is the summation operator, x represents the individual values, and n is the number of values. The mean is designated by $\bar{x}$ or mean in this study.

The standard deviation. The standard deviation is the basic measure of variability. If most of a set of data cluster close to their mean value, the standard deviation will be small. If, on the other hand, many of the data are either much smaller or much larger than the mean, the standard deviation will be large. By definition, the standard deviation is the square root of the average (i.e., arithmetic mean) of the squared deviations from the mean value. In formula, the standard deviation equals

$$SD = \sqrt{\Sigma (x-\bar{x}) 2/n}$$

where Σ is the summation operator, x represents the individual values, $\bar{x}$ their arithmetic mean, and n the number of values.

A useful way of conceptualizing the standard deviation is to consider the middle two-thirds of a set of data such as the values of stature. The smallest value in this middle two-thirds will be about one standard deviation below the mean value and the largest value in this set will be roughly equal to the mean value plus one standard deviation. Similarly, the middle 95 percent of the data will have values ranging from approximately two standard deviations below the mean to two standard deviations above it. Almost all of them will fall within the range from three standard deviations below the mean to three standard deviations above it. The standard deviation is designated by SD in this study.

The coefficient of variation. This statistic is a restatement of the standard deviation as a percent of the mean, and it is usually denoted by the letter V. Thus,

$$V = 100\ SD/\bar{x}$$

Veta I--a measure of symmetry. The statistic β_1 is based on the fact that in a symmetric distribution every value lying an equal distance below mean, so that the cubes of the deviations from the mean--half negative and half positive--will add to zero. Although the converse of this fact is by no means true--a zero sum of the cubed deviations in no way implies a symmetric distribution--the size of this sum when properly adjusted is often considered a useful indication of whether a set of data is unsymmetrically distributed and, if so, how badly.

Veta I is computed from the sum of the cubed deviations by dividing it by the sample size and the cube of the standard deviation, producing a dimensionless statistic:

$$\beta_1 \frac{\Sigma(x-\overline{x})^3}{n \cdot SD^3}$$

The percentiles. This group of statistics belongs to a class of measures designated as "measures of order or position." These measures can be thought of as being obtained by arranging the data in order from the smallest value to the largest one and then observing the value of the datum which lies at a specified position in the array.

Perhaps the most useful of these statistics are the percentiles. The 99 percentiles--ranging from the first to the 99th--are the values at the points which separate consecutive blocks or units of one percent of the data in the ordered array. The fifth percentile is the value which separates the smallest five percent of the data from the 95 percent of the data with larger values; the 25th percentile separates the smallest 25 percent from the larger 75 percent and so on.

The percentiles that are presented in this report were estimated by multiplying 1.65 times the standard deviation of the individual measurement and either subtracting this value from the mean value for the fifth percentile or adding this value to the mean value for the 95th percentile; e.g., the mean value for female shoulder flexion strength was found to be 22.6 kiloponds with a standard deviation of 3.8 kiloponds. Therefore,

$$\begin{array}{r} 3.8 \\ \times\ \underline{1.65} \\ 6.27 \end{array}$$

$$5\%\text{ile} = \begin{array}{r} 22.60 \\ \underline{6.27} \\ 16.33 \end{array} \qquad 95\%\text{ile} = \begin{array}{r} 22.60 \\ \underline{6.27} \\ 28.87 \end{array}$$

The correlation coefficients. The correlation coefficient describes the degree of relationship between two or more variables. The most common statistical measure of such relationships is the Pearsonian product-moment correlation coefficient (usually designated by the letter "r"). The correlation coefficient varies, in numerical value, from 0.0 to 1.0. Values of 0.0 indicate no relationship and those of 1.0 indicate perfect relationships. Positive values of these coefficients indicate that large values of one member of a pair of variables tend to occur simultaneously with large values of the other, and that small values of one tend to occur along with small values of the other. Negative values indicate the reverse; small values of one variable being associated, in general, with large values of the other. The degree of association is independent of the sign of the coefficient; a correlation of -0.50 and one of +0.50 represent the same intensity of relationship.

In formula, the Pearson product-moment correlation equals

$$r = \frac{N\Sigma xy - \Sigma x \Sigma y}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2]\ [n\Sigma y^2 - (\Sigma y)^2]}}$$

APPENDIX III

DESCRIPTION OF ANTHROPOMETRIC DIMENSIONS

All the anthropometric dimensions were taken according to the techniques and methods described by Clauser, et al., 1972, except that of lateral thumb-tip reach which was measured according to the description given by Kroemer, 1969. The reader is referred to these two original publications for more exacting details than are given here.

Weight. Taken on a standard medical type scale to the nearest 1/10 of a kilogram.

Stature. Subject stands erect, head in the Frankfort plane, heels together, and weight distributed equally on both feet. With the arm of the anthropometer firmly touching the scalp, measure the vertical distance from the standing surface to the top of the head.

Acromial Height. Subject stands erect looking straight ahead, heels together, and weight distributed equally on both feet. With an anthropometer, measure the vertical distance from the standing surface to the right acromial landmark.

Sitting Height. Subject sits erect, head in the Frankfort plane, upper arms hanging relaxed, forearms and hands extended forward horizontally. With the anthropometer arm firmly touching the scalp, measure the vertical distance from the sitting surface to the top of the head.

Tibiale Height. Subject stands erect, heels together, and weight distributed equally on both feet. With an anthropometer, measure the vertical distance from the standing surface to the tibiale landmark on the right leg.

Lateral Malleolus Height. Subject stands with weight distributed equally on both feet. With an anthropometer, measure the vertical distance from the standing surface to the lateral malleolus landmark on the right leg.

Thumb-Tip Reach. Subject stands erect with heels, buttocks, shoulder blades and head in contact with a vertical surface. The preferred arm is extended forward and perpendicular to the vertical surface, the tip of the index finger touching the tip of the extended thumb, the thumb in the plane of the extended arm. Using the anthropometer, measure the horizontal distance from the vertical surface to the tip of the thumb.

Lateral Thumb-Tip Reach. Subject stands erect with her side toward a vertical surface, her shoulder touching the wall. The preferred arm is extended laterally and perpendicular to the vertical surface, the tip of the index finger touching the tip of the extended thumb, the thumb in the plane of the extended arm. Using the anthropometer, measure the horizontal distance from the vertical surface to the tip of the thumb.

Acromiale-Radiale Length. Subject stands erect looking straight ahead and with arms relaxed. With a beam caliper held parallel to the long axis of the right upper arm, measure the distance from the acromiale landmark to the radiale landmark.

Radiale-Stylion Length. Subject stands erect with arms relaxed. With a beam caliper held parallel to the long axis of the right forearm, measure the distance from the radiale landmark to the stylion landmark.

Hand Length. Subject sits, right forearm and hand raised with palm up. The fingers are together and straight but not hyperextended. With the bar of a sliding caliper parallel to the long axis of the hand, measure the distance from the wrist landmark to dactylion.

Biceps Circumference, Relaxed. Subject stands with right arm slightly abducted. With a tape held in a plane perpendicular to the long axis of the upper arm, measure the circumference of the arm at the level of the biceps landmark.

Biceps Circumference, Flexed. Subject stands, right upper arm raised so that its long axis is horizontal, elbow flexed 90 degrees, biceps strongly contracted, and fist tightly clenched. With a tape held in a plane perpendicular to the long axis of the upper arm, measure the circumference of the arm at the level of the biceps landmark.

Forearm Circumference, Relaxed. Subject stands erect with right arm slightly abducted and hand relaxed. With a tape held in a plane perpendicular to the long axis of the forearm, measure the circumference of the arm at the level of the forearm landmark.

Calf Circumference. Subject stands erect, heels approximately 10 cm apart, and weight distributed equally on both feet. With a tape held in a plane perpendicular to the long axis of the right lower leg, measure the circumference of the calf at the level of the calf landmark.

Humerus Breadth. Subject sits, right upper arm abducted, and elbow flexed. With a sliding caliper and using firm pressure, measure the maximum distance between the epicondyles of the humerus.

Femur Breadth. Subject sits on a table, lower legs hanging over its side, and feet unsupported. With a spreading caliper and using firm pressure, measure the maximum distance between the epicondyles of the right femur.

Skinfold Triceps. Subject stands with right elbow flexed 90 degrees. Locate the level on the back of the upper arm halfway between acromion and the tip of the elbow. At the level previously located, pick up a skinfold parallel to the long axis of the upper arm. Using a Lange skinfold caliper, measure the thickness of the fold.

Skinfold Subscapular. Subject stands relaxed. Pick up a skinfold just below the inferior angle of the right scapula and parallel to the tension lines of the skin. Using a Lange caliper, measure the thickness of the fold.

Skinfold Suprailiac. Subject stands relaxed. Pick up a skinfold in the right mid-axillary line at the level of the crest of the ilium and following the border of the crest. Using a Lange skinfold caliper, measure the thickness of the fold.

Skinfold Medial Calf. Subject stands with right foot resting on a platform so that right hip and knee are flexed about 90 degrees. Pick up a skinfold parallel to the long axis of the lower leg at the right calf landmark. Using a Lange skinfold caliper, measure the thickness of the fold.

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