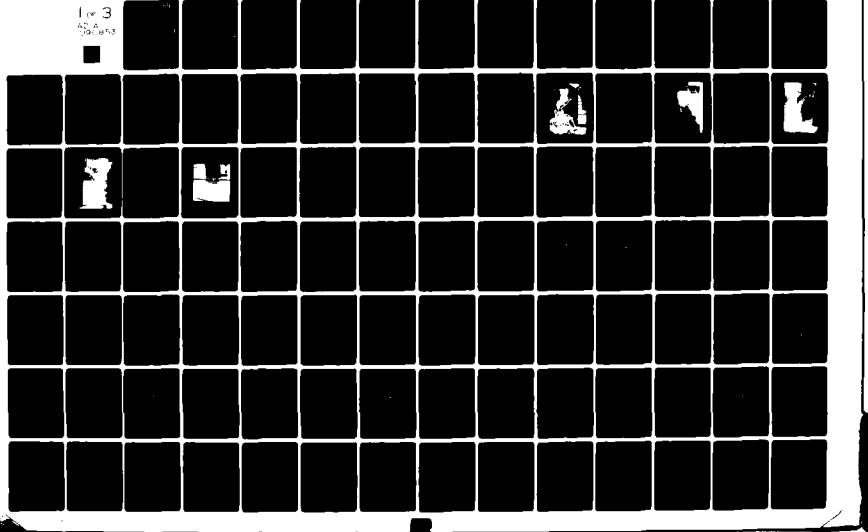
AD-A090 853 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 5/5
MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAI--ETC(U)
DEC 78 L A GOEBEL
UNCLASSIFIED AFIT-CI-79-181T NL

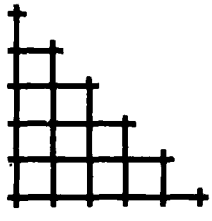


AD A090853

(1)

LEVEL II

DTIC
ELECTE
OCT 2 3 1980
S D
F



TEXAS A&M UNIVERSITY
Industrial Engineering Department
COLLEGE STATION, TEXAS 77843

DDC FILE COPY.

80 10 16 088

(1)

79-151T

40

MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAIRMENTS OF THE UPPER EXTREMITIES

by

LUCKY ARLAN GOEBEL

December, 1978

LEVEL II

DTIC
ELECTE
OCT 23 1980
S D
F

Accession For
NTIS GRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

UNCLASS

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 79-181T ✓	2. GOVT ACCESSION NO. AD-A090	3. RECIPIENT'S CATALOG NUMBER 853
4. TITLE *(and Subtitle)* (16) Maximum Grasping Reach of Operators Possessing Functional Impairments of the Upper Extremities		5. TYPE OF REPORT & PERIOD COVERED Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Lucky Arlan Goebel	(12) 220	8. CONTRACT OR GRANT NUMBER(s) (11) Dec 78
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT Student at: Texas A&M University ✓		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433 (9) Master's thesis		12. REPORT DATE December 1978 13. NUMBER OF PAGES 206
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)* (14) AFIT-CI-79-181T		15. SECURITY CLASS. *(of this report)* UNCLASS 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*
Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*
APPROVED FOR PUBLIC RELEASE AFR 190-17.
FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs
23 SEP 1980

18. SUPPLEMENTARY NOTES
Approved for public release; IAW AFR 190-17

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

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

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASS 022300

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

ABSTRACT

MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAIRMENTS OF THE UPPER EXTREMITIES

(December 1978)

Lucky Arlan Goebel, B.S., New Mexico State University

Co-Chairmen of Advisory Committee: Dr. Richard D. Huchingson
Dr. Donald R. Smith

This study documents the difference between the maximum grasping reach of non-disabled people and disabled people who have functional impairments of the upper extremities. A methodology for measuring and analyzing the grasping reach distance within eight vertical and thirteen horizontal planes is presented. Graphs are used to illustrate the differences between the fifth percentile data of both groups. Statistically significant differences were obtained between the non-disabled and disabled groups at the 5% level. Each disabled subject was categorized into one of four subgroups according to the extent his disability impaired performance of the assigned grasping reach task. The non-disabled group was compared to the subgroups to observe the extent to which the degree of impairment affected the reach capability of each group.

MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAIRMENTS OF THE UPPER EXTREMITIES

A Thesis

by

LUCKY ARLAN GOEBEL

Approved as to style and content by:

R. D. Huchingson
(Co-Chairman of Committee)

Donald R. Smith
(Co-Chairman of Committee)

James T. McMillan
For Newton Ellis
(Head of Department)

William P. Dyke
(Member)

December 1978

ABSTRACT

MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAIRMENTS OF THE UPPER EXTREMITIES

(December 1978)

Lucky Arlan Goebel, B.S., New Mexico State University

Co-Chairmen of Advisory Committee: Dr. Richard D. Huchingson
Dr. Donald R. Smith

This study documents the difference between the maximum grasping reach of non-disabled people and disabled people who have functional impairments of the upper extremities. A methodology for measuring and analyzing the grasping reach distance within eight vertical and thirteen horizontal planes is presented. Graphs are used to illustrate the differences between the fifth percentile data of both groups. Statistically significant differences were obtained between the non-disabled and disabled groups at the 5% level. Each disabled subject was categorized into one of four subgroups according to the extent his disability impaired performance of the assigned grasping reach task. The non-disabled group was compared to the subgroups to observe the extent to which the degree of impairment affected the reach capability of each group.

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. Richard D. Huchingson and Dr. Donald R. Smith for their guidance of the research study and in the direction of this work. I also wish to thank Dr. William P. Fife for his constructive criticism of the proposal and project. A special note of thanks is extended to my family for their understanding and help. I am also indebted to the management and staff of the Vocational Industrial Rehabilitation Center at Houston, especially Mr. Richard L. Biddy and Mr. Al Swarts for their infinite patience and consideration. Mr. Dan White and Mr. Ted Elliott of the Texas Rehabilitation Commission in Bryan, Texas, assisted the study through their contacts with the handicapped. Ms. Jan Bertch spent many hours editing and typing this report; my gratitude for her efforts is unbounded. Last but by no means least, the subjects of this study deserve the greatest amount of recognition and thanks. Without the generous contribution of their time and effort, this paper would not have been possible.

The basis for this research was supported in part by a Rehabilitation Engineering Center grant from the U. S. Department of Health, Education and Welfare - RSA Grant No. 23-P-5788/6-02.

DEDICATED TO

The brave souls who are generally referred to as the handicapped, but who in many ways are more able than the rest of us.

TABLE OF CONTENTS

		Page
ABSTRACT		iii
ACKNOWLEDGEMENTS		iv
DEDICATION		v
LIST OF TABLES		viii
LIST OF FIGURES		ix
CHAPTER		
I	INTRODUCTION	1
II	EXPERIMENTAL METHODS	7
	Overview	7
	Subjects	7
	Apparatus	9
	Baseboards	11
	Chair	15
	Boom and arc assembly	17
	Measuring rods	19
	Other design variations	20
	Procedures	21
	Data Analysis	26
	Data reduction	26
	Measurements	26
	Standardization of measurements	27
	Order of administration	28

III RESEARCH RESULTS 30
Overview 30
Reporting techniques 30
Control group data 31
Experimental group data 31
Comparison of group findings 34
IV CONCLUSION 42
Overview 42
Recommendations 47
Suggestions for further study 47
REFERENCES 50
APPENDIX A 53
APPENDIX B 98
APPENDIX C 141
APPENDIX D 184
APPENDIX E 187
APPENDIX F 189
APPENDIX G 192
APPENDIX H 197
APPENDIX I 202
VITA 206

LIST OF TABLES

Table		Page
1	EXPERIMENTAL GROUP STRUCTURE	8
2	SUMMARY OF GROUP STRUCTURE	8
3	EXPLANATION OF DISABILITY CODES	9
4	EXPLANATION OF LEVEL OF DISABILITY	9
5	EXAMPLE OF NUMBER AND TYPES OF MEASUREMENT	25
6	MEAN AND STANDARD DEVIATION OF GRASPING REACH (inches) OF THE ABLE GROUP	32
7	MEAN OF GRASPING REACH (inches) OF THE DISABLED GROUP	35
8	VALUES OF HORIZONTAL REACH, RIGHT ARM. VERTICAL POSITION 0 DEGREES	37
9	VALUES OF HORIZONTAL REACH, LEFT ARM. VERTICAL POSITION 0 DEGREES	38
10	VALUES OF VERTICAL GRASPING REACH, RIGHT ARM. HORIZONTAL POSITION 0	39
11	VALUES OF VERTICAL GRASPING REACH, LEFT ARM. HORIZONTAL POSITION 0	40

LIST OF FIGURES

Figure		Page
1	WHEELCHAIR SUBJECT PERFORMING MAXIMUM GRASPING REACH	10
2	VIEW OF THE CHAIR BASE BOARD SHOWING HORIZONTAL POSITION MARKINGS	12
3	REAR VIEW OF ENTIRE MEASURING APPARATUS	14
4	FRONT VIEW OF BOOM-ARC ASSEMBLY	16
5	VIEW OF 0 VERTICAL POSITION MEASURING ROD-SLIDE BLOCK	18
6	HORIZONTAL REACH, RIGHT ARM. VERTICAL POSITION 0 DEGREES	37
7	HORIZONTAL REACH, LEFT ARM. VERTICAL POSITION 0 DEGREES	38
8	VERTICAL GRASPING REACH, RIGHT ARM HORIZONTAL POSITION 0	39
9	VERTICAL GRASPING REACH, LEFT ARM. HORIZONTAL POSITION 0	40

CHAPTER I

INTRODUCTION

This thesis provides an insight to the question, what is the maximum grasping reach of seated disabled subjects? The position assumed by the subject, in conjunction with the measuring apparatus, simulates a disabled operator seated in a wheelchair or on a conventional type chair at a workbench.

Extensive studies have been completed on the non-disabled seated operator to determine specific anthropometric measurements. Judicious application of these measurements led to improved work station designs and greater operator efficiency. The literature provides a wealth of information dealing with the seated operator. However, despite this abundance, numerous areas of interest remain unexplored. One of the unknown areas relates to anthropometric data applicable specifically to the seated handicapped operator.

In some instances, measurements currently available on nondisabled or able operators could be adapted. However, extrapolation of data from the able to the disabled population would involve the risk of error. Instead of incurring the liability of errors that inevitably result from extrapolation from one population to the other, the users or operators should be evaluated as a functional part of the system in which they are expected to operate. The latter approach would ensure the best and usually the most practical union of the operator and his or her work station.

Paper follows the style required for publication in the Human Factors Journal.

Bullock (1974) commented on the large volume of basic human measurements available in design guides and other sources. Virtually every function and member of the human body has been measured either singularly or in combination with each other for length, width, height, or depth. She concluded, however, that the basic data is generally not applicable in most instances of system designing. Bullock utilized nine methods of collecting data on pilots as they performed basic functions in the cockpit of an aircraft. She determined that the general information available on the measurements of interest did not satisfy her requirements. Therefore, she evaluated members of the population of interest to her, in a setting similar to which they would be operating in order to obtain the required data.

Design guides are composed largely of anthropometric data obtained using static measurement techniques. Although a great deal of knowledge can be gained from static measurements, no true substitute exists for a measurement taken while the task-function of interest is actually being performed or closely simulated. While static measurements are highly accurate and useful in understanding the basic dimensional constraints of the body, the standardized procedures set forth as a condition of the measurements often prohibit application to specific design situations. For example, the measurements of sitting eye and shoulder height are taken with the back in an unnaturally erect position. This causes the measured heights to be significantly greater than they would be if the subject were in his normal sitting position and performing an operational task. Slump factors may be used to compensate for the unnatural erectness of the measured position, but as

these factors are introduced, new sources of error often arise. Therefore, to maximize the applicability of anthropometric measurements to a particular design, the designer should strive to obtain the data of interest from a setting which reproduces or simulates operational conditions as faithfully as possible.

Roebuck et al. (1975) advanced the design philosophy that mismatches between the operator and a work station may be avoided by building the station around the seated operator. This achieves the proper work space volume in which to do the work, and ensures the proper location of tools and hardware to accomplish assigned tasks. Strict attention to these factors will provide conditions which tend to increase the work efficiency and safety of the individual. Application of this philosophy to design for the handicapped population is of paramount importance. To do this properly, however, the functional limitations of handicapped operators must be known. Proper system designs for the handicapped will be realized only to the extent that anthropometric data of this population are available and used by system designers.

Dreyfuss (1973) is the most publicized of the practitioners of functional dimensions for the handicapped. His publications are primarily written for commercial designers who are concerned with workaday situations. Unfortunately, the data provided by Dreyfuss cannot be consistently applied or generalized to other groups. For example, the reaching height and distance measurements recommended by his Human Scale b Chart, for a person confined to a wheelchair, applies only to groups which have not suffered functional impairment of the upper

extremities. This prohibits application of the data to the segment of the handicapped population most in need of the help that functional reach information may provide.

Impairment of the upper extremities has the greatest implications when considered in light of obtaining and holding a job, or attending to the basic functions of day-to-day living. It appears that one who has lost the function of only his lower extremities can adapt his performance to our society more readily than one who has functional impairment of the upper extremities. Considering this, one may wonder why there has been so little effort to provide adequate guidelines for adapting or modifying the able person environment to accommodate the handicapped, particularly those impaired in the upper extremities. The answer may lie in the difficulty associated with training, or the lack of impetus on the part of management to hire a handicapped person. Considering these factors and others too numerous to mention, it is not surprising that so few significant steps have been taken to provide parity between able and disabled workers.

U.S. Congressional action provided employers with an incentive to learn more about the needs of the handicapped and to design appropriately for them. Public Law 93-112, enacted by Congress in 1973, makes it a matter of discrimination if rejection or exclusion of any type is based solely on the individual's handicap. The handicapped person has now been guaranteed rights in a manner similar to the way civil rights were ensured for minorities and women. The time is not too distant when employers, particularly those receiving federal fiscal

assistance or contracts, will be engaged more in employing handicapped workers.

As one might expect, when a subject becomes the center of new or increased awareness, an information vacuum usually exists. So it is with data on the capabilities of the handicapped; there is insufficient information on the handicapped person's abilities. This thesis and its associated research intends to increase basic knowledge of the handicapped person's abilities. Specifically, the purpose of this research is to functionally measure the maximum distance a person with motor impairment of the upper extremities can reach and grasp an object. In this case, "functional" implies that the grasping reach is measured as the subjects perform the grasping reach in a natural manner.

The term "grasping reach" is used in several contexts. For our purpose, the term is defined as follows: "Grasping reach", also known as thumb-tip reach and functional reach, is defined as the length of the subject's horizontally extended arm from the center of the shoulder joint ball to the tip of his thumb as his thumb and the first digit of the forefinger are pressed together. The subject sits erect with his back firmly against the back of a chair and performs a grasping reach to the maximum distance possible. It should be pointed out that the grasping reach data arrived at in this study cannot be compared directly to most of the functional or thumb-tip reach data found in engineering guides. The reason for this is the way the measurements are referenced to a standard point (Van Cott and Kinkade 1972). This does not, however, detract from the results of the study. On the contrary,

referencing the results to a standard reference vertical (to be discussed later) makes the data more suitable for generalization.

The maximum functional grasping reach of each subject was measured on an apparatus designed specifically for this research. The measuring device uses the same principles as Kennedy's ARML Grasping Reach measuring device. Kennedy (1964) performed grasping reach measurements on a sample of 20 U.S. Air Force male personnel in 1964. Several of his techniques and methods have been applied to this study.

A major goal of this study was to determine the relationship between the subject's maximum grasping reach and the category or degree of disability. This relationship and results of the comparison are discussed in detail in Chapter III. The remainder of the text will report on the experimental methods, and discuss the comparative results between the able and disabled groups. Finally, recommendations for future research will be suggested.

CHAPTER II

EXPERIMENTAL METHODS

Overview

This chapter describes methods used to measure arm reach of disabled subjects in horizontal and vertical planes. The same method was applied to a control group so that comparison could be made between the two groups.

Subjects

The evaluation of subjects was completed into two phases; the control group measurements and the experimental group measurements. The control group was composed of U.S. Air Force Personnel from the Texas A&M Air Force ROTC Detachment. The experimental group came from two sources. The primary source was the vocational Industrial Rehabilitation Center at Houston, Texas. The second from the Bryan office of the Texas Rehabilitation Commission.

The control groups consisted of ten males meeting the medical standards of an Air Force flight physical. They were measured for maximum grasping reach distances in the Texas A&M Industrial Engineering Department's Human Factors Laboratory. Evaluation of part of the experimental group was also accomplished in the Human Factors Laboratory, while the remainder of the group was evaluated at the Rehabilitation Center at Houston. The experimental group consisted of 15 handicapped subjects. Six were obtained through the Texas Rehabilitations Commission and other local sources, and nine were obtained from the Vocational Industrial Rehabilitation Center at Houston.

The following table shows the experimental group structure.

TABLE 1

EXPERIMENTAL GROUP STRUCTURE

Disability (Level)	Upper Extremity Involvement	Age	Sex
TP	None	30	F
CD	Both severe	37	F
ND	Right medium	24	F
CD	None	18	F
TQ (C-7)	Both severe	49	M
TP (T-4)	None	37	F
ND (T-4)	Right medium	29	M
OR (T-2)	Slight	30	F
TQ (C-7) (T-1)	Left severe Right medium	32	M
PP	Severe	29	F
TP (T-12)	None	26	M
OR	Both slight	36	M
OR	Right slight	27	M
OR (L-5)	None	27	M
OR	Right medium Left severe	61	M

TABLE 2

SUMMARY OF GROUP STRUCTURE

Sex		Upper Extremity Involvement			
Male	Female	None	Slight	Medium	Severe
8	7	5	3	2	5

A brief explanation of the applicable disability codes and the level of disability may be found in the tables which follow:

TABLE 3

EXPLANATION OF DISABILITY CODES

Disability Code*	Meaning
CD	Congenital deformity
ND	Neurological disorder
PP	Polio paraplegic
TP	Traumatic paraplegic
TQ	Traumatic quadriplegic
OR	Other

*Codes used by Texas Institute for Rehabilitation and Research

TABLE 4

EXPLANATION OF LEVEL OF DISABILITY

Disability Level Classification**	Muscles Affected
Cervical - 7 (C-7)	Tricepts, extensor digitorum
Thoracic - 2 (T-2)	Intercostal (between ribs)
Thoracic - 4 (T-4)	
Thoracic - 12 (T-12)	
Lumbar - 5 (L-5)	Lateral hamstrings tibialis posterior, peroneals

**Burke 1975

Apparatus

The apparatus described in this section was used to measure the grasping reach of subjects who were wheelchair bound or ambulatory. Each subject was handicapped by a spinal injury or had some degree of motor function impairment of the upper extremities. Evaluation of the grasping reach was made as the subject stretched out his arm and hand as far as possible, while observing postural constraints. The hand was

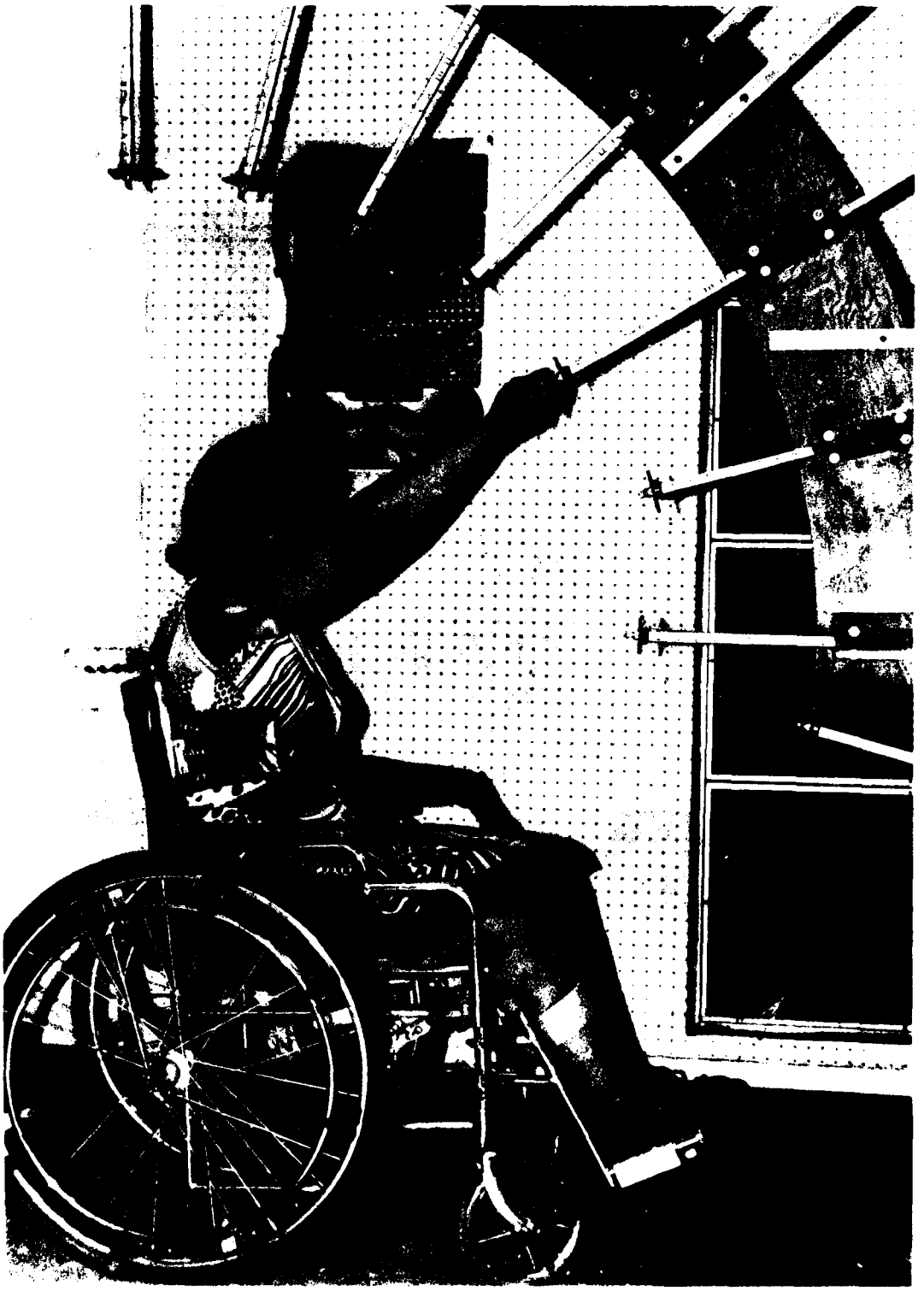


Figure 1 Wheelchair subject performing maximum grasping reach.

formed as though trying to pick up or grasp an object between the thumb and forefinger. A measuring rod was extended from the apparatus toward the subject, who would grasp a small switch knob at the end of the rod with the outstretched thumb and forefinger. The rod was calibrated in inches and thus provided the means of measuring the length of the subject's maximum grasping reach.

As mentioned above, the measuring apparatus was designed specifically for this study, the purpose of the device being two-fold. First, it measured the subject's arm reach; and second, it provided an object for the subject to grasp with the forefinger and thumb. Photographs of the apparatus are provided in Figures 1 through 5 on pages 10, 12, 14, 16, and 18. The apparatus consisted of the following components.

1. Baseboards (see Figure 2)
   a. Chair baseboard
   b. Boom-arc baseboard
2. Chair (see Figure 3)
3. Boom and arc assembly (see Figure 4)
4. Measuring rods (see Figure 5)

Each will be examined in detail and their functions fully explained.

Baseboards. These boards were used for multiple purposes: for chair mounting, mounting the boom and arc assembly, and positioning the arc. Both boards were 48 inches wide. The length of the chair baseboard was 42.5 inches, and the length of the boom baseboard was 48 inches. This difference in length is not significant since the chair was positioned on the board to provide a constant separation between chair back and boom. A separation of forty inches between the chair back and the measuring arc was chosen. The assumption was that the maximum reach encountered would be some 1 to 2 inches less than 40

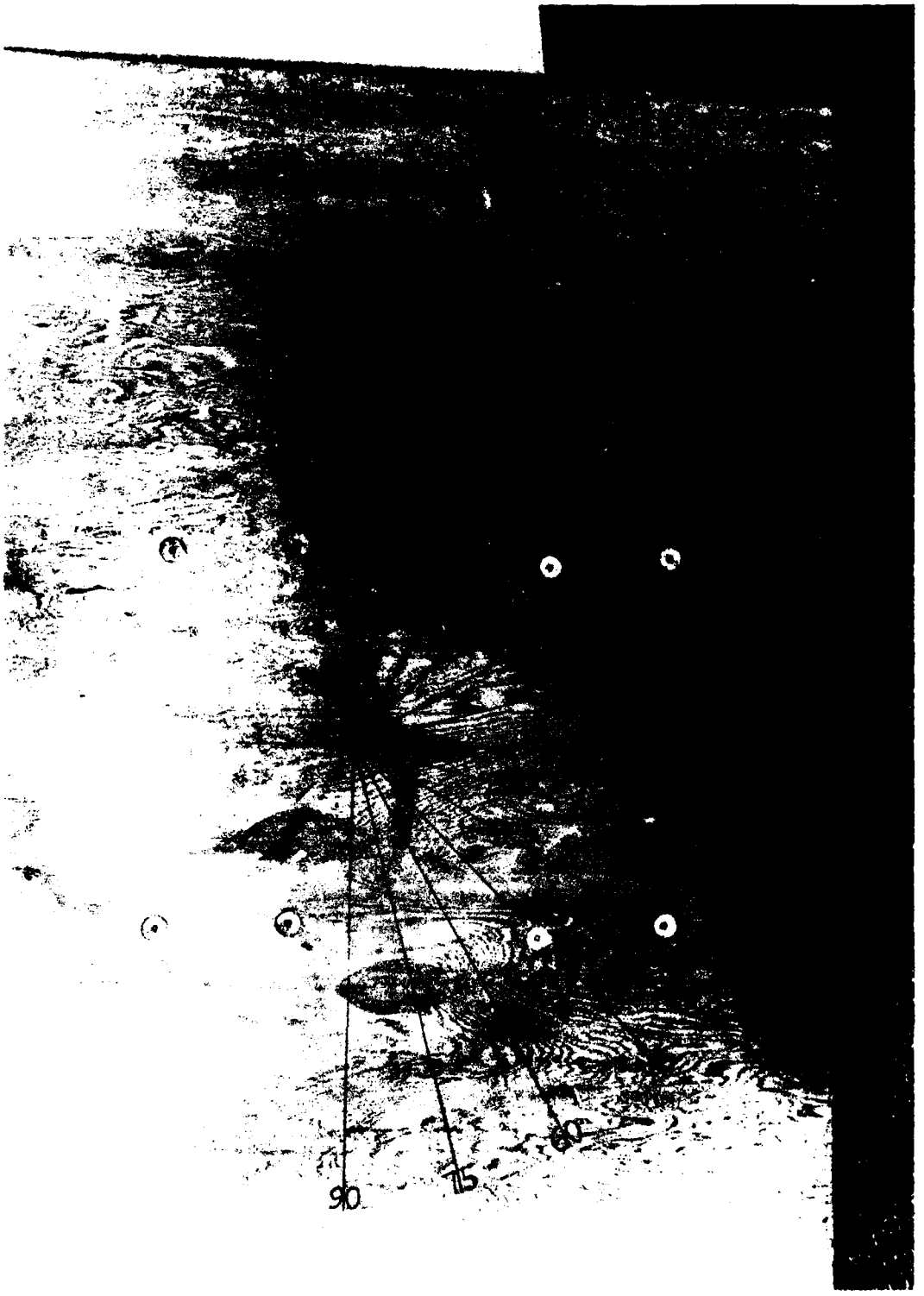


Figure 2 View of the chair baseboard showing horizontal position markings.

inches. This proved to be correct except when some subjects reached to their immediate right or left with the right and left arm respectively. In the most extreme case, this assumed maximum reach was exceeded by about two inches. This was compensated for, however, by a minor procedural change which did not alter the data. The 48 inch width and depth of the boom baseboard provided adequate room to mount the boom arc assembly and the boom stabilizing support bars. The chair baseboard (see Figure 2 page 12) was marked with a semicircle, and indexed at 15 degree increments. Zero degrees was located directly in front of the seated subject's shoulder as the chair faces the measuring arc. This position placed the subject's shoulders perpendicular to the measuring arc. The semicircle was further labeled by having the area to the right of zero marked off in 15 degree increments and designated as right 15 through 90 degrees. The left side was marked in the same manner, and designated left 15 through 90 degrees. This semicircle and its divisions were the horizontal reference points used for each measurement. The chair was indexed on these reference points to ensure uniform orientation of subjects for each trial.

When placed together, the baseboards provided a fixed distance from the seat reference point (SRP) to the leading edge of the 0 degree rod-slide block mounted on the measuring arc. An explanation of the SRP is provided by Van Cott and Kinkade (1972). Using his definition, the SRP is the midpoint of the intersection of the plane of the seat surface with the plane of the back rest surface of the seat. The vertical plane passing through this point is the standard reference vertical (SRV). These standard references are important because all

Figure 3 Rearview of entire measuring apparatus.

data were referenced from these points. Thus the SRP and SRV become the common denominator, not only between subjects, but from study to study as well. Further information and discussion of these reference points may be found in Appendix A.

Increased flexibility was obtained by using two small boards instead of one. They allow independent movement of the boom-arc baseboard and the chair baseboard, which enabled the measuring arc to be properly positioned with respect to the arm being measured. Being able to position the arc in this manner greatly increased the flexibility of the apparatus as well as simplified its design and fabrication. One final note about the advantage of the two boards: The entire unit was designed for easy transporting. The use of two small baseboards instead of one large one contributed to this significantly.

Chair. The chair incorporated as part of the measuring apparatus was a modified commercial type. The seat pan and back were one unit of molded plastic, produced by Unit Plastics, Inc. The base was constructed of steel and produced by Line Masters Products. The seat pan rotated and had a knurled knob that clamped the chair to its base to prevent it from rotating. The pan height from the baseboard was 18 inches. This, incidentally, was also the height of the SRP. To provide a fixed location for the chair legs, four holes were drilled in the chair baseboard. The seat pan and back unit made contact with the base at a single point. The base had an upward protruding shaft and pan-back unit had a metal sleeve mounted to the bottom. This sleeve fit over the shaft to provide support, and allow the back-pan to rotate as the base remained stationary. The base-shaft and seat-sleeve

Figure 4 Front view of boom-arc assembly.

joined at the center of the seat pan. Two formed metal braces were bolted to the seat pan fasteners and the metal under structure to further stabilize the chair. The center of the chair was placed over the center of the semicircle marked on the baseboard, and retained in this position by the four leg holes.

The chair just described was removable to accommodate wheelchair subjects. Positioning the wheelchair was accomplished in a similar manner, but with some minor variations. The underside cross members of the standard wheelchair was the point of reference which was placed over the center of the semicircle on the baseboard. Compensating measurements were used which allowed comparison of the wheelchair SRP to the conventional chair.

Boom and arc assembly. The arc may be thought of as a thin slice of the circular volume in front, to the sides, and overhead of a person seated at a table. The total volume may be conceptualized as a quarter section of sphere and may be considered the maximum working or reach area in front, directly to the sides, and directly overhead of a seated person.

Seven blocks were mounted on the sides of the measuring arc. An eighth block was mounted on the stationary pedestal of the boom. One of the arc's end blocks was placed at 90 degrees directly above the subject while the other end block was located at 0 degrees or parallel to the baseboard. The arc could be adjusted vertically by up or down movement of the boom. This allowed the positioning of the 0 degree end block and measuring rod in the same horizontal plane as the subject's outstretched arm. The five remaining blocks were mounted on the arc at

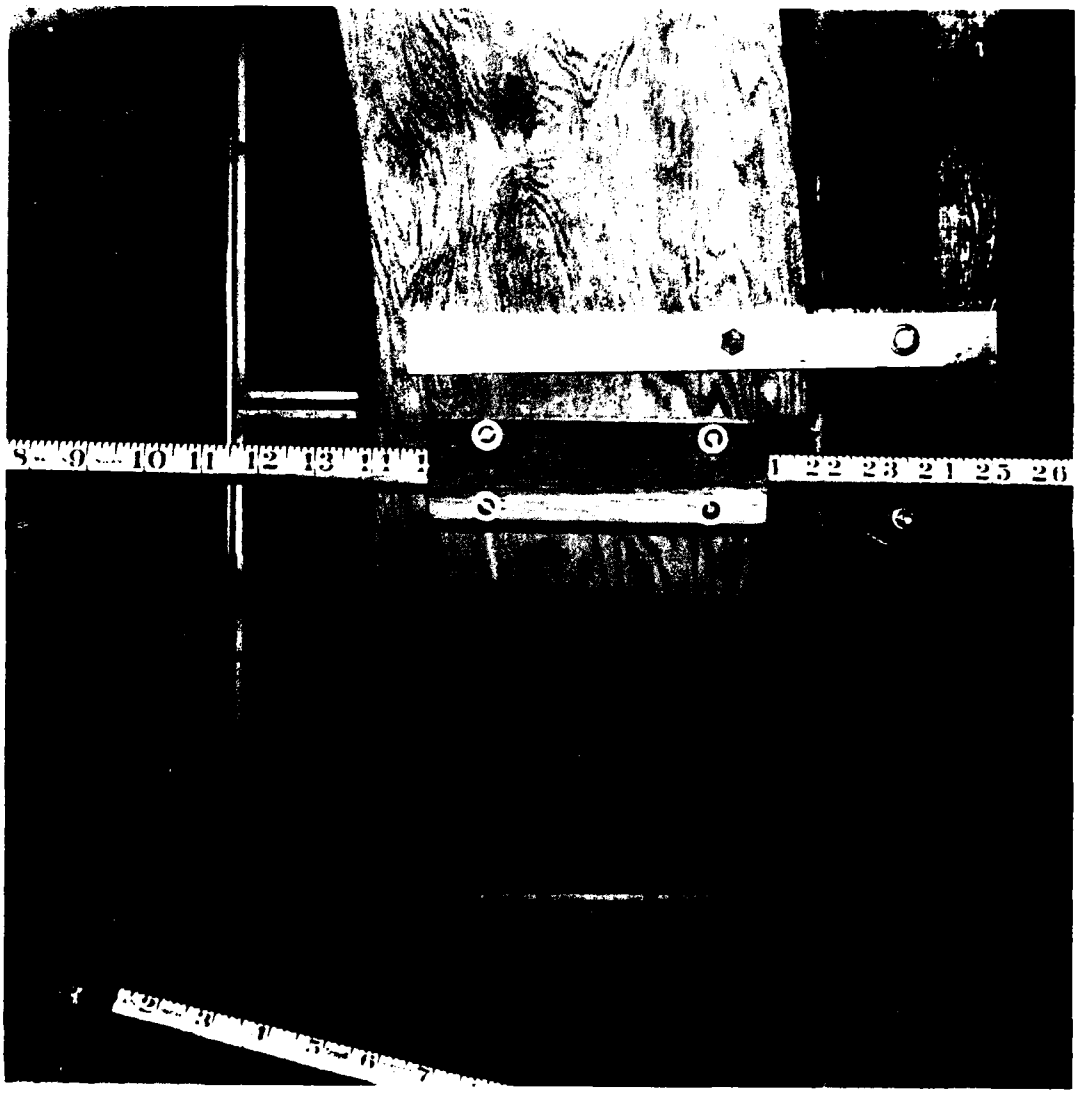


Figure 5 View of the 0 vertical position measuring rod-slide block.

15 degree increments between 0 and 90 degrees. Each block was marked with a number corresponding to the degrees at which it was positioned. The eighth block, as mentioned earlier, was mounted on the stationary portion of the boom. This block was maintained at a constant height of 29.75 inches and represented the work table surface height, marked "T".

Measuring rods. The blocks discussed in the preceding section were drilled and cut in half lengthwise. A 3/4 inch diameter, thin wall conduit tube was passed through the hole and allowed to slide back and forth. The length of the rods were 36 inches, except for the one in the 0 degree block, which was 61 inches. This rod length was greater because it was used to measure the subject's shoulder-to-arc distance and had to be extended a greater distance than the other rods. The two halves of the blocks could be drawn closer together or further apart by the use of screws which passed through the blocks. This varied the amount of friction on the rod and in turn the ease with which the rod could move through the block. The length of the rods were indexed in inches by cementing measuring tapes to them. Therefore, each rod had its length indicated by the measuring tapes that was attached to it. In order to provide smooth rod travel, the inside of the block holes were lined with felt cloth. Talcum powder was used to further reduce friction and provide for easier travel.

Attached to the end of each rod, closest to the subject, was a small electronic switch. The switches were not connected electrically, serving only as a task or function for the subject to perform at the point of maximum grasping reach. Each subject was required to reach out and grasp the switch knob and rotate it one quarter of a turn until

it clicked. The blocks through which the rods passed were positioned on the arc so that when the rods were extended, they would intersect at the center of the arc. In effect, each rod was a line of radius extending from the center of the circle to the circle boundary which was the measuring arc.

Other design variations. The rod and measuring arc principle on which the apparatus was based has been used by several investigators. Using this principle, Kennedy (1964) developed a device which measured the right arm grasping reach of a sample of U.S. Air Force personnel. Faulkner and Day (1970) applied the principle of functional reach to females. Frankenstein (cited in Kennedy, 1964) also made use of the rod and arc for the design of his anthropometric measuring apparatus.

The various designs which have emerged, were particularly suitable and unique to the experiment for which they were designed. The design of the apparatus used in this experiment was no different. It was both unique and particularly suitable to this experiment. It also offered some advantages over the previous designs just mentioned. The primary difference between each apparatus lay in the actual arc design and its supporting structure. For Kennedy's 1964 study, the word "arc" was actually a misnomer. It was actually no arc at all, but a truncated circle constructed so that a subject's reach distance could be measured through 360 degrees at 15 degree increments. Faulkner and Day (1970) used a much smaller measuring arc, which he placed on a worktable and measured the maximum functional reach of female operators. Each of these designs proved particularly advantageous to the experiment for which it was intended.

In this experiment, the apparatus design reduced preliminary measurements. It provided the ability to measure both arms which was particularly advantageous. The principle advantage of reducing the number of preliminary measurements was the amount of time saved. An example of a preliminary measurement that was eliminated was sitting height. Kennedy and Faulkner's studies were sensitive to the sitting height of the subject. In this study, the sitting height was eliminated as a factor by vertical adjustment of the measuring arc to accommodate a range of sitting heights. Thus, when the arc was properly adjusted to each subject, sitting height was eliminated as a variable.

Another advantage offered by this design was the ability to measure the reach distance of both arms. Kennedy (1964) and most other researchers measured only the right arm and then inferred the parameters of the left arm by assuming symmetry of the human body. As a matter of interest, the seat of the apparatus used by Kennedy excluded the possibility of measuring the left arm. Since the symmetry assumption is not valid for the handicapped, the apparatus used to determine their maximum grasping reach had to be able to measure right and left arm. As mentioned earlier in the discussion of the baseboards, this was accomplished by moving one baseboard laterally with respect to the other.

Procedures

This section describes the procedures used to obtain maximum grasping reach measurements on subjects functionally impaired in the upper extremities. A total of 208 measurements were taken on each

subject. This total was divided equally between the right and left arm. Subjects were rotated horizontally through 180 degrees and measured at every 15 degree increments, which equates to 13 orientations. At each orientation, eight vertical measurements were taken. Measurements were completed on first the right arm and then on the left arm.

As each subject arrived for evaluation, they were given an explanation of the research and its intended goals. As they observed the device, they were briefed on its operation and their required actions. The instructions were primarily regarding postural constraints and exercising caution not to strain themselves while performing the required reaching movements.

Posture constraints were emphasized to the subjects, to ensure their understanding of the need to keep their back firmly against the back of the chair. Particular emphasis was given to the times that the subject was required to reach across his chest. Because of the nature of the task (maximum reach) the examiner continually checked the subject's posture during the evaluation to ensure each reach was properly executed.

A primary concern to the examiner was the tendency of the subjects to try too hard to extend their reach distance. They were cautioned against doing this during the initial instruction period. As explained to the subjects, the maximum grasping reach being evaluated did not require them to inflict pain or suffering on themselves. On the contrary, the maximum reach desired was the "normal" they would use if

doing work at a workbench, restricted somewhat by the imposed postural constraints.

Ambulatory subjects were seated in the regular chair provided as part of the measuring device. For those in wheelchairs, the regular chair was removed and the wheelchair rolled onto the chair baseboard. A plumb bob was suspended from the underside cross member of the wheelchair (the center of the seat). The point of the plumb bob was positioned over the center of the semicircle marked on the baseboard. The distance from the wheelchair seat reference point to the cross member was measured and recorded. The wheelchair height was also measured and recorded. It should be noted that this height included the depressed cushion height which varied slightly from subject to subject.

After the measurements dealing with the subject and the chair were completed, the subject's position with respect to the measuring arc was measured. The subject was instructed to sit erect with his arms hanging at the sides or resting on the lap. The chair was placed at the horizontal orientation of 0 degrees which caused the subject to face the measuring arc. The measuring rod, located at the vertical position of 0 degrees, was extended toward the subject. This rod was used as a "slight" to properly adjust the vertical and horizontal position of the measuring arc to the height and breadth of the subject. The vertical distance from the boom-arc baseboard to the center of the 0 degree measuring rod was measured and recorded. With the arc at the proper height, the distance from the center of the subject's shoulder joint to the leading edge of the 0 degree block was measured and recorded. This distance was designated as SA. To ensure the measuring

arc was properly aligned in the vertical plane, two bubble levels were attached to the boom which provided an accurate visible reference. When the levels registered properly, the measuring arc was perpendicular to the baseboards.

When all the preliminary measurements were completed, the measuring of the subject's maximum grasping reach distance was begun. The subject was instructed to stretch out his arm as far as possible while observing the instructed postural constraints. As the subject did this, the measuring rod was extended from the arc toward the hand until the switch knob could be grasped. The subject was instructed to push the rod away from himself, if possible. When the subject was satisfied that the rod was positioned as far as his grasping reach would allow under the constraints imposed, he would then move to the next rod. The distances were recorded after the subject completed positioning all eight rods. This procedure was repeated for each of the 13 horizontal chair positions, which completed evaluation of the right arm. The boom-arc baseboard was moved laterally to the subject's left side where the measuring arc was positioned in the same manner as described for the right arm . The grasping reach measurements were then taken for the left arm using the same procedure as described for the right arm measurements. Each subject began at horizontal and vertical points according to a randomized starting procedure.

Table 5 illustrates the number and type of measurements taken on each subject. Note that this table is applicable to both the right and left arm.

TABLE 5

EXAMPLE OF NUMBER AND TYPES OF MEASUREMENTS

Horizontal Orientation (degrees)	Vertical Position (degrees)							
	T	0	15	30	45	60	70	90
Left 90								
75								
60								
45								
30								
15								
0								
Right 15								
30								
45								
60								
75								
90								

With 208 measurements to be taken on each subject, the duration of the evaluations was quite lengthy. It was observed that the sessions utilizing the standard chair averaged one hour. Evaluation time increased for subjects in wheelchairs due primarily to the extra motion and effort required to orient the wheelchair. The least time required for wheelchair subjects was about 55 minutes and the greatest for a motorized wheelchair was almost 2 1/2 hours.

Because of the duration of the sessions, methods to reduce fatigue on subjects were continually sought. A procedural change was incorporated after the second subject to reduce their effort. Instead of

requiring the subjects to push the rods away from their body, the rods were drawn toward their outstretched arm and hand by the examiner. This resulted in an observed decrease in effort required by the subject and decreased the amount of time required for each session.

Data Analysis

The measurements obtained on the control group and experimental group were analyzed separately and then compared. This section relates the method of data collection, the measurements analyzed, and the transformation required to standardize the results.

Data reduction. The measurements of each subject were recorded on preprinted data collection forms. The integrity of the data and the ability to relate it to a specific subject was preserved. The forms contained two 8x13 matrices for recording the measuring rod readings for each arm. The rows and columns for the matrices corresponded to the vertical and horizontal increments of the measuring apparatus (see Table 5 page 25). A means of documenting the specific subject's medical classification as well as the preliminary measurements was also provided on the form.

Measurements. The measurements recorded on the data collection forms for each subject included:

1. Boom height from the baseboard.
2. Shoulder-joint-ball to the standard reference vertical.
3. Subject's height.
4. Right and left shoulder-to-arc lengths.

For wheelchair subjects, additional measurements were required. Those measurements, in addition to the ones already mentioned, were:

1. Wheelchair seat from baseboard.
2. Seat pad depth (depressed at the seat reference point).
3. Standard reference vertical to the underside cross member of the chair.

In general, these measurements made it possible to determine the subject's position with respect to the measuring arc. In addition, they provided the necessary data for transforming the measurements to the standard reference points. It should be noted that the accuracy of each measurement was to the nearest one-quarter inch.

Standardization of measurements. As is often the case when measuring experimental variables, the raw data collected during the experiment must be converted to another form to be meaningful. So it was for this study also; the lengths indicated on the apparatus' measuring rods were an indirect measurement of the subject's maximum grasping reach. To obtain the actual reach length, it was necessary to subtract the rod reading from a transformed shoulder-to-arc length, previously designated as SA.

Individual differences between subjects, and apparatus design prevented direct application of the original shoulder-to-arc length (SA) discussed previously. The following are the two foremost reasons why this is so. First, while it is true that for each subject, the center of their shoulder-joint-ball to the standard reference vertical was constant, this distance varied from subject to subject according to individual stature. Additionally, the seat reference point, although fixed in relation to the chair and subject, pivoted 180 degrees about

the center of the chair pan. This caused the distance with respect to the measuring arc to vary for each chair orientation. These two factors required the SA measurements for each subject to be standardized. If this were not done, the data could not be generalized and applied to situations other than those specifically defined in this experiment.

In order to standardize the data, the initial shoulder-to-arc measurements were transformed to the standard reference vertical. This transformation was accomplished using the Trigonometric Law of Cosines, $R = \sqrt{a^2 + b^2 - 2ab \cos c}$. A detailed explanation of this transformation procedure may be found in Appendix I.

Once the SA length was transformed, the maximum grasping reach could then be calculated by subtracting the apparatus rod readings from the R value obtained in the preceding paragraph. The maximum grasping reach of each subject was then arrayed in matrix form and the mean and standard deviation of the composite data were computed. Using this information, graphs were prepared to show the relationship between the control and experimental groups.

Order of administration. Although it would have been impractical to randomize all the factors of the study, a minor form of randomization was used. Each subject was started at a horizontal and vertical position selected by a random process. This was incorporated into the experiment in order to distribute the effects of joint and muscle limbering as a result of usage.

A uniform way of orienting the chair, as well as positioning the vertical rods was used. The chair was placed in the starting horizontal position specified by the random starting order. Similarly, the

the center of the chair pan. This caused the distance with respect to the measuring arc to vary for each chair orientation. These two factors required the SA measurements for each subject to be standardized. If this were not done, the data could not be generalized and applied to situations other than those specifically defined in this experiment.

In order to standardize the data, the initial shoulder-to-arc measurements were transformed to the standard reference vertical. This transformation was accomplished using the Trigonometric Law of Cosines, $R = \sqrt{a^2 + b^2 - 2ab \cos c}$. A detailed explanation of this transformation procedure may be found in Appendix I.

Once the SA length was transformed, the maximum grasping reach could then be calculated by subtracting the apparatus rod readings from the R value obtained in the preceding paragraph. The maximum grasping reach of each subject was then arrayed in matrix form and the mean and standard deviation of the composite data were computed. Using this information, graphs were prepared to show the relationship between the control and experimental groups.

Order of administration. Although it would have been impractical to randomize all the factors of the study, a minor form of randomization was used. Each subject was started at a horizontal and vertical position selected by a random process. This was incorporated into the experiment in order to distribute the effects of joint and muscle limbering as a result of usage.

A uniform way of orienting the chair, as well as positioning the vertical rods was used. The chair was placed in the starting horizontal position specified by the random starting order. Similarly, the

subject began at a vertical rod position dictated by the random starting order. From these initial positions, a counterclockwise movement was used to advance to the next position. This method prevailed throughout the full cycle of measuring the subject.

Two hundred eight measured points were recorded on each subject. Those readings were synthesized into the maximum grasping reach data. Reporting techniques and graphic illustrations of the results of this synthesis are presented as Research Results in Chapter III.

CHAPTER III

RESEARCH RESULTS

Overview

The results of measuring the maximum grasping reach of twenty five subjects are summarized in this chapter. The subjects were divided into two major groups: a control group consisting of ten non-disabled males and a second group of fifteen disabled male and female subjects. The subjects of the second group, (disabled group), were further divided into four subgroups according to degrees of impairment. The data gathered for each group and subgroup are presented using graphs and tables which serve to compare and contrast the maximum grasping reach. Statistical t tests providing evidence of the level of significance between the measured means of the two groups, are given in Appendix F.

Reporting Techniques

This study measured maximum grasping reach distances in eight horizontal and thirteen vertical planes which, for both arms, yielded 208 data points per subject. Because of the number of reach planes measured, the results could not be reduced to a single two dimensional graph or table for presentation. Included in a section of this chapter entitled Comparison of Group Findings, are presented tables and graphs for the horizontal and vertical 0 planes. They are examples of the method used to present the disabled and non-disabled maximum grasping reaches. The remainder of the tables and graphs relating to the reaches of the two groups may be found in Appendix A. Included at the

beginning of Appendix A is a detailed explanation of the method used to label these graphs. Each graph portrays the 5th percentile data for the able and disabled groups. The 5th, as opposed to the 50th percentile, was selected for presentation since it is the critical measurement. "Critical" here means that an object that can be reached by a 5th percentile person may also be reached by a 50th and 95th percentile person, but the converse of this is not true.

Control Group Data

The control group or "able" group data consisted of measurements taken on ten male, caucasian U.S. Air Force personnel. Mean and standard deviations of their reach measurements are in Table 6. The control group's 5th percentile measurements are depicted by dashed curves on all graphs of comparison data.

Experimental Group Data

The experimental group data consisted of measurements on fifteen disabled subjects. This group included Negroes, Anglos, Latins and an Israeli. Eight were males and seven were females. The disabled group was subdivided into four subgroups based on the degree of impairment.

The data for this group could not be compared directly with the all male control group due to the use of seven females in the disabled group. To be able to compare the groups, a "composite experimental group" was developed using the method described by Roebuck et al., (1975). Basically, this method resulted in weighting the 5th, 50th, and the 95th percentile reach values of each subject. Weighting factors were 0.533 for males and 0.467 for females based on the percentage

Table 6

Mean and Standard Deviation of Grasping Reach

(inches) of the Able Group

Right Arm

Horz. Angle		Vertical Position							
		Table	0	15	30	45	60	75	90
L90	$\bar{X}$	17.27	24.92	24.49	24.67	25.34	26.82	26.04	25.64
	$S_{\bar{X}}$	3.136	3.193	3.640	3.387	3.521	5.094	2.699	2.378
L75	$\bar{X}$	19.66	26.91	26.91	27.09	27.26	27.61	27.51	27.64
	$S_{\bar{X}}$	2.647	2.827	2.827	3.125	3.130	2.996	2.225	1.703
L60	$\bar{X}$	22.5	28.90	28.75	28.53	28.60	28.68	28.69	27.81
	$S_{\bar{X}}$	2.951	1.868	2.307	2.613	2.805	2.608	2.595	4.230
L45	$\bar{X}$	23.45	30.15	30.25	30.02	30.05	30.02	30.13	30.25
	$S_{\bar{X}}$	2.309	26.43	2.641	2.551	2.371	2.353	2.137	2.009
L30	$\bar{X}$	25.25	32.0	31.85	31.85	31.37	30.25	31.27	31.37
	$S_{\bar{X}}$	1.818	1.761	1.798	1.798	20.97	2.730	1.938	1.770
L15	$\bar{X}$	27.35	33.69	33.54	32.89	32.81	32.39	32.19	31.99
	$S_{\bar{X}}$	2.349	1.493	1.527	1.753	1.813	1.929	1.877	1.859
0	$\bar{X}$	28.07	34.74	34.78	34.19	33.87	33.03	32.66	32.31
	$S_{\bar{X}}$	1.208	1.377	1.749	1.619	1.752	1.715	1.715	1.82
R15	$\bar{X}$	29.26	35.76	35.66	35.09	34.24	33.69	32.91	32.63
	$S_{\bar{X}}$	1.325	1.528	1.504	1.761	1.796	1.763	1.903	1.709
R30	$\bar{X}$	30.22	36.75	36.62	35.8	34.82	33.9	33.02	32.61
	$S_{\bar{X}}$	1.139	1.245	1.462	1.448	1.668	1.706	1.840	2.899
R45	$\bar{X}$	30.90	37.61	37.41	36.81	35.31	33.96	32.48	31.36
	$S_{\bar{X}}$	1.449	1.699	1.829	2.054	1.840	1.766	1.891	1.890
R60	$\bar{X}$	31.45	37.98	37.73	36.93	35.27	33.65	31.65	30.48
	$S_{\bar{X}}$	2.185	2.470	2.064	2.174	2.113	2.049	2.193	2.406
R75	$\bar{X}$	31.25	38.49	38.11	37.21	35.01	32.97	30.81	28.94
	$S_{\bar{X}}$	2.237	2.766	2.528	2.492	1.926	1.819	2.017	2.396
R90	$\bar{X}$	31.32	38.57	38.32	36.92	34.87	32.59	39.52	27.57
	$S_{\bar{X}}$	19.94	2.137	2.250	2.127	1.979	2.069	2.018	2.501

Table 6

(continued)

Left Arm

Horz. Angle		Vertical Position							
		Table	0	15	30	45	60	75	90
L90	$\bar{X}$	31.36	38.36	38.41	36.89	34.99	32.71	30.04	27.56
	S_x	1.533	2.480	2.031	2.226	2.068	2.091	2.321	2.942
L75	$\bar{X}$	31.84	38.79	38.44	37.21	35.61	33.51	31.51	28.91
	S_x	1.979	2.214	2.472	2.446	2.323	2.197	2.150	2.836
L60	$\bar{X}$	31.6	38.15	38.02	27.17	35.72	34.20	32.32	30.30
	S_x	1.686	1.879	3.231	2.343	2.398	2.361	2.221	2.648
L45	$\bar{X}$	31.19	38.02	37.95	36.77	35.50	34.50	32.95	31.30
	S_x	1.982	2.102	2.244	2.079	2.382	2.273	2.219	2.420
L30	$\bar{X}$	30.32	37.07	36.92	36.20	35.25	34.42	33.20	32.10
	S_x	1.713	1.767	1.879	2.200	2.395	2.344	2.356	2.742
L15	$\bar{X}$	29.42	35.69	35.59	35.59	35.19	34.56	33.99	32.86
	S_x	1.758	2.245	1.948	1.922	1.732	1.987	2.340	2.469
0	$\bar{X}$	28.54	34.88	34.86	34.34	33.89	33.51	33.16	32.89
	S_x	1.569	1.631	1.356	1.676	1.816	1.809	1.974	2.088
R15	$\bar{X}$	27.16	34.26	33.94	33.66	33.37	33.21	33.04	32.81
	S_x	2.273	2.165	2.163	2.165	2.057	2.194	2.265	2.056
R30	$\bar{X}$	26.72	32.90	33	32.70	32.45	32.40	32.35	31.55
	S_x	2.085	2.184	2.324	2.225	2.144	2.082	2.146	2.804
R45	$\bar{X}$	24.30	31.40	31.00	30.87	30.87	30.85	30.75	30.87
	S_x	2.591	2.594	2.716	2.828	2.463	2.465	2.373	2.295
R60	$\bar{X}$	22.67	29.37	29.62	29.24	29.50	29.50	29.55	29.72
	S_x	2.707	2.814	2.782	2.829	2.678	2.573	2.615	2.612
R75	$\bar{X}$	20.61	27.48	27.60	27.39	27.54	28.31	28.41	28.51
	S_x	3.537	3.729	3.426	3.233	3.003	3.213	2.164	2.109
R90	$\bar{X}$	18.51	25.16	25.86	26.16	26.39	26.55	26.71	26.79
	S_x	2.503	2.732	2.655	2.987	3.182	2.922	2.648	2.144

of males and females in the composite experimental group. The respective weighted results of the male and female grasping reach values were added to produce the 5th, 50th, and 95th percentiles of the composite experimental group, referred to in this thesis as the experimental or disabled group. The mean values of this group's maximum grasping reach are shown in Table 7.

Comparison of Group Findings

Two types of group comparisons were conducted. First, comparisons were made between the reach distances of the composite experimental group and the control (able) group. This datum is given in Appendix A since there are forty-four sets of data for the various reach positions. However, as an illustration of the horizontal and vertical reach data, tables and associated graphic data are presented in Tables 8 and 10 (right arm) and 9 and 11 (left arm). The graphs shown in Figures 6 through 9 are plots of the table 5th percentile tabular data. The graphs permit ready observation of major deviations between the groups.

A second comparison was between each of the four disabled subgroups and the able group. This datum is in the appendix because there are 84 tables of comparative data. Appendix B presents data for subjects with little or slight impairment. Appendix C presents data for those with medium and severe impairment.

The four disabled subgroups mentioned above were based on the degree of impairment and designated: None, Slight, Medium, and Severe. To avoid misunderstanding, the subjects placed in the "None" category were handicapped by functional impairment of the upper

Table 7

Mean of Grasping Reach (inches) of the Disabled Group

Right Arm

Horizontal Angle	Vertical Position							
	Table	0	15	30	45	60	75	90
L90	18.78	21.43	20.74	21.27	22.38	23.23	22.49	21.63
L75	16.25	23.79	24.42	23.56	23.78	24.37	23.35	23.88
L60	18.87	26.08	26.03	25.70	24.67	25.17	25.1	25.78
L45	20.69	27.40	26.25	25.97	26.00	26.29	25.93	27.32
L30	22.20	28.63	27.63	27.67	27.31	27.67	27.81	29.27
L15	23.06	30.00	29.41	29.56	28.85	29.60	29.17	30.21
0	26.09	30.95	30.27	29.99	29.56	29.16	31.13	32.96
R15	22.46	31.85	31.35	30.96	30.88	31.03	31.83	31.49
R30	26.35	33.60	32.49	31.70	32.24	31.45	31.68	31.06
R45	27.25	33.86	32.50	32.14	32.22	31.50	30.50	29.82
R60	27.85	34.81	33.67	32.78	32.39	31.00	29.53	28.47
R75	28.42	34.74	33.56	32.31	30.20	30.13	28.06	26.80
R90	28.74	36.49	34.13	32.56	31.31	29.02	27.09	25.52

Left Arm

L90	27.82	34.95	33.21	31.60	29.28	30.57	27.82	25.27
L75	27.30	34.55	32.88	34.47	32.52	30.97	28.82	26.97
L60	26.67	33.57	32.39	29.96	31.71	31.92	30.12	28.90
L45	26.07	32.97	31.97	30.50	32.06	30.65	31.26	30.11
L30	25.56	32.38	31.60	30.45	29.78	31.27	31.92	31.07
L15	24.03	31.49	30.49	29.35	28.96	28.76	28.10	28.31
0	22.29	29.13	28.70	28.34	28.13	27.84	27.41	27.02
R15	21.21	29.33	27.47	25.21	26.71	26.81	26.74	26.67
R30	20.07	26.82	26.28	25.74	25.74	25.07	29.32	24.82
R45	18.86	25.22	25.07	24.93	24.57	25.15	25.18	24.61
R60	16.92	23.78	23.64	23.35	23.17	23.28	23.28	23.21
R75	15.49	22.35	21.78	21.49	21.6	21.60	21.49	21.49
R90	13.03	23.71	20.07	19.67	20.21	19.67	19.53	20.10

extremities. Their impairment, however, did not significantly hamper their ability to perform the assigned grasping reach tasks. Nevertheless, these subjects did possess some form of upper extremity disability. Since the examiner subjectively categorized the subjects according to their relative ability to perform the assigned tasks, those who appeared to have no difficulty were placed in the "None" category. The results of statistical tests between each of the groups and subgroups are given in Appendixes F through H. These results showed that the differences between the means of the groups were highly significant, i.e. at the .0005 level.

Figures 6 and 7 illustrate the maximum horizontal grasping reach at the vertical position of 0 degrees for the right and left arm respectively. Note the decreased reaching capability of the disabled group shown by the solid line as compared to the able group represented by the dashed line. The graphs show the 5th percentile values listed in Tables 8 and 9. As observed on the graph (Figure 6), the greatest difference between the right arms of the two groups in this plane existed at the L45 through L15 horizontal angles. Figure 7 indicates the differences between the left arms of the two groups seemed to be more uniform. There were two "extreme points", however, for the disabled group at positions L30 and L15. These are represented by the two points positioned off the solid curved line.

The vertical reach of both groups at the horizontal position 0 are portrayed in Figures 8 and 9. Extreme points again occurred for the right arm of the disabled group, (see Figure 8). One can see that the

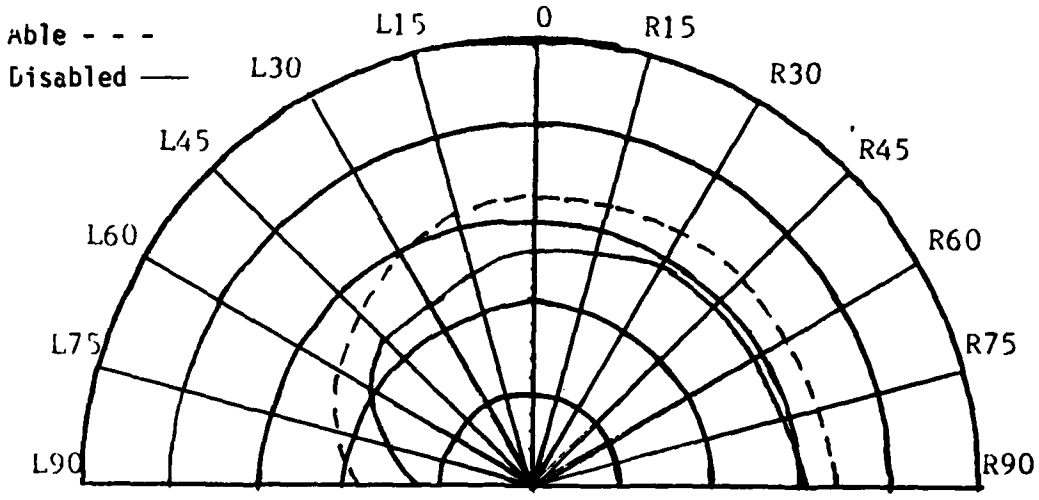


Figure 6 Horizontal Reach, Right Arm. Vertical Position 0 Degrees.

Table 8

Values of Horizontal Reach, Right Arm. Vertical Position 0 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	19.66	24.92	30.17	13.71	21.43	29.16	15
L75	22.26	26.91	31.56	17.67	24.36	31.06	13
L60	25.83	28.90	31.97	21.44	27.15	32.77	13
L45	25.80	30.15	34.50	23.64	28.65	23.65	13
L30	29.10	32.0	34.9	23.70	29.47	35.24	14
L15	31.23	33.69	36.15	25.71	31.48	37.25	14
0	32.48	34.74	37.01	26.35	32.80	39.27	14
R15	33.25	35.76	38.27	27.51	33.77	40.04	14
R30	34.70	36.75	38.80	29.10	34.95	40.82	14
R45	34.82	37.61	40.41	28.41	34.89	41.39	14
R60	33.92	37.98	42.04	28.58	34.26	42.05	14
R75	33.94	38.49	43.04	29.50	36.12	42.73	14
R90	35.06	38.57	42.09	30.41	37.03	43.64	14

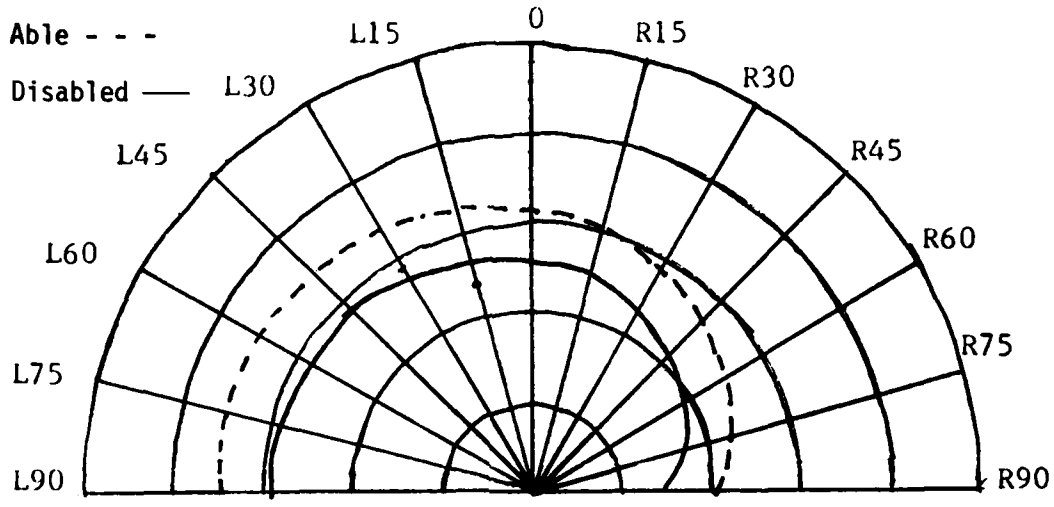


Figure 7 Horizontal Reach, Left Arm. Vertical Position 0 Degrees.

Table 9

Values of Horizontal Reach, Left Arm. Vertial Position 0 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	34.28	38.26	42.44	29.24	36.11	42.98	14
L75	35.15	38.79	42.43	29.04	36.19	43.33	13
L60	35.06	38.15	41.24	28.78	35.85	42.92	14
L45	34.56	38.02	41.48	29.07	35.51	41.94	14
L30	34.16	37.07	39.98	28.89	34.84	40.79	14
L15	32.39	35.69	38.79	24.71	32.80	40.89	14
0	32.20	34.88	37.56	25.66	31.90	38.15	14
R15	30.70	34.26	37.82	26.90	31.14	35.60	14
R30	29.31	32.90	36.49	23.79	29.58	35.37	13
R45	27.13	31.4	35.67	21.58	27.64	33.25	14
R60	24.74	29.37	34.00	19.70	25.45	31.21	14
R75	21.35	27.48	33.61	18.24	23.25	28.26	14
R90	20.67	25.16	29.65	15.42	22.61	29.78	14

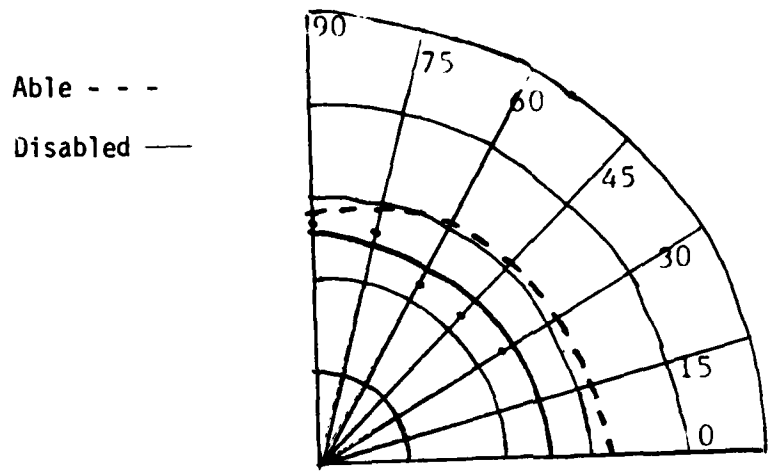


Figure 8 Vertical Grasping Reach, Right Arm. Horizontal Position 0.

Table 10

Values of Vertical Grasping Reach, Right Arm. Horizontal Position 0.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	32.48	34.74	37.01	26.35	32.80	39.27	15
15	31.90	34.78	37.76	26.16	32.14	38.12	15
30	31.53	34.19	36.85	24.83	31.73	38.63	15
45	30.99	33.87	36.75	24.64	31.32	38.01	15
60	30.21	33.03	35.85	24.60	31.27	37.93	15
75	29.84	32.66	35.48	27.04	31.77	36.50	14
90	29.28	32.31	35.34	27.03	32.52	38.02	14

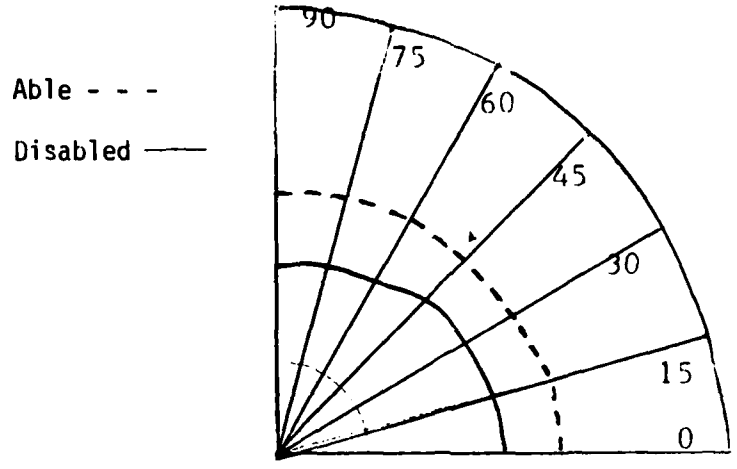


Figure 9 Vertical Grasping Reach, Left Arm. Horizontal Position 0.

Table 11

Values of Vertical Grasping Reach, Left Arm. Horizontal Position 0.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	32.30	34.88	37.56	25.66	31.90	38.15	14
15	23.63	34.86	37.09	25.37	31.58	37.80	14
30	31.58	34.34	37.10	24.28	31.12	37.94	14
45	31.04	33.89	36.74	23.54	31.05	38.57	14
60	30.53	33.51	36.49	22.92	30.67	38.42	14
75	29.91	33.16	36.41	22.24	30.39	38.54	14
90	29.29	32.89	36.48	20.89	30.04	39.19	14

maximum grasping reach of the two groups tended to merge for the right arm but not for the left.

The remainder of the tables of values and their associated graphs are given in the appendices. For a more detailed discussion of the results the reader is directed to the conclusions and discussions of Chapter IV which follows.

CHAPTER IV

CONCLUSIONS

Overview

This study was conducted to determine the maximum grasping reach of people possessing functionally impaired upper extremities. The fact that the group of impaired subjects had a shorter reach than the group of non-disabled subjects does not in itself provide greater knowledge for design solutions. This chapter deals with interpretations of the results obtained from measuring fifteen widely differing impaired subjects and comparing them to a test group comprised of ten non-disabled subjects. The information obtained from the results of this study may be applied to situations which incorporate reaching tasks for an upper extremity, functionally impaired, seated operator. The absence of a widely accepted criterion which serves to describe a handicapped person in terms suitable for systems design, impedes design progress for the handicapped. Research is needed to develop a standard taxonomy by which a handicap person may be evaluated and those results universally interpreted.

As depicted by the graphs and tables of values in the appendixes, the reaching distance of the disabled group when compared to the non-disabled group was shorter in all planes studied. Several factors could account for the observed shorter grasping reach of the disabled group. Variations in the arm lengths of subjects within each group could account for the difference. As is common knowledge, the female reach is generally shorter than the male reach and could have had a major influence in the differences between the groups. These factors,

as well as the disability factor, need to be examined to determine their impact on the results. If these factors can be quantified and related to one another, then their contribution could be more clearly understood. The method of experimentation and the results of this study did not lead to a final conclusion that identifies each specific factor and its contribution to the overall reach decrement. However, there is sufficient information available to partially explain the impact of sex, the variability of arm length, and the role of disability.

Combining males and females in the disabled group was accomplished in the manner described in Chapter III. The weighting factors minimized but did not eliminate the influence of including the female data in the experimental group. Comparison of the 50th percentile values of the male and female subjects shows that the influence of the female data on the overall experimental group was very slight. This comparison showed that the maximum reaching distance of the female group was 1.01 inches or 2.7% less than the males for the right arm and 2.18 inches or 5.9% less for the left arm. When one compares the segregated male values (from the experimental group) to the composite experimental group (male and female) it may be observed that a decrease in the right arm grasping reach of 0.47 inches or 1.25% existed. For the left arm, the decrease was 1.02 inches or 2.74%.

These are small and insignificant. This conclusion is based on the fact that Van Cott and Kinkade (1972) state that to obtain the arm reach distance for the female population, one should subtract 3.5 inches from the figures of the male population. This equates to a 9.4% reduction when subtracted from the figures shown in Van Cott's table of

values for arm reaches. Thus in comparison, a 1.25% and a 2.74% reach reduction for the composite group due to including the female data is relatively minor.

Arm length differences between the able group and the composite disabled group also accounted for a small portion of the overall reach loss. The means of reach distances for right and left arms of each group, abled and disabled, at the points of greatest reach were found to be within 1.54 inches or 4% of each other for the right arm and 2.25 inches or 5.9% for the left arm. As was the case when the female data was included in the experimental group, the percentage of reach loss due to arm length variation between groups was minor. Comparing the able and disabled groups, the most severe loss for the right arm occurred at the horizontal R60 angle and at the T vertical position. A loss of 39.9% was incurred at this point. The least amount of loss for the right arm, 6.9%, was noted at horizontal angle R15 and vertical position 90. A 36.7% loss was the highest involving the left arm, and was present at the horizontal angle R90 and vertical position 75. At horizontal angle L60 and vertical position 90, the point of minimum loss for both arms was observed. A slight but insignificant change of 0.1% was noted at this point. It is interesting that this change was negative, i.e. the disabled group at this measurement point demonstrated a 0.1% greater reach than the able group. This anomaly occurred a total of three times, twice for the left arm and once for the right arm.

In summary, including females in the experimental group resulted in a minor decrease at the point of maximum reach (L90 and R90) of 2.7%

and 5.9% for the right and left arm reaches respectively. Second, the differences between the able and disabled subjects' arm lengths had a minimal influence on the decreased reach capability of the disabled group. The differences in arm lengths between groups was 1.25% for the right and 2.74% for the left arm. These percentages indicate the degree to which the factors of interest may have influenced the reaching distance reductions between the able and disabled groups. It can be reasonably concluded that the impairment of the subjects is the principle cause of the reach reduction. Although quantifying the degree or percentage of influence is not possible from this study, the other factors discussed may be assumed to be negligible.

Results of the statistical t tests showed the difference between the means of the able group and the disabled group were significant at the 5% level. In fact the results were found to be significant at the .0005 level, i.e. highly significant.

Dividing the disabled group into subgroups based on the degree of impairment and comparing them to the able group did not provide significant additional information. The vertical and horizontal grasping reach data of both the able and disabled subgroups were subjected to t tests. The able vs. none-group horizontal reach comparisons were, with the exception of three planes, found to be significant at the .05 level. The three exceptions were the 30 degree plane for the right arm and the 30 and 90 degree planes for the left arm. Except for the 30 degree plane in the able vs. slight comparison, all other t tests between the able vs. slight, able vs. medium, and able vs. severe groups were significant at the 5% level.

Similarly, the vertical reach comparison of the able, none, slight, medium, and severe subgroups, except for the none subgroup, were found to be significant at the same alpha level. The right arm comparisons in the none subgroup were found to be significant only in the R15 plane. Comparison of the left arm indicated significance in all planes except L90, L60, L30, 0, and R30.

A comparison between subgroups was made and a portion of the results elude explanation. In general, the relative order of magnitude for the reach distances coincided with the expectation one has for this type of data. That is, the reach distance would decrease as the degree of impairment increased. At several points, however, this expectation was violated and the subgroup with the greater degree of impairment had a greater reach distance then the adjacent subgroup with the lesser impairment.

Analysis of these occurrences yielded the following information. Occurrences were much more frequent for the right arm. These instances occurred 31 out of 208 times between the severe and medium subgroups. Medium subgroup values exceeded the slight subgroup values 3 times out of 208. The none subgroup exceeded the able group values 64 out of 208. Occurrences of this reverse order of magnitude in the data for the left arm were considerably less. The reversal did not occur between the Severe/Medium and Medium/Slight subgroups. Eight occurrences were noted between slight and none and 11 times between none and able. Explanation of this phenomenon is not apparent. Why this occurred may or may not be significant. Investigation of several

groups may be necessary to determine whether or not this was isolated to this particular study.

Recommendations

Findings of this research have defined the grasping reach limits of people possessing functional impairments of the upper extremities. The reach limits are applicable to systems configured to accommodate a seated, upper extremity impaired operator. Since the posture of the subjects was restricted during this study, the reach values presented should be considered the "minimum reach" values when applied to an operational situation because the postural constraints may not be present.

The reach values have been presented with respect to the able population. This provides conversion factors, which will aid in modifying a system designed for the physically non-disabled operator, to one which is capable of accommodating a disabled operator. It has been shown by other research that operator efficiency is increased and errors are decreased when a system is designed for the specific population which will use it in the operational environment. Application of the grasping reach measurements defined by this study will lead to a greater degree of integration of the personnel and hardware subsystems of systems designed for use by disabled operators.

Suggestions for Further Study

Normally, application of sound human factors principles to system design would ensure the operator could function as part of the system without being over burdened mentally or physically. However, unless

the system is designed specifically for the disabled operator, this may not be assumed. The design engineer needs to consider from the view point of the operator how fatiguing the required tasks may be. Studies need to be undertaken to determine and evaluate the lessening in the capacity for the will to work of the handicapped operator. Relationships that show the performance of a disabled worker as a function of time need to be developed in an attempt to measure worker fatigue.

Although there seemed to be only minor differences in the mean reach distance of the male and female subjects of this study, the difference between them may be more pronounced than indicated. Disabled males and females should be evaluated separately to determine the differences in reach length. Disabled males and females should be evaluated separately, using a matched group design. This would provide a better understanding of the effect of the disability on their maximum reaching distance. The matched group design would experimentally minimize variables such as arm length differences between subjects, which tended to be confounding in this study. Care must also be exercised to include in each group a large number of subjects to reduce the effects of the remaining variability among subjects.

Clearance studies need to be conducted on the handicapped population. Wheelchair clearances have been well defined but refinement of this information is needed. For example, motorized wheelchairs have several dimensional characteristics which set them apart from non-motorized wheelchairs. These differences should be documented to ensure the compatibility of the motorized wheelchairs to future

systems. Hand work space dimensions need to be examined since, like the reach envelope, the disabled person's hand movement envelope may be altered considerably.

Results of this study may be extended to areas of research which emphasize the physiological requirements for handicap design. Methods need to be developed and incorporated into a work station design so that people with spinal cord injuries would periodically be required to shift, or in some manner, force movement of that part of the body which is in contact with the chair seat pad. Frequent position shifts for this area are necessary to prevent pressure from being applied to small areas for extended periods. Severe complications to the individual may result if the pressure is not released and redistributed periodically. Using techniques similar to those employed to measure the maximum grasping reach, researchers could extend the reach distance requirement so as to force the subject to lift or shift his sitting position. In this manner, the reach distance required to accomplish the movement could be measured. This distance could be incorporated into a work station design and thus build in a task which would require the operator to extend his reach far enough to cause the desired position shift.

A standard taxonomy should be developed which would provide classification of a disabled person according to the effects of the disability and not its cause. During the course of this study, it became apparent that the lack of terminology to describe and thus classify a handicapped person was a major obstacle. This should be one of the most emphasized needs of study.

REFERENCES

Referenced

Bullock, M.I. The determination of functional arm reach boundaries for operation of manual controls. Ergonomics, 1974, 17, 375-388.

Dreyfuss, Henry. 3[a] Humanscale Wheelchair User and 3[b] Humanscale Handicapped and Elderly. MIT Press, Cambridge, Mass. 1973.

Faulkner, T.W. and Day, R.A. The maximum functional reach for the female operator. AIIE Transactions, 1970, II, 126-131.

Kennedy, K.W. Reach capability of the USAF population: Phase I. The outer boundaries of grasping - reach envelopes for the shirt sleeved seated operator. USAF, ARML, technical report TDR 64-59, 1964.

Roebuck, J.A., Kroemer, K.H.E., and Thomson, W.G. Engineering Anthropometry Methods, Wiley & Sons, N.Y., 1975.

Van Cott, H.P. and Kinkade, R.G. Design of individual workspaces. Human engineering guide to equipment design, rev. ed. U.S. Govt, Printing Office WADE, 1972. ch. 9.

Supplemental Sources Consulted

Applied Ergonomics Handbook. IPC Science and Technology Press Ltd. Unspecified date. Published Surry, England.

Ayoub, M.M. Work place design and posture. Human Factors, 1973, 15, 265-268.

Burke, David C. and Murray, Duncan D. Handbook of Spinal Cord Medicine, Raven Press, New York, 1975.

Dempster, W.T. and Gabel, W.C. Workspace for the seated operator. American Journal of Physical Anthropology, 17, 1959.

Dreyfuss, Henry. Designing for People, Simon and Schuster, New York, 1955.

Floyd, W.F. and Fogerts, D.F. Anatomical and physiological principles in chair and table design, Ergonomics, 1958, 1958, 2, 1-16.

Freund, L.E. and Sadosky, T.L. Linear programming applied to optimization of instrument panels and work-place layout. Human Factors, 1967, 9, 295-300.

Gortner, R.V. IE's help handicapped workers raise productivity. Industrial Engineering, 1973, 5, 10-15.

Hansen, R., and Cornog, D.Y. Annotated bibliography of applied physical anthropology in human engineering. USAF, WADE, technical report, 56-30, May, 1958.

Hertzberg, H.T.E. Some contributions of applied physical anthropology to human engineering. USAF, WADE, technical report 60-19, January, 1960.

Hertzberg, H.T.E. Dynamic anthropometry of working positions. Human Factors, 1960, 2, 147-155.

Human Engineering Data Digest. U.S. Army Missile Research, Development and Engineering Laboratory, Redstore Arsenal, Alabama 35809, 1975.

McCormick, E.J. Human Factors in Engineering, McGraw Hill, N.Y., 4th ed. 1976.

Razier, Carolin K., Three-dimensional work space of the amputee. Human Factors, 19, 6, 1977.

Taylor, C.L. and Blaschke, A.C. A method for kenematic analysis of motion of the shoulder, arm and hand complex. Ann. N.Y. Acad. Sci., 51, 1251-1265.

Tichauer, E.R. Industrial Engineering in the rehabilitation of the handicapped. Proceedings of the 18th Annual Institute Conference and Convention. American Institute of Industrial Engineers, 1967, 171-180.

Ward, J.S. Ergonomic techniques in determination of optimum work surface heights. Applied Ergonomics, 1971, 2, 171-177.

APPENDIX A

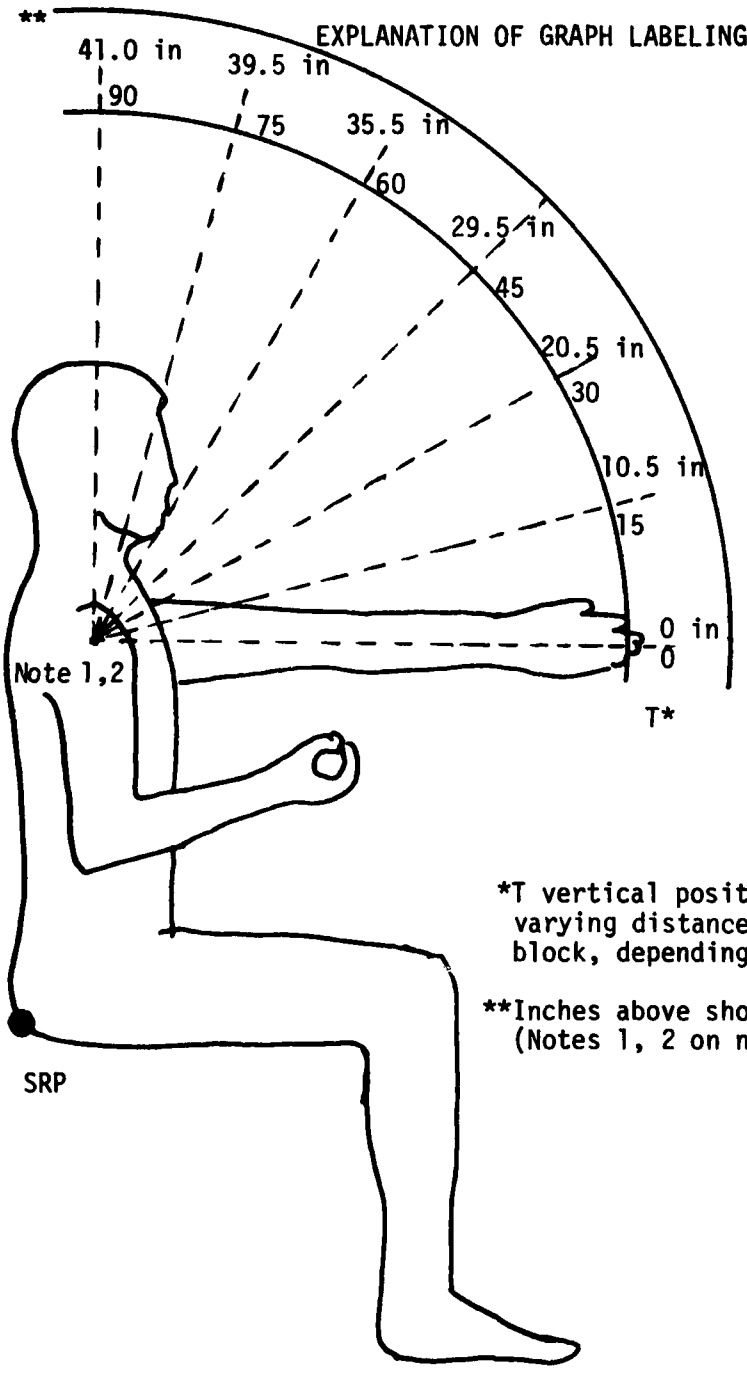
HORIZONTAL AND VERTICAL

GRASPING REACH

(ABLE AND COMPOSITE EXPERIMENTAL GROUPS)

APPENDIX A

EXPLANATION OF GRAPH LABELING



*T vertical position is located at varying distances below the 0 position block, depending on boom height

**Inches above shoulder joint ball. (Notes 1, 2 on next page)

Diagram A1 Vertical Grasping Reach.

Note 1) shoulder ball joint height above seat reference point (SRP)

Disabled (N=15): $\bar{X}$ = 20.65, S_x = 1.256
Able (N=10): $\bar{X}$ = 21.75, S_x=0.808

2) shoulder ball joint height above T level (T level = 29.75 inches from floor)

Disabled (N=15): $\bar{X}$ = 7.92, S_x = 2.298
Able (N=10): $\bar{X}$ = 7.53, S_x = 0.795

Note: Observe the corresponding reach angle for each chair orientation, i.e. chair R30 = reach angle L30

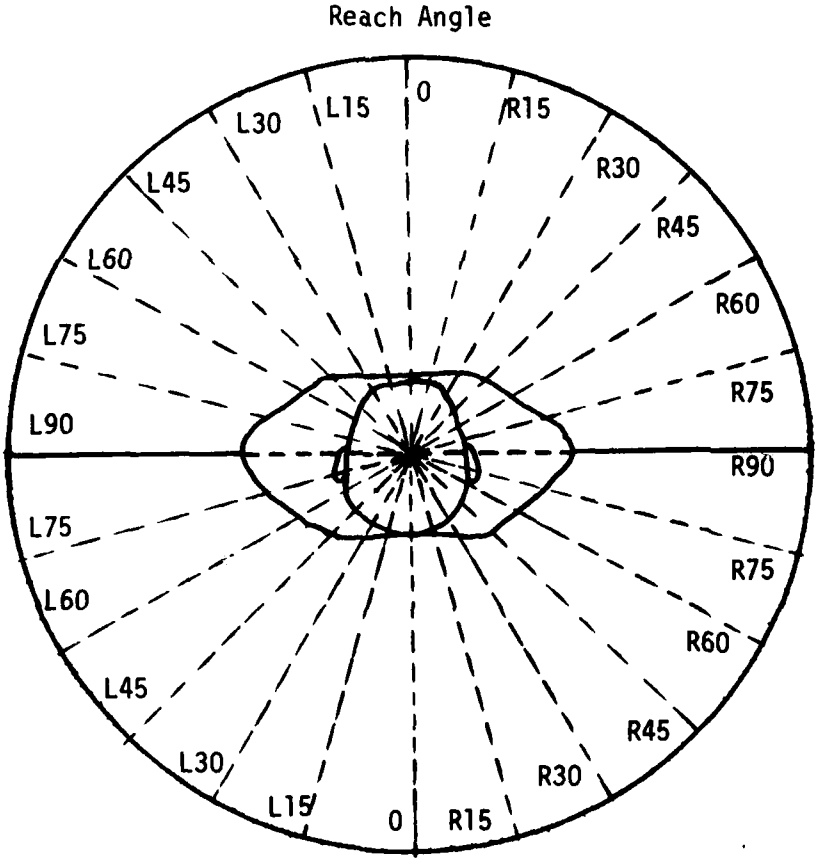


Diagram A2 Horizontal Grasping Reach.

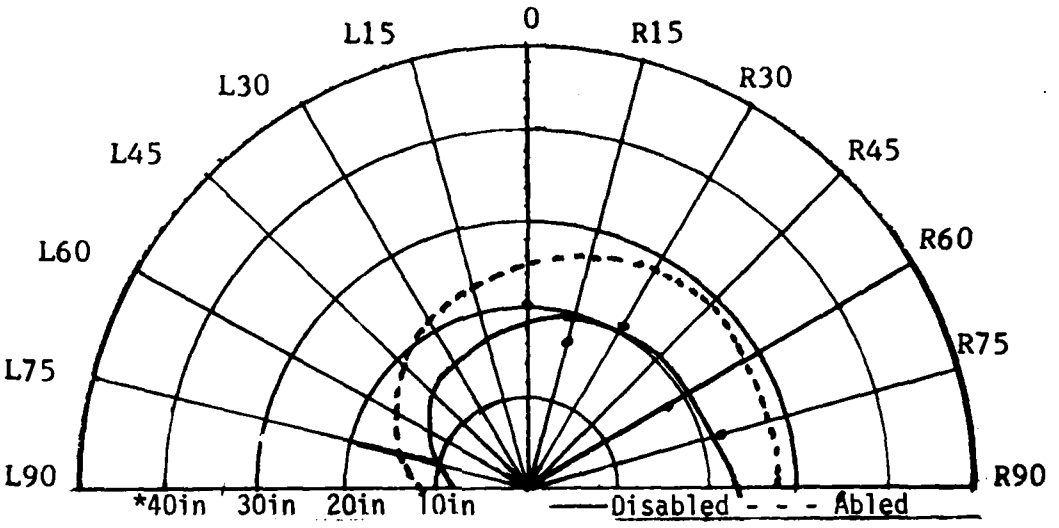


Figure A1 Horizontal Reach, Right Arm. Vertical Position T

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	12.11	17.27	22.43	8.05	16.40	24.75	13
L75	15.31	19.66	24.01	10.50	17.18	23.87	13
L60	17.65	22.5	27.35	13.30	19.75	26.19	13
L45	19.65	23.25	27.24	16.14	21.38	26.62	13
L30	22.26	25.25	28.24	17.12	23.30	29.46	14
L15	23.49	27.35	31.21	18.38	14.48	30.50	14
0	26.08	28.07	30.06	21.33	26.47	31.61	15
R15	27.08	29.26	31.44	16.88	25.57	34.27	14
R30	28.35	30.22	32.09	21.71	27.80	33.89	14
R45	28.52	30.90	33.28	21.68	28.27	33.26	14
R60	27.86	31.45	35.04	16.74	26.57	36.40	14
R75	27.57	31.25	34.93	22.58	29.30	36.02	14
R90	28.04	31.32	34.60	23.59	30.25	36.91	14

Table A1 Values of Horizontal Reach. Vertical Position T.

*These distances and line designations are the same for all remaining graphs.

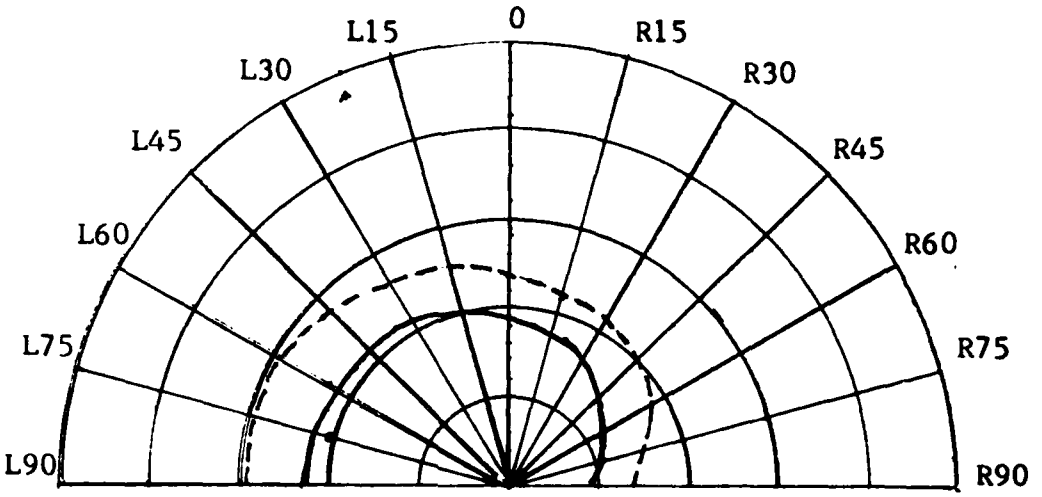


Figure A2 Horizontal Reach, Left Arm. Vertical Position T

Horizontal Angle	Able N=10 Percentile 5	50	95	Disabled Percentile 5	50	95	N
L90	28.84	31.36	33.88	22.80	28.88	34.96	14
L75	28.59	31.84	33.10	20.78	29.03	35.83	12
L60	28.83	31.6	34.37	22.30	28.90	35.48	13
L45	27.93	31.19	34.45	21.20	28.60	36.03	13
L30	27.50	30.32	33.14	21.46	27.83	34.20	14
L15	26.53	29.42	32.31	19.81	26.39	32.96	14
0	25.96	28.54	31.12	18.72	25.26	31.81	14
R15	23.42	27.16	30.90	22.99	23.60	29.55	14
R30	23.29	26.72	30.15	16.55	22.41	28.27	13
R45	20.04	24.30	28.56	14.40	20.54	26.68	14
R60	18.22	22.67	27.12	12.79	18.52	24.25	14
R75	14.79	20.61	26.42	11.45	16.32	21.19	14
R90	14.39	18.51	22.63	9.12	13.81	18.47	14

Table A2 Values of Horizontal Reach. Vertical Position T.

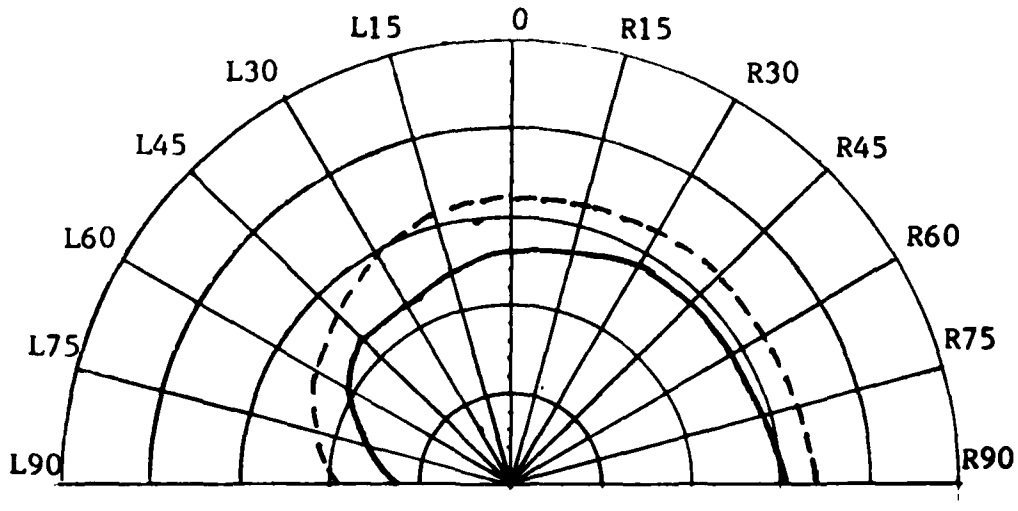


Figure A3 Horizontal Reach, Right Arm. Vertical Position 0 Degrees

Horizontal Angle	Able N=10 Percentile 5	50	95	Disabled Percentile 5	50	95	N
L90	19.66	24.92	30.17	13.71	21.43	29.16	15
L75	22.26	26.91	31.56	17.67	24.36	31.06	13
L60	25.83	28.90	31.97	21.44	27.15	32.77	13
L45	25.80	30.15	34.50	23.64	28.65	23.65	13
L30	29.10	32.0	34.9	23.70	29.47	35.24	14
L15	31.23	33.69	36.15	25.71	31.48	37.25	14
0	32.48	34.74	37.01	26.35	32.80	39.27	14
R15	33.25	35.76	38.27	27.51	33.77	40.04	14
R30	34.70	36.75	38.80	29.10	34.95	40.82	14
R45	34.82	37.61	40.41	28.41	34.89	41.39	14
R60	33.92	37.98	42.04	28.58	34.26	42.05	14
R75	33.94	38.49	43.04	29.50	36.12	42.73	14
R90	35.06	38.57	42.09	30.41	37.03	43.64	14

Table A3 Values of Horizontal Reach, Right Arm. Vertical Position 0 Degrees.

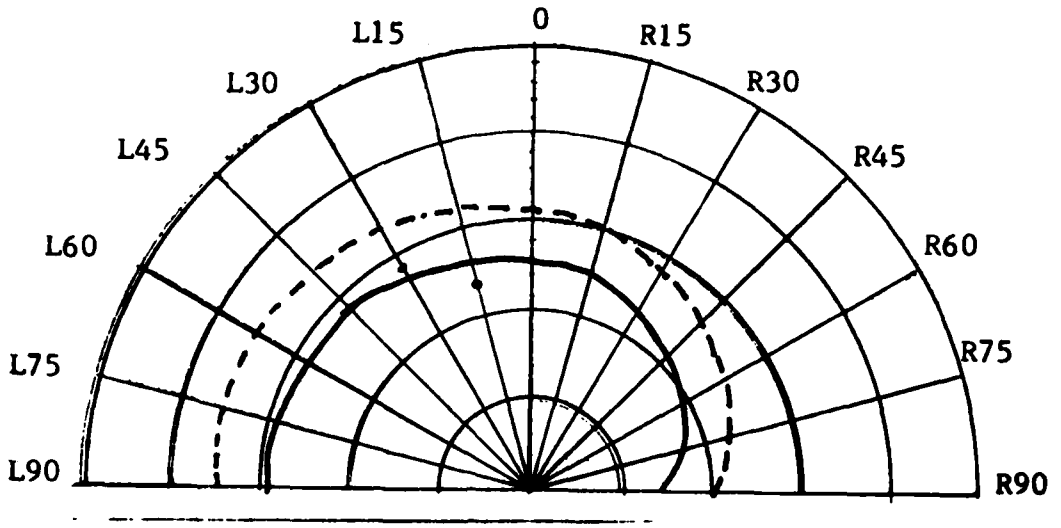


Figure A4 Horizontal Reach, Left Arm. Vertical Position 0 Degrees

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	34.28	38.26	42.44	29.24	36.11	42.98	14
L75	35.15	38.79	42.43	29.04	36.19	43.33	13
L60	35.06	38.15	41.24	28.78	35.85	42.92	14
L45	34.56	38.02	41.48	29.07	35.51	41.94	14
L30	34.16	37.07	39.98	28.89	34.84	40.79	14
L15	32.39	35.69	38.79	24.71	32.80	40.89	14
0	32.20	34.88	37.56	25.66	31.90	38.15	14
R15	30.70	34.26	37.82	26.90	31.14	35.60	14
R30	29.31	32.90	36.49	23.79	29.58	35.37	13
R45	27.13	31.4	35.67	21.58	27.64	33.25	14
R60	24.74	29.37	34.00	19.70	25.45	31.21	14
R75	21.35	27.48	33.61	18.24	23.25	28.26	14
R90	20.67	25.16	29.65	15.42	22.61	29.78	14

Table A4 Values of Horizontal Reach, Left Arm. Vertical Position 0 Degrees.

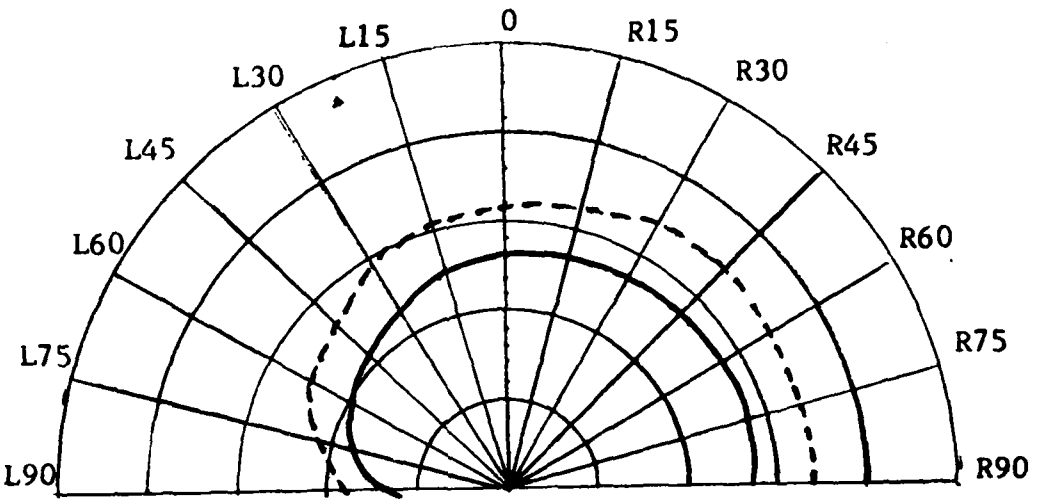


Figure A5 Horizontal Reach, Right Arm. Vertical Position 15 Degrees.

Horizontal Angle	Able N=10 Percentile 5	50	95	Disabled Percentile 5	50	95	N
L90	18.50	24.49	30.48	12.68	21.11	29.51	15
L75	22.26	26.91	31.56	18.66	24.73	30.80	13
L60	24.96	28.45	32.55	21.12	27.02	32.91	13
L45	25.91	30.25	34.60	22.97	28.68	34.38	14
L30	28.89	31.85	34.81	22.56	29.54	36.53	14
L15	31.03	33.54	36.05	24.40	31.17	37.94	14
0	31.90	34.78	37.36	26.16	32.14	38.12	14
R15	33.19	35.66	38.13	26.79	33.32	39.87	14
R30	34.22	36.62	39.03	27.92	34.06	40.19	14
R45	34.40	37.41	40.42	27.46	24.17	40.87	14
R60	34.34	37.73	41.13	27.25	34.71	42.18	14
R75	33.92	38.11	42.27	28.61	35.32	42.04	14
R90	34.62	38.32	42.02	27.84	35.55	43.45	14

Table A5 Values of Horizontal Reach, Right Arm. Vertical Position 0 Degrees.

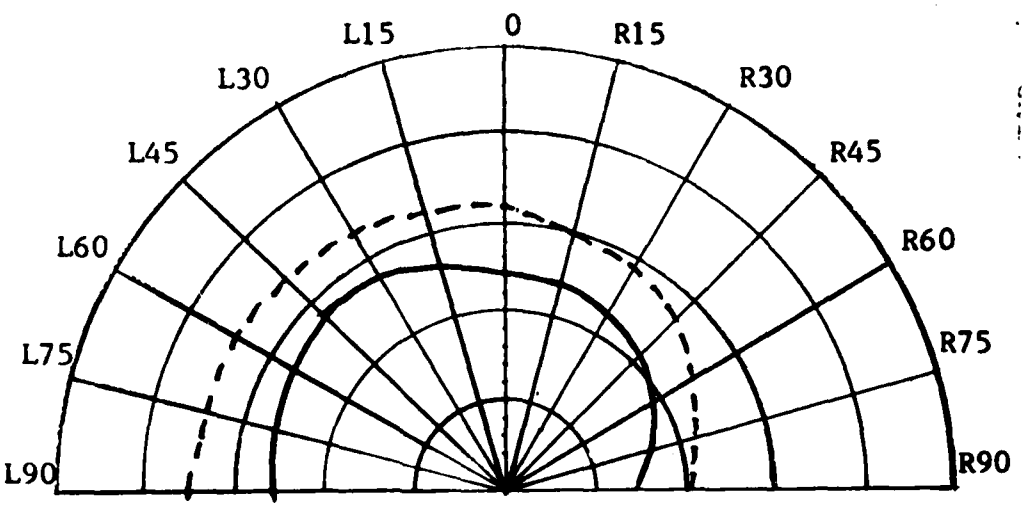


Figure A6 Horizontal Reach, Left Arm. Vertical Position 15 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	35.07	38.41	41.75	26.88	35.41	43.96	14
L75	34.37	38.44	42.51	26.65	35.29	43.93	13
L60	34.35	38.02	41.69	27.14	34.82	42.49	14
L45	34.26	37.95	41.64	28.05	34.79	41.53	14
L30	33.83	36.92	40.01	28.03	34.48	40.93	14
L15	32.38	35.59	38.80	26.63	32.85	39.07	14
0	32.63	34.86	37.09	25.37	31.58	37.80	14
R15	30.28	33.94	37.50	24.20	30.14	36.09	14
R30	29.18	33.00	36.82	23.10	29.03	34.94	13
R45	26.53	31.00	35.47	21.74	27.23	32.73	14
R60	25.04	29.62	34.20	19.22	25.25	31.28	14
R75	21.96	27.60	33.24	17.24	23.21	28.94	14
R90	21.49	25.86	30.23	15.38	20.98	26.77	14

Table A6 Values of Horizontal Reach, Left Arm. Vertical Position 15 Degrees.

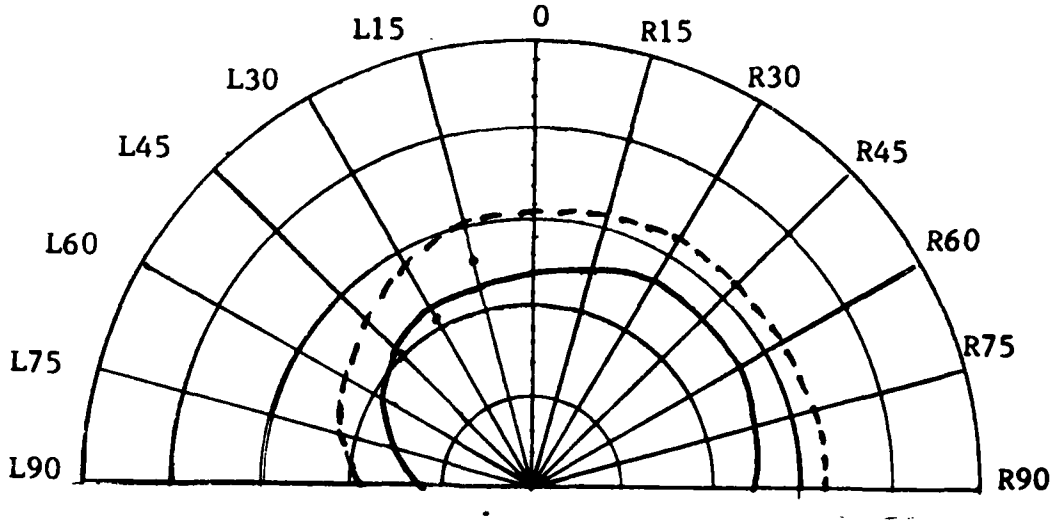


Figure A7 Horizontal Reach, Right Arm. Vertical Position 30 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	19.16	24.67	30.18	12.46	21.82	31.16	15
L75	21.95	27.09	32.23	17.50	24.47	31.43	14
L60	24.23	28.53	32.83	19.62	26.92	34.21	13
L45	25.82	30.02	34.22	21.13	27.71	34.29	14
L30	28.89	31.85	34.81	22.39	29.46	36.55	14
L15	30.01	32.89	35.77	26.76	31.79	36.81	14
0	31.53	34.19	36.85	24.83	31.73	38.63	14
R15	32.19	35.09	37.99	26.61	32.96	39.31	14
R30	33.41	35.8	38.18	26.90	33.59	40.29	14
R45	33.43	36.81	40.19	26.41	33.52	40.65	14
R60	33.35	36.93	40.51	26.71	33.94	41.17	14
R75	33.11	37.21	41.31	27.45	34.03	40.61	14
R90	33.42	36.92	40.42	26.60	34.19	41.78	14

Table A7 Values of Horizontal Reach, Right Arm. Vertical Position 30 Degrees.

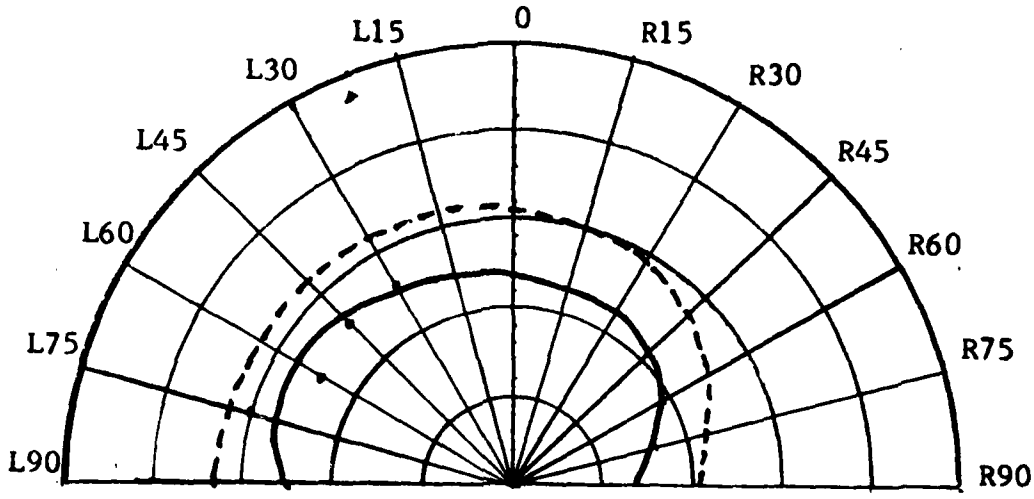


Figure A8 Horizontal Reach, Left Arm. Vertical Position 30 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	33.23	36.89	40.55	25.24	34.02	42.70	15
L75	33.19	37.21	41.23	31.32	35.48	39.65	12
L60	33.15	37.17	41.19	25.03	33.18	41.34	14
L45	33.35	36.77	40.19	26.33	33.72	41.13	14
L30	32.58	36.2	39.82	26.60	33.35	40.11	14
L15	32.43	35.59	38.75	25.39	32.30	39.02	14
0	31.58	34.34	37.10	24.28	31.12	37.94	14
R15	30.10	33.66	37.22	22.87	29.11	35.34	14
R30	29.04	32.70	36.36	22.82	28.80	34.79	13
R45	26.22	30.87	35.52	21.44	27.07	32.71	14
R60	24.59	29.24	33.89	19.09	24.98	30.87	14
R75	22.07	27.39	32.71	17.75	22.99	27.63	14
R90	21.25	26.16	31.07	14.33	20.91	27.48	14

Table A8 Values of Horizontal Reach, Left Arm. Vertical Position 30 Degrees.

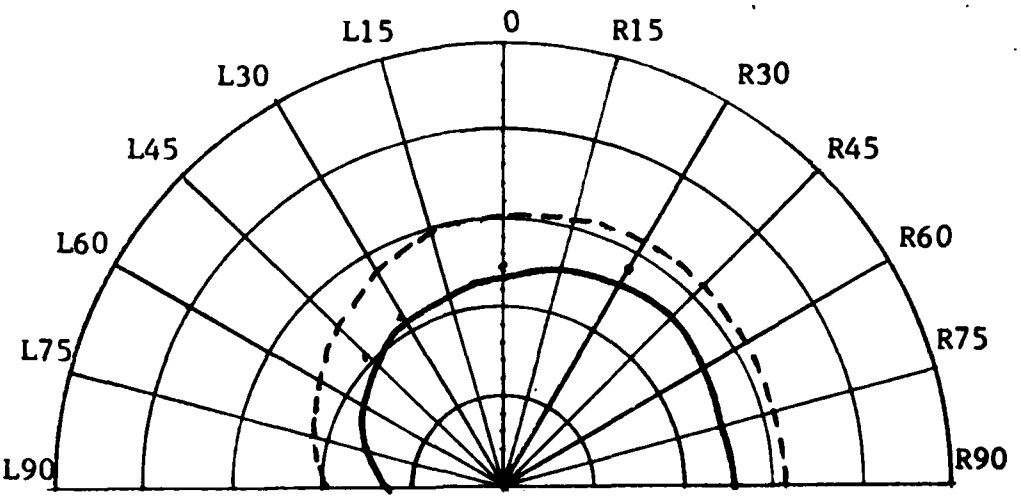


Figure A9 Horizontal Reach, Right Arm. Vertical Position 45 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	19.55	25.34	31.13	13.42	22.69	31.98	15
L75	22.11	27.26	32.41	17.68	29.26	31.66	14
L60	23.99	28.60	33.21	18.87	24.11	31.49	14
L45	26.15	30.05	33.95	21.51	27.78	34.05	14
L30	27.92	31.37	34.82	22.36	29.26	36.17	14
L15	29.83	32.81	35.79	23.46	30.78	38.12	14
0	30.99	33.87	36.75	24.64	31.32	38.01	14
R15	31.29	34.24	37.19	26.22	32.69	39.16	14
R30	32.08	32.82	35.56	28.07	33.51	38.93	14
R45	32.28	35.31	38.34	27.52	33.22	38.92	14
R60	31.79	35.27	38.75	27.14	33.17	39.20	14
R75	31.84	35.01	38.18	25.42	32.38	39.34	14
R90	31.62	34.87	38.13	27.18	32.90	38.62	14

Table A9 Values of Horizontal Reach, Right Arm. Vertical Position 45 Degrees.

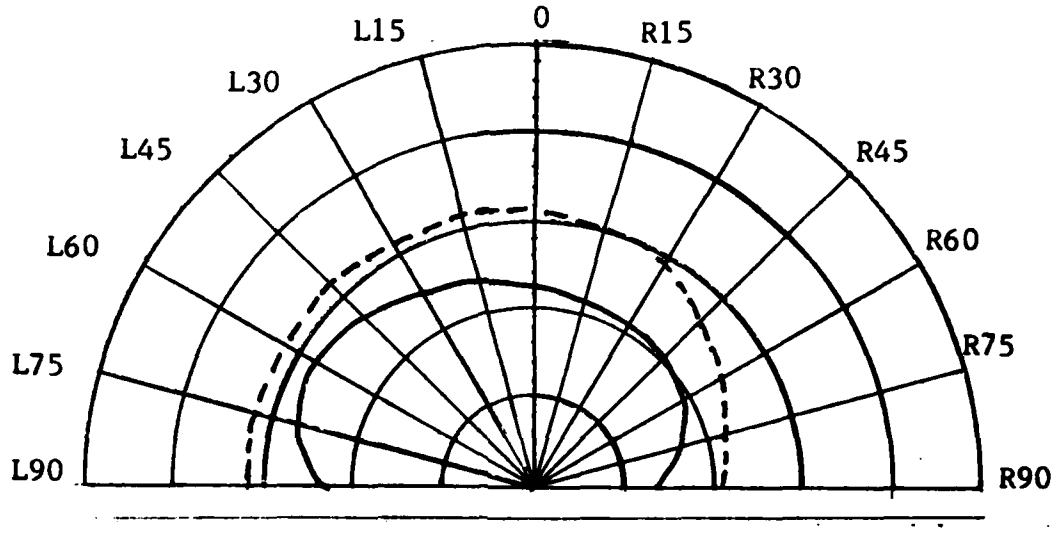


Figure A10 Horizontal Reach, Left Arm. Vertical Position 45 Degrees.

Horizontal Angle	Able N=10 Percentile 5	50	95	Disabled Percentile 5	50	95	N
L90	31.59	34.99	38.39	22.77	32.02	41.22	12
L75	31.79	35.61	39.43	29.37	33.68	37.97	12
L60	31.78	35.72	39.67	28.32	33.47	38.62	13
L45	31.98	35.90	39.82	28.82	33.80	38.79	13
L30	31.31	35.25	39.19	25.01	32.59	40.16	14
L15	32.34	35.19	38.04	24.54	31.51	38.47	14
0	31.04	33.89	36.74	23.54	31.05	38.57	14
R15	29.99	33.37	36.75	22.97	29.58	36.20	14
R30	28.92	32.45	35.98	21.66	28.65	35.61	13
R45	26.82	30.87	34.92	20.61	26.96	33.32	14
R60	25.45	29.50	33.55	18.44	25.27	32.11	14
R75	22.60	27.54	32.48	16.48	23.24	30.01	14
R90	21.16	26.39	31.62	14.56	21.35	28.15	14

Table A10 Values of Horizontal Reach, Left Arm. Vertical Position 45 Degrees.

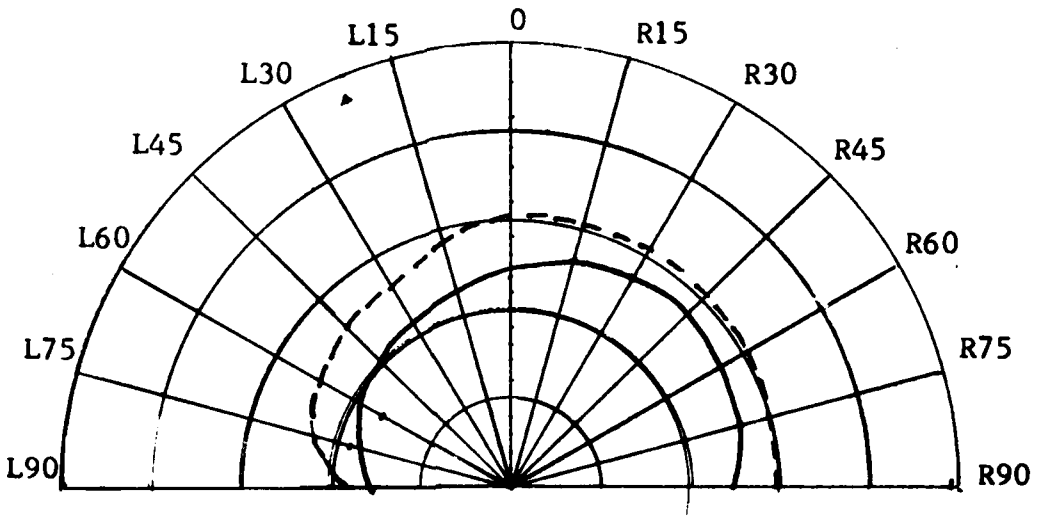


Figure All Horizontal Reach, Right Arm. Vertical Position 60 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	18.44	26.82	35.20	15.96	23.89	33.42	14
L75	22.68	27.61	32.54	18.41	25.30	32.21	13
L60	24.39	28.68	32.97	16.50	25.66	34.80	14
L45	26.15	30.02	33.89	21.57	27.78	34	14
L30	25.76	30.25	34.74	22.50	29.38	36.26	14
L15	29.22	32.39	35.56	24.24	30.96	37.70	14
0	30.21	33.03	35.85	24.60	31.27	37.93	14
R15	30.79	33.69	36.59	26.78	32.45	38.13	14
R30	31.09	33.9	36.71	27.31	32.64	37.98	14
R45	31.06	33.96	36.87	26.77	32.33	37.88	14
R60	30.28	33.65	37.02	26.25	31.87	37.49	14
R75	29.98	32.97	35.96	26.47	31.45	36.44	14
R90	29.19	32.59	36.00	25.92	30.72	35.52	14

Table All Values of Horizontal Reach, Right Arm. Vertical Position 60 Degrees.

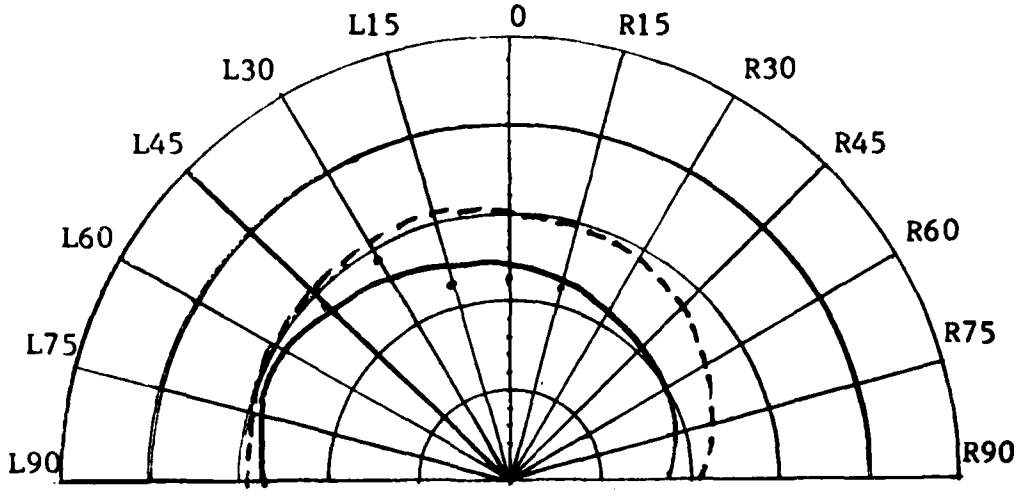


Figure A12 Horizontal Reach, Left Arm. Vertical Position 60 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	29.27	32.71	36.15	27.89	31.31	34.71	12
L75	29.90	33.51	37.12	28.12	31.88	35.64	12
L60	30.32	34.20	38.08	29.43	32.85	36.41	12
L45	30.76	34.5	38.24	27.07	32.38	37.70	13
L30	30.56	34.42	38.28	27.97	32.88	37.80	13
L15	31.29	34.56	37.83	23.86	31.20	38.54	14
0	30.53	33.51	36.49	22.92	30.67	38.42	14
R15	29.60	33.21	36.82	22.76	29.72	36.50	14
R30	28.98	32.40	35.83	21.72	28.36	35	13
R45	26.80	30.85	34.90	20.49	27.46	34.43	14
R60	25.33	29.50	33.67	17.95	25.39	32.83	14
R75	23.03	28.31	33.60	18.78	24.00	29.22	14
R90	21.74	26.55	31.36	18.13	23.39	28.65	14

Table A12 Values of Horizontal Reach, Left Arm. Vertical Position 60 Degrees.

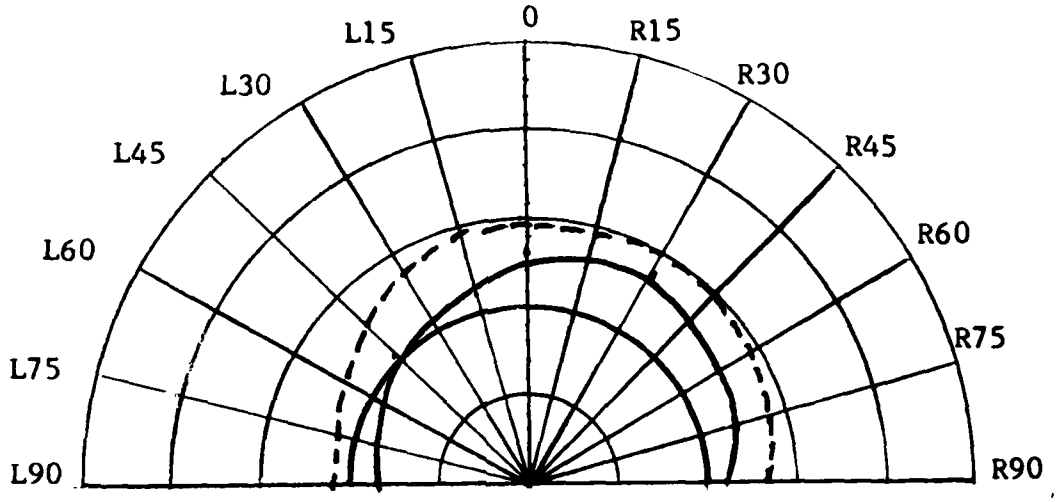


Figure A13 Horizontal Reach, Right Arm. Vertical Position 75 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	21.72	26.04	30.37	17.22	24	30.77	15
L75	23.85	27.51	31.17	18.25	24.96	31.67	14
L60	24.42	28.69	32.96	16.97	25.74	34.51	14
L45	26.62	30.13	33.65	20.76	27.52	34.28	14
L30	28.08	31.27	34.46	22.04	29.25	36.45	14
L15	29.10	32.19	35.28	23.99	30.65	37.31	14
0	29.84	32.66	35.48	27.04	31.77	36.50	13
R15	29.78	32.91	36.04	27.71	32.39	37.06	13
R30	29.99	33.02	36.05	27.75	32.26	36.76	13
R45	29.37	32.48	35.59	26.23	32.09	30.98	14
R60	28.04	31.65	35.26	25.55	30.78	36.02	14
R75	27.49	30.81	34.13	25.32	29.66	34	14
R90	26.20	29.52	32.84	23.94	28.32	32.72	14

Table A13 Values of Horizontal Reach, Right Arm. Vertical Position 75 Degrees.

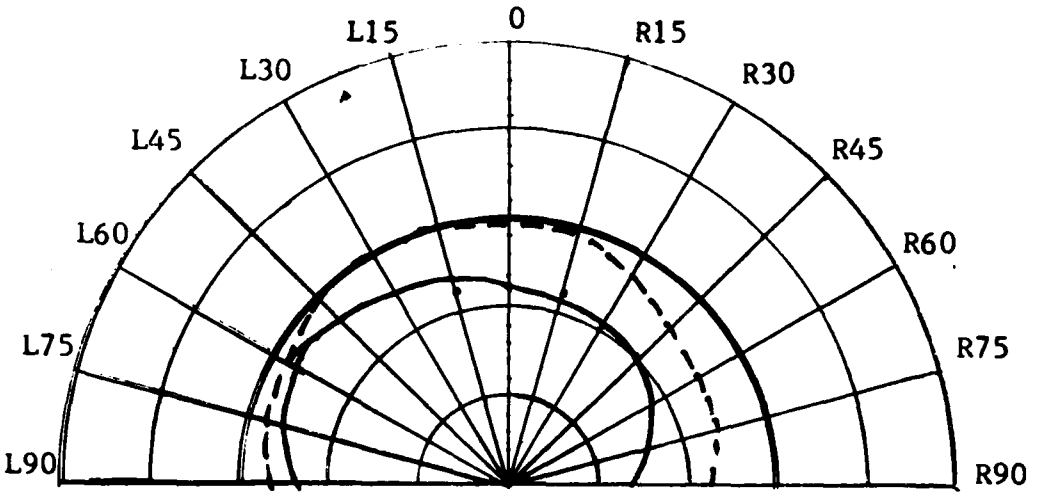


Figure A14 Horizontal Reach, Left Arm. Vertical Position 75 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	26.22	30.04	33.86	24.70	28.38	32.07	12
L75	28.20	31.51	34.82	26.01	29.62	33.23	12
L60	28.45	32.32	36.19	27.40	31	34.59	14
L45	29.30	32.95	36.60	28.62	31.89	35.16	14
L30	29.32	33.2	37.08	29.19	32.44	35.69	14
L15	30.14	33.99	37.84	23.50	30.77	38.06	14
0	29.91	33.16	36.41	22.24	30.39	38.54	14
R15	29.31	33.04	36.77	22.11	29.59	37.08	14
R30	28.82	32.35	35.88	20.76	30.30	39.85	13
R45	26.85	30.75	34.65	20.77	27.75	34.75	14
R60	25.25	29.55	33.85	18.18	25.77	33.35	14
R75	24.85	28.41	31.97	16.58	23.93	31.29	14
R90	22.35	26.71	31.07	14.15	21.99	29.82	14

Table A14 Values of Horizontal Reach, Left Arm. Vertical Position 75 Degrees.

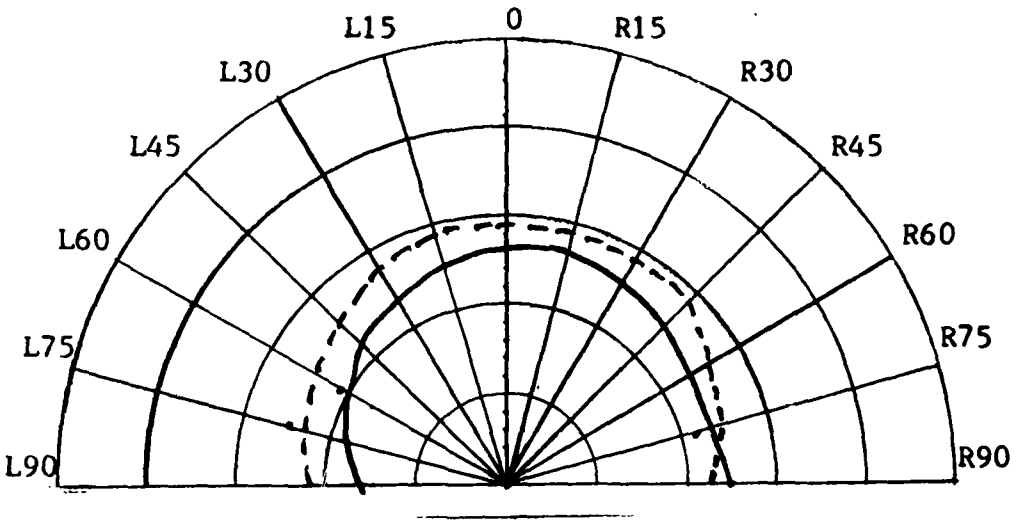


Figure A15 Horizontal Reach, Right Arm. Vertical Position 90 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile 5	50	95	Percentile 5	50	95	N
L90	21.73	25.64	29.55	15.96	23.25	30.54	15
L75	24.84	27.64	30.44	19.74	25.13	30.52	14
L60	20.85	27.81	34.77	17.94	25.92	33.92	14
L45	26.95	30.25	33.96	23.20	28.39	33.59	14
L30	28.43	31.37	34.25	24.64	30.	35.36	14
L15	28.93	31.99	35.05	25.58	30.95	36.32	14
0	29.28	32.31	35.34	27.03	32.52	38.02	13
R15	29.82	32.63	35.44	27.76	32.40	37.02	13
R30	27.84	32.61	37.38	26.78	31.77	36.75	13
R45	28.25	31.36	34.47	25.13	30.70	36.26	13
R60	26.52	30.48	34.44	24.15	29.47	34.78	13
R75	25.00	28.94	32.88	22.51	27.22	31.93	13
R90	23.46	27.57	31.68	25.99	29.44	32.90	13

Table A15 Values of Horizontal Reach, Right Arm. Vertical Position 90 Degrees.

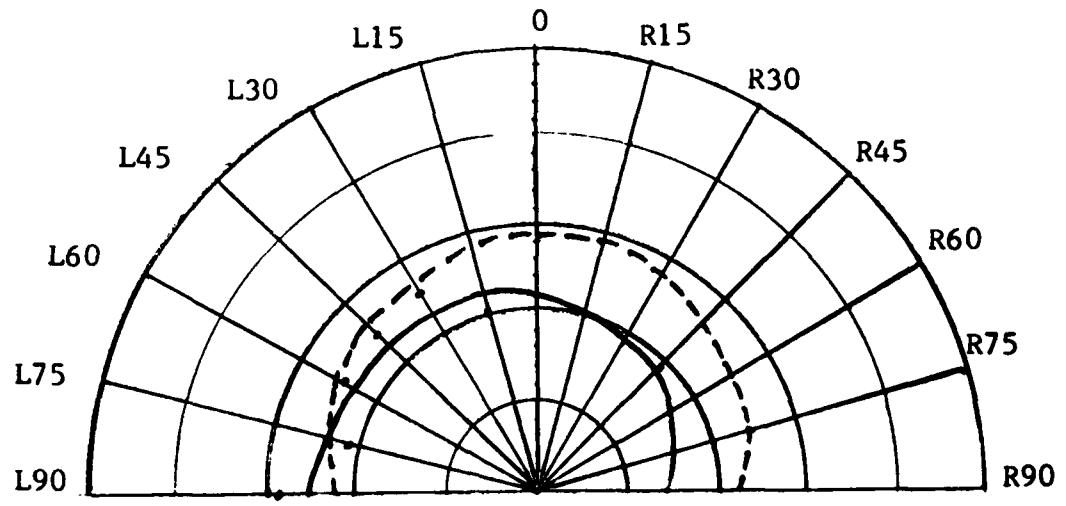


Figure A16 Horizontal Reach, Left Arm. Vertical Position 90 Degrees.

	Able N=10			Disabled			
Horizontal Angle	Percentile			Percentile			
	5	50	95	5	50	95	N
L90	22.72	27.56	32.40	28.31	25.36	30.68	12
L75	24.24	28.91	33.58	22.51	27.22	31.93	12
L60	25.94	30.30	34.66	25.99	29.44	32.90	11
L45	27.34	31.32	35.30	25.94	30.30	34.66	12
L30	27.59	32.10	36.61	26.45	31.22	36	12
L15	28.80	32.86	36.92	21.27	30.46	39.64	13
0	29.29	32.89	36.48	20.89	30.04	39.19	14
R15	29.43	32.81	36.19	20.78	29.54	38.30	14
R30	26.94	31.55	36.16	19.79	28.22	36.65	13
R45	27.09	30.87	34.65	19.28	27.57	35.85	14
R60	25.42	29.72	30.02	17.89	25.98	34.07	14
R75	25.04	28.51	31.98	16.47	24.20	31.93	14
R90	23.26	26.79	30.32	15.03	22.50	29.97	14

Table A16 Values of Horizontal Reach, Left Arm. Vertical Position 90 Degrees.

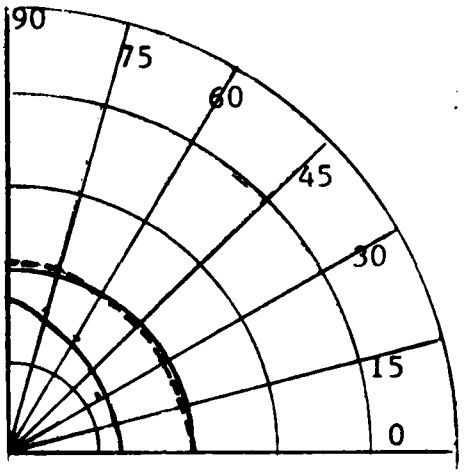


Figure A17 Vertical Grasping Reach, Right Arm. Horizontal Position of L90.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	19.66	24.92	30.17	13.71	21.43	29.16	15
15	18.50	24.49	30.48	12.68	21.11	29.51	15
30	19.16	24.67	30.18	12.46	21.82	31.16	15
45	19.55	25.34	31.13	13.42	22.69	31.98	15
60	18.44	26.82	35.20	15.96	23.89	33.42	14
75	21.72	26.04	30.37	17.22	24	30.77	15
90	21.73	30.37	29.55	15.96	23.25	30.54	15

Table A17 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L90.

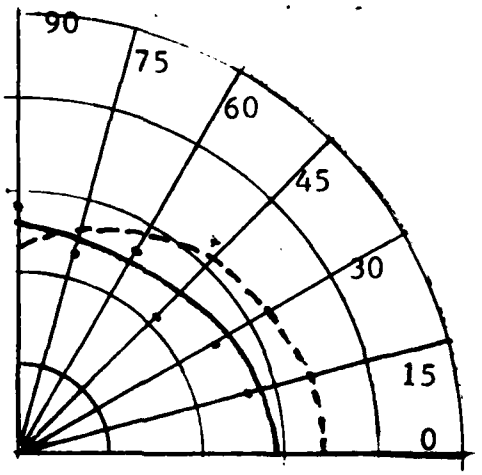


Figure A18 Vertical Grasping Reach, Left Arm. Horizontal Position of L90.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	34.28	38.36	42.44	29.24	36.11	42.98	14
15	35.07	38.41	41.75	26.88	35.41	43.96	14
30	33.23	36.89	40.55	25.24	34.02	42.70	14
45	31.59	34.99	38.39	22.77	32.02	41.22	12
60	29.27	32.71	36.15	27.89	31.31	34.71	13
75	22.22	30.04	33.86	24.70	28.38	32.07	13
90	22.27	27.56	32.40	28.31	25.36	30.68	13

Table A18 Values of Vertical Grasping Reach, Left Arm. Horizontal Position L90.

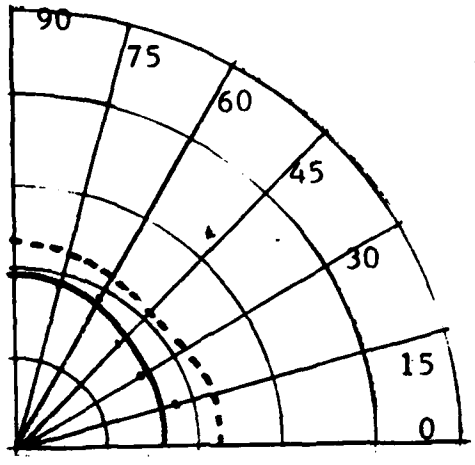


Figure A19 Vertical Grasping Reach, Right Arm. Horizontal Position of L75.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	22.26	26.91	31.56	17.67	24.36	31.06	14
15	22.26	26.91	31.56	18.66	24.73	30.80	14
30	21.95	27.09	27.26	17.50	24.47	31.43	14
45	22.11	27.26	32.41	17.68	29.26	31.66	14
60	22.68	27.61	32.54	18.41	25.30	32.21	14
75	23.85	27.51	31.17	18.25	24.96	31.67	14
90	24.84	27.64	30.44	19.74	25.13	30.52	14

Table A19 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L75.

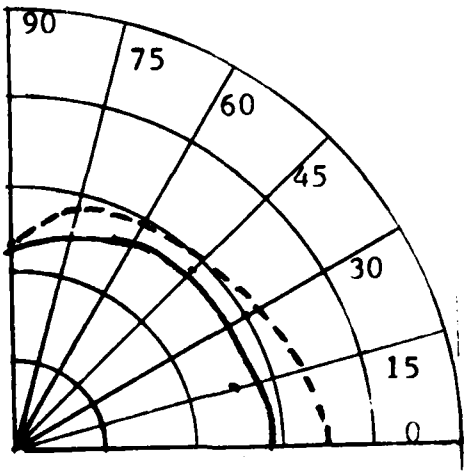


Figure A20 Vertical Grasping Reach, Left Arm. Horizontal Position of L75.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	35.15	38.79	42.43	29.04	36.19	43.33	13
15	34.37	38.44	42.51	26.65	35.29	43.93	13
30	33.19	37.21	41.23	31.32	34.48	39.65	13
45	31.79	35.61	39.43	29.37	33.68	37.97	12
60	29.90	33.51	37.12	28.12	31.88	35.64	12
75	28.20	31.51	34.82	26.01	29.62	33.23	12
90	24.24	28.91	35.58	22.51	27.22	31.93	12

Table A20 Values of Vertical Grasping Reach, Left Arm. Horizontal Position L75.

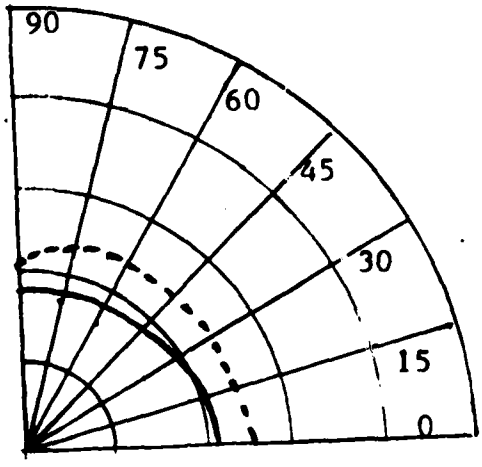


Figure A21 Vertical Grasping Reach, Right Arm. Horizontal Position of L60.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	25.83	28.90	31.97	21.44	27.15	32.77	13
15	24.96	28.45	32.55	21.12	27.02	32.91	13
30	24.23	28.53	32.83	19.62	26.92	34.21	13
45	23.99	28.60	33.21	18.87	24.11	31.49	14
60	24.39	24.42	20.85	16.50	25.66	34.80	15
75	24.42	28.69	32.96	16.97	25.74	34.51	15
90	20.85	27.81	34.77	17.94	25.92	33.92	15

Table A21 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L60.

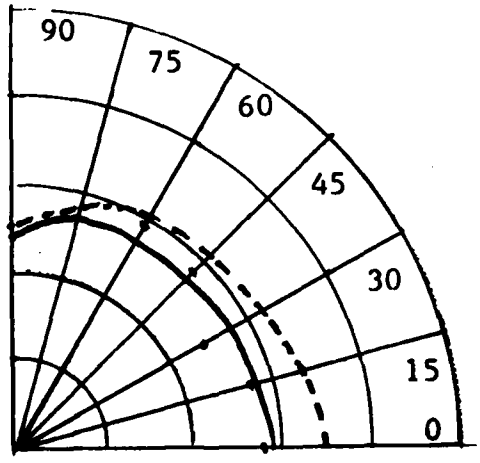


Figure A22 Vertical Grasping Reach, Left Arm. Horizontal Position of L60.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	35.06	38.15	41.24	28.78	35.85	42.92	14
15	34.25	28.02	41.69	27.14	34.82	42.49	14
30	33.15	37.17	41.19	25.03	33.18	41.34	14
45	31.78	35.72	39.67	28.32	33.47	38.62	13
60	30.32	34.20	38.08	29.43	32.85	36.41	12
75	28.45	32.32	36.19	27.40	31.00	34.59	12
90	25.94	30.30	34.66	25.99	29.44	32.90	10

Table A22 Values of Vertical Grasping Reach, Left Arm. Horizontal Position L60.

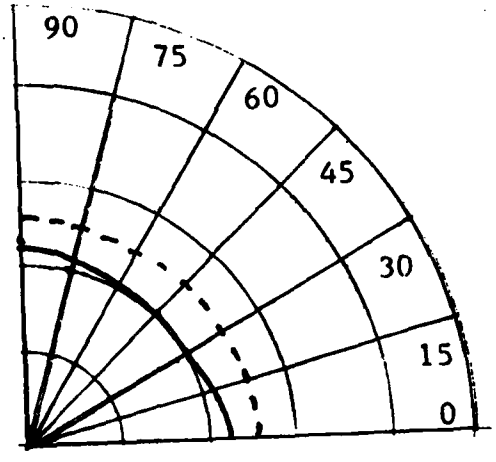


Figure A23 Vertical Grasping Reach, Right Arm. Horizontal Position of L45

	Able N=10			Disabled			
Vertical Posi-tion	Percentile			Percentile			
	5	50	95	5	50	95	N
0	25.80	30.15	34.50	23.64	28.65	23.64	13
15	25.91	30.25	34.60	22.97	28.68	34.38	13
30	25.82	30.02	34.22	21.13	27.71	34.79	14
45	26.15	30.05	33.95	21.51	27.78	34.05	14
60	26.15	30.02	33.89	21.57	27.78	34.00	14
75	26.62	30.13	33.65	20.76	27.52	34.28	14
90	26.95	30.25	33.56	23.20	28.39	33.59	14

Table A23 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L45.

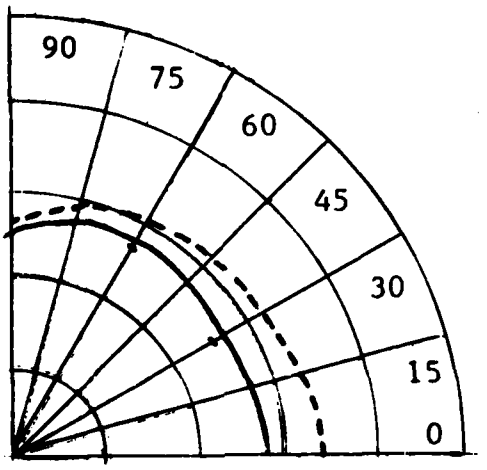


Figure A24 Vertical Grasping Reach, Left Arm. Horizontal Position of L45.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	34.56	38.02	41.48	29.07	35.51	41.94	14
15	34.26	37.95	41.64	28.05	34.79	41.53	14
30	33.35	36.77	40.19	26.33	33.72	41.13	14
45	31.98	35.90	39.82	28.82	33.80	38.79	13
60	30.76	34.50	38.24	27.07	32.38	37.70	13
75	29.30	32.95	36.60	28.62	31.89	35.16	12
90	27.34	31.32	35.30	25.94	30.30	34.66	12

Table A24 Values of Vertical Grasping Reach, Left Arm. Horizontal Position L45.

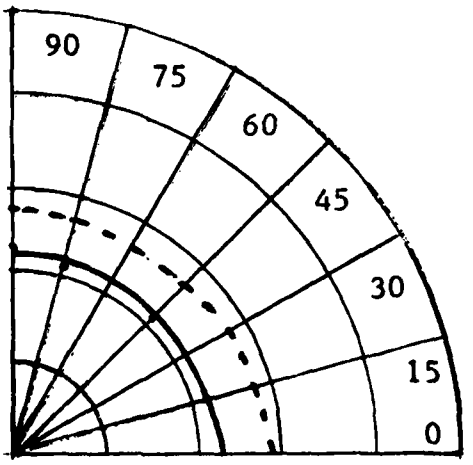


Figure A25 Vertical Grasping Reach, Right Arm. Horizontal Position of L30.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	29.10	32.00	34.90	23.70	29.47	35.24	14
15	28.89	31.85	34.81	22.56	29.54	36.53	14
30	28.89	31.85	34.81	22.39	29.46	36.55	14
45	27.92	31.37	34.82	22.36	29.26	36.17	14
60	25.76	30.25	34.74	22.50	29.38	36.26	14
75	28.08	31.27	34.46	22.04	29.25	36.45	14
90	28.43	31.37	34.25	24.64	30	35.36	14

Table A25 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L30.

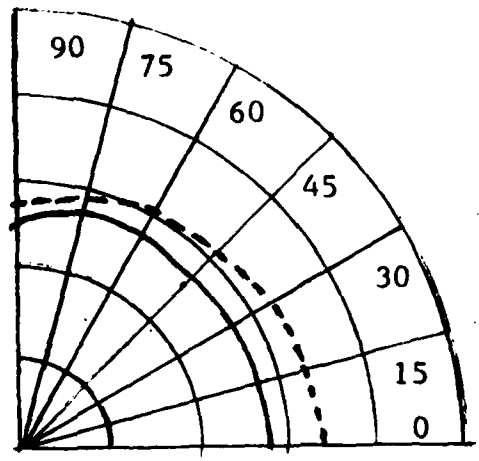


Figure A26 Vertical Grasping Reach, Left Arm. Horizontal Position of L30

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	34.16	37.07	39.88	28.89	34.84	40.79	14
15	33.83	36.92	40.01	28.03	34.48	40.93	14
30	32.58	36.20	39.82	26.60	33.35	40.11	14
45	31.31	35.25	39.19	25.01	32.59	40.16	14
60	30.56	34.42	38.28	27.97	32.88	37.80	13
75	29.32	33.20	37.08	29.19	32.44	35.69	12
90	27.59	32.10	36.61	26.45	31.22	36	12

Table A26 Values of Vertical Grasping Reach, Left Arm. Horizontal Positoin L30.

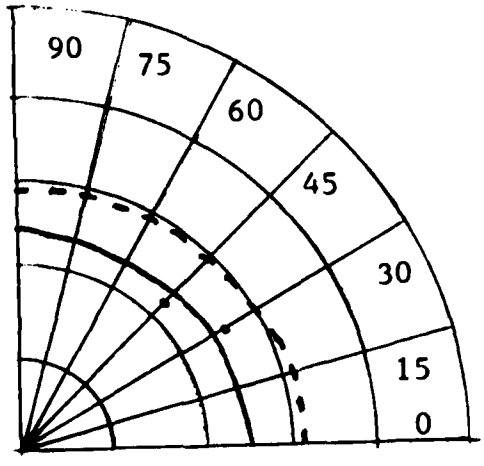


Figure A27 Vertical Grasping Reach, Right Arm. Horizontal Position of L15.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	31.23	33.69	36.15	27.71	31.48	37.25	14
15	31.03	33.54	36.05	24.40	31.17	37.94	14
30	30.01	32.89	35.77	26.76	31.79	36.81	14
45	29.83	32.81	35.79	23.46	30.78	38.12	14
60	29.22	32.39	35.56	24.24	30.96	37.70	14
75	29.10	32.19	35.28	23.99	30.65	37.31	14
90	28.93	31.99	35.05	25.58	30.95	36.32	14

Table A27 Values of Vertical Grasping Reach, Right Arm. Horizontal Position L15.

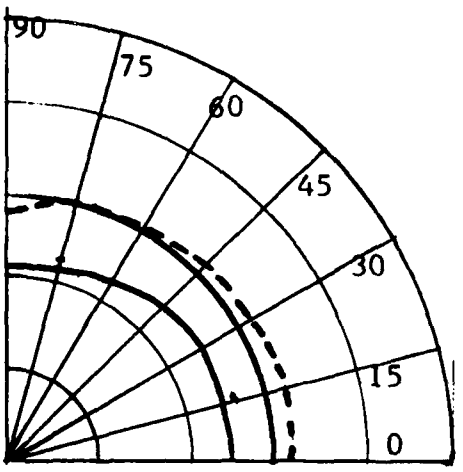
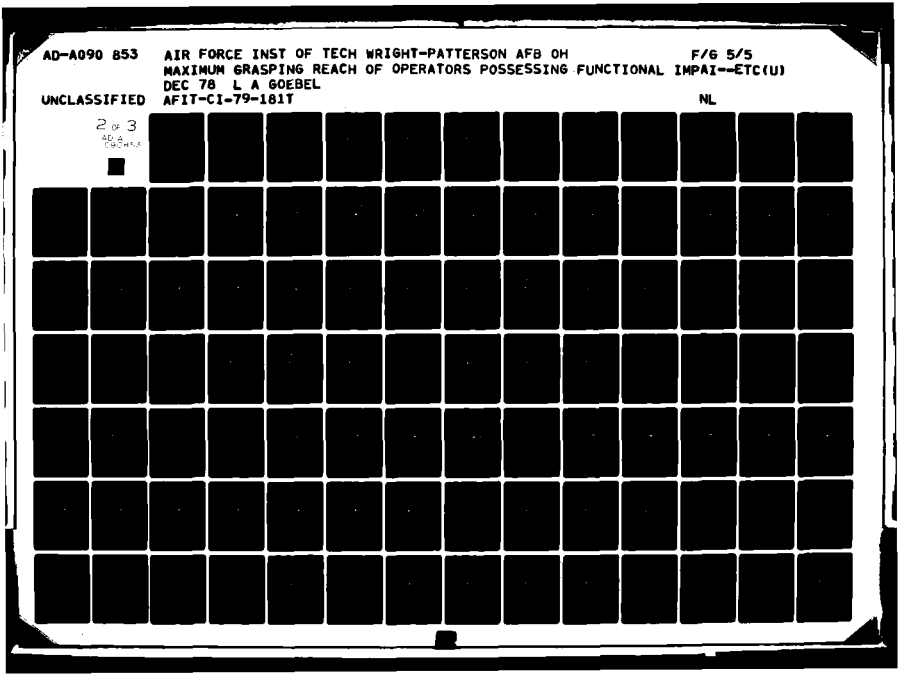


Figure A28 Vertical Grasping Reach, Left Arm. Horizontal Position of L15.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	32.39	35.69	38.79	24.71	32.80	40.89	14
15	32.38	35.59	38.80	26.63	32.85	39.07	14
30	32.43	35.59	38.75	25.39	32.30	39.02	14
45	32.34	35.19	38.04	24.54	31.51	38.47	14
60	31.29	34.56	37.83	23.86	31.20	38.54	14
75	30.14	33.99	37.84	23.50	30.17	38.06	14
90	28.80	32.86	36.92	21.27	30.46	39164	13

Table A28 Values of Vertical Grasping Reach, Left Arm. Horizontal Position L15.

AD-A090 853 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 5/5
MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAI--ETC(U)
DEC 78 L A GOEBEL
UNCLASSIFIED AFIT-CI-79-181T NL



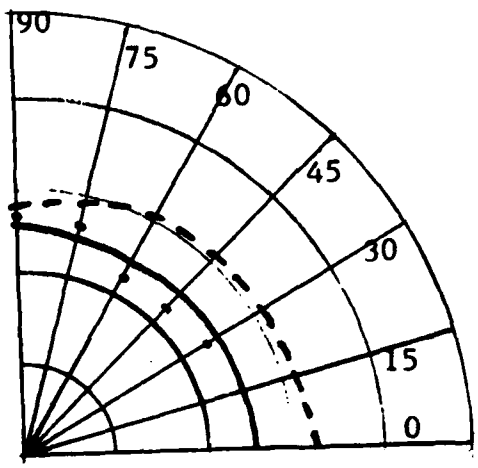


Figure A29 Vertical Grasping Reach, Right Arm. Horizontal Position of 0.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	32.48	34.74	37.01	26.35	32.80	39.27	15
15	31.90	34.78	37.76	26.16	32.14	38.12	15
30	31.53	34.19	36.85	24.83	31.73	38.63	15
45	30.99	33.87	36.75	24.64	31.32	38.01	15
60	30.21	33.03	35.85	24.60	31.27	37.93	15
75	29.84	32.66	35.48	27.04	31.77	36.50	14
90	29.28	32.31	35.34	27.03	32.52	38.02	14

Table A29 Values of Vertical Grasping Reach, Right Arm. Horizontal Position 0.

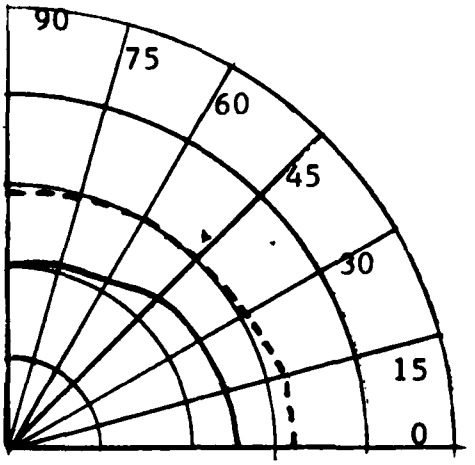


Figure A30 Vertical Grasping Reach, Left Arm. Horizontal Position of 0.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	32.30	34.88	37.56	25.66	31.90	38.15	14
15	23.63	34.86	37.09	25.37	31.58	37.80	14
30	31.58	34.34	37.10	24.28	31.12	37.94	14
45	31.04	33.89	36.74	23.54	31.05	38.57	14
60	30.53	33.51	36.49	22.92	30.67	38.42	14
75	29.91	33.16	36.41	22.24	30.39	38.54	14
90	29.29	32.89	36.48	20.89	30.04	39.19	14

Table A30 Values of Vertical Grasping Reach, Left Arm. Horizontal Position 0.

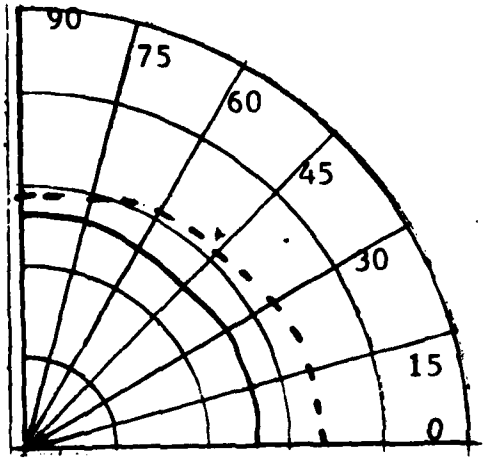


Figure A31 Vertical Grasping Reach, Right Arm. Horizontal Position of R15.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	33.25	35.76	38.27	27.51	33.77	40.04	14
15	33.19	35.66	38.13	26.79	33.32	39.87	14
30	32.19	35.09	37.99	26.61	32.96	39.31	14
45	31.29	34.24	37.19	26.22	32.69	39.16	14
60	30.79	33.69	36.59	36.78	32.45	38.13	14
75	29.78	32.91	36.04	27.71	32.39	37.06	13
90	29.82	32.63	35.44	27.76	32.40	37.02	12

Table A31 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R15.

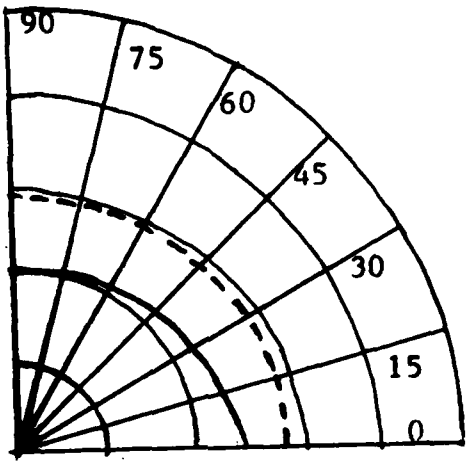


Figure A32 Vertical Grasping Reach, Left Arm. Horizontal Position of R15.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	30.70	34.26	37.82	26.90	31.14	35.60	14
15	30.38	33.94	37.50	24.20	30.14	36.09	14
30	30.10	33.66	37.22	22.87	29.11	35.34	14
45	29.99	33.37	36.75	22.97	29.58	36.20	14
60	29.60	33.21	36.82	22.76	29.72	36.50	14
75	29.31	33.04	36.77	22.11	29.59	37.08	14
90	29.43	32.81	36.19	20.78	29.54	38.30	14

Table A32 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R15.

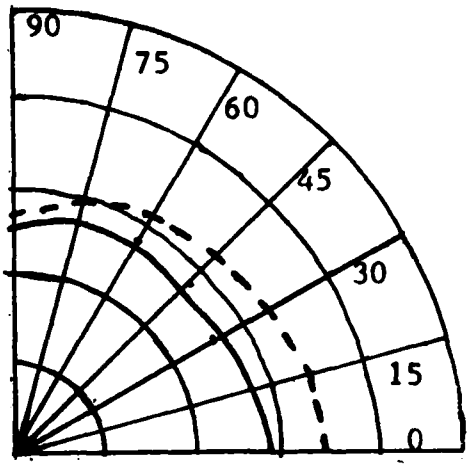


Figure A33 Vertical Grasping Reach, Right Arm. Horizontal Position of R30.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	24.70	36.75	38.80	29.10	34.95	40.82	14
15	34.22	36.62	39.03	27.92	34.06	40.19	14
30	33.41	35.8	38.18	26.90	33.59	40.29	14
45	32.08	32.82	35.56	28.07	33.51	38.93	14
60	31.09	33.9	36.71	27.31	32.64	37.98	14
75	29.99	33.02	36.05	27.75	32.26	36.76	13
90	27.84	32.61	37.38	26.78	31.77	36.75	12

Table A33 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R30.

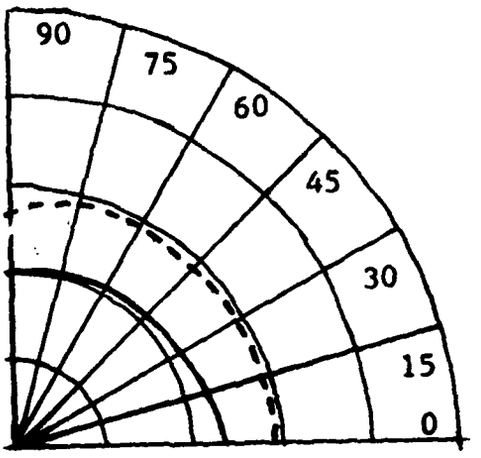


Figure A34 Vertical Grasping Reach, Left Arm. Horizontal Position of R30.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	29.31	32.90	36.49	23.79	29.58	35.37	14
15	29.18	33	36.82	23.10	29.03	34.94	14
30	29.04	32.70	36.36	22.82	28.80	34.79	14
45	28.92	32.45	35.98	21.66	28.65	35.61	14
60	28.98	32.40	35.83	21.72	28.36	35	14
75	28.82	32.35	35.88	20.76	30.30	39.85	14
90	26.94	31.55	36.16	19.79	28.22	36.65	14

Table A34 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R30.

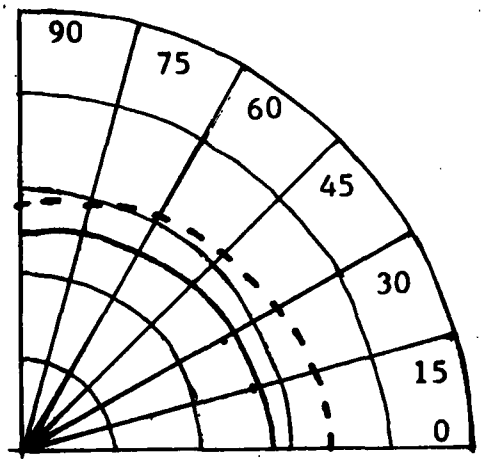


Figure A35 Vertical Grasping Reach, Right Arm. Horizontal Position of R45.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	34.82	37.61	40.41	28.41	34.89	41.39	14
15	34.40	37.41	40.42	27.46	24.17	40.87	14
30	33.43	36.81	40.19	26.41	33.52	40.65	14
45	32.28	35.31	38.34	27.52	33.22	38.92	14
60	31.06	33.96	36.87	26.77	32.33	37.88	14
75	29.37	32.48	35.59	26.23	32.09	30.98	14
90	28.25	31.36	34.47	25.13	30.70	36.26	12

Table A35 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R45.

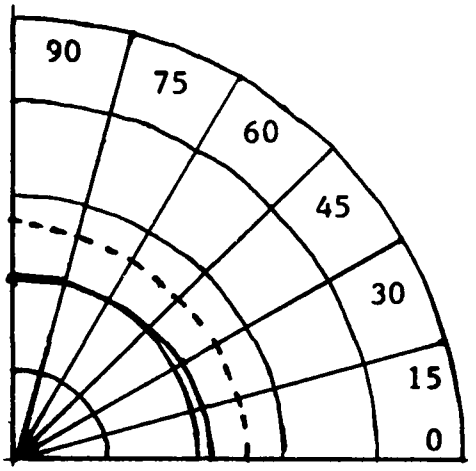


Figure A36 Vertical Grasping Reach, Left Arm. Horizontal Position of R45.

	Able N=10			Disabled			
Vertical Position	Percentile 5	50	95	Percentile 5	50	95	N
0	27.13	31.4	35.67	21.58	27.64	33.25	14
15	26.53	31	35.47	21.74	27.23	32.73	14
30	26.22	30.87	35.52	21.44	27.07	32.71	14
45	26.82	30.87	34.92	20.61	26.96	33.32	14
60	26.80	30.85	34.90	20.49	27.46	34.43	14
75	26.85	30.75	34.65	20.77	27.75	34.75	14
90	27.09	30.87	34.65	19.28	27.57	35.85	14

Table A36 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R45.

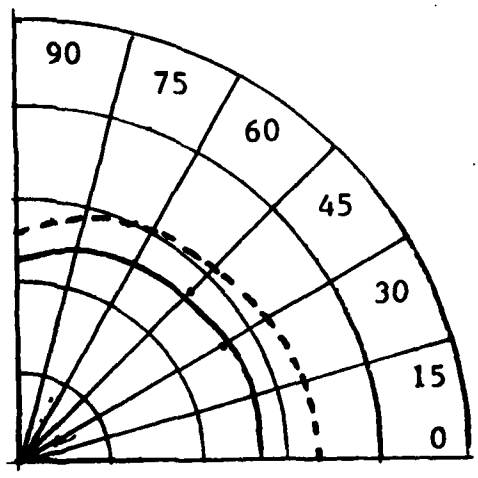


Figure A37 Vertical Grasping Reach, Right Arm. Horizontal Position of R60.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	33.92	37.88	42.04	28.58	34.26	42.05	14
15	34.34	37.73	41.13	27.25	34.71	42.18	14
30	33.35	36.93	40.51	26.71	33.94	41.17	14
45	31.79	35.27	38.75	27.14	33.17	39.20	14
60	30.28	33.65	37.02	26.25	31.87	37.49	14
75	28.04	31.65	35.26	25.55	30.78	36.02	13
90	26.52	30.48	34.44	24.15	29.47	34.78	12

Table A37 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R60.

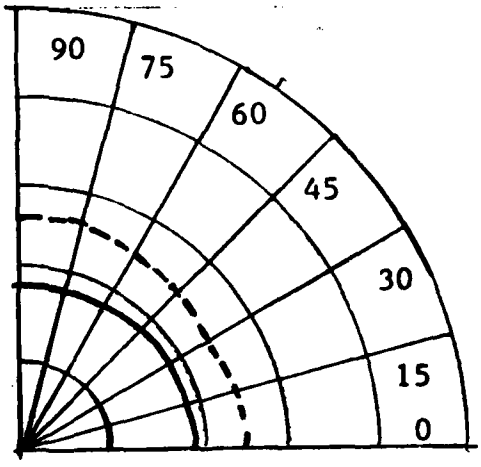


Figure A38 Vertical Grasping Reach, Left Arm. Horizontal Position of R60.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	24.74	29.37	34	19.70	25.45	31.21	14
15	25.04	29.62	34.20	19.22	25.25	31.28	14
30	24.59	29.24	33.89	19.09	24.98	30.87	14
45	25.45	29.50	33.55	18.44	25.27	32.11	14
60	25.33	29.50	33.67	17.95	25.39	32.83	14
75	25.25	29.55	33.85	18.18	25.77	33.35	14
90	25.42	29.72	30.02	17.89	25.98	34.07	14

Table A38 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R60.

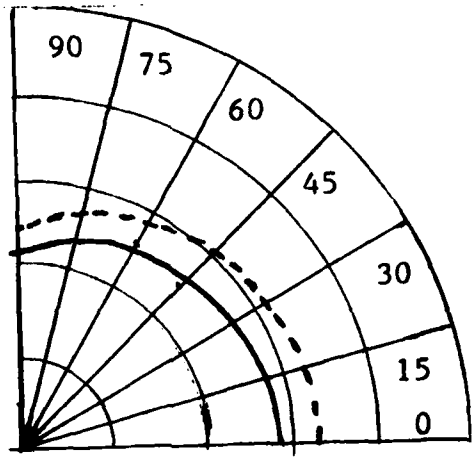


Figure A39 Vertical Grasping Reach, Right Arm. Horizontal Position of R75.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	33.94	38.49	43.04	29.50	36.12	42.73	14
15	33.95	38.11	42.27	28.61	35.32	42.04	14
30	33.11	37.21	41.31	27.45	34.03	40.61	14
45	31.84	35.01	38.18	25.42	32.38	39.34	14
60	29.98	32.97	35.96	26.47	31.45	36.44	14
75	27.49	30.81	34.13	25.32	29.66	34	13
90	25	28.94	32.88	22.51	27.22	31.93	12

Table A39 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R75.

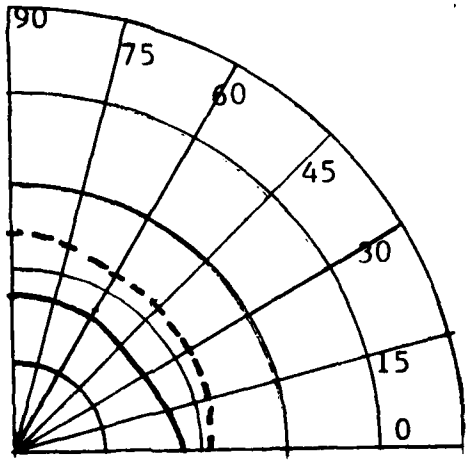


Figure A40 Vertical Grasping Reach, Left Arm. Horizontal Position of R75.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	21.35	27.48	33.61	18.24	23.25	28.26	14
15	21.96	27.60	33.24	17.24	23.21	28.94	14
30	22.07	27.39	32.71	16.75	22.99	27.63	14
45	22.60	27.54	32.48	16.48	23.24	30.01	14
60	23.03	28.31	33.60	18.78	24	29.22	14
75	24.85	28.41	31.97	16.58	23.93	31.29	14
90	25.04	28.51	31.98	16.47	24.20	31.93	14

Table A40 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R75.

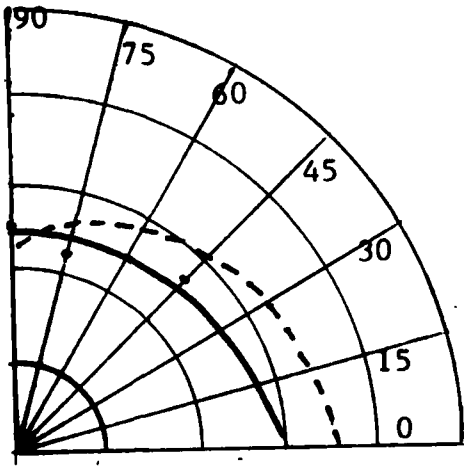


Figure A41 Vertical Grasping Reach, Right Arm. Horizontal Position of R90.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	35.06	38.75	42.09	30.41	37.03	43.64	14
15	34.62	38.32	42.02	27.84	35.55	43.45	14
30	33.42	36.92	40.42	26.60	34.19	41.78	14
45	31.62	34.87	38.13	27.18	32.90	38.62	13
60	29.19	32.59	36	25.92	30.72	35.52	13
75	26.20	29.52	32.84	23.94	28.32	32.72	13
90	23.46	27.57	31.68	25.99	29.44	32.90	12

Table A41 Values of Vertical Grasping Reach, Right Arm. Horizontal Position R90.

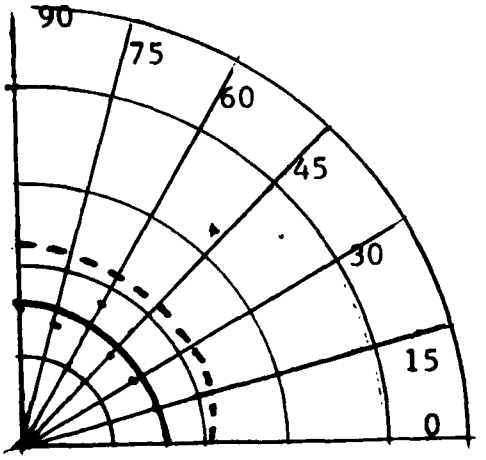


Figure A42 Vertical Grasping Reach, Left Arm. Horizontal Position of R90.

	Able N=10			Disabled			
Vertical Position	Percentile			Percentile			
	5	50	95	5	50	95	N
0	20.67	25.16	29.65	15.42	22.61	29.78	14
15	21.49	25.86	30.23	15.38	20.98	26.77	14
30	21.25	26.16	31.07	14.33	20.91	27.48	14
45	21.16	36.39	31.62	14.56	21.35	28.15	14
60	21.74	26.55	31.36	18.13	23.39	28.65	14
75	22.35	26.71	31.07	14.15	21.99	29.82	14
90	23.26	26.79	30.32	15.03	22.50	29.97	14

Table A42 Values of Vertical Grasping Reach, Left Arm. Horizontal Position R90.

APPENDIX B

HORIZONTAL AND VERTICAL GRASPING REACH (ABLE GROUP AND DISABLED SUBGROUPS: NONE AND SLIGHT)

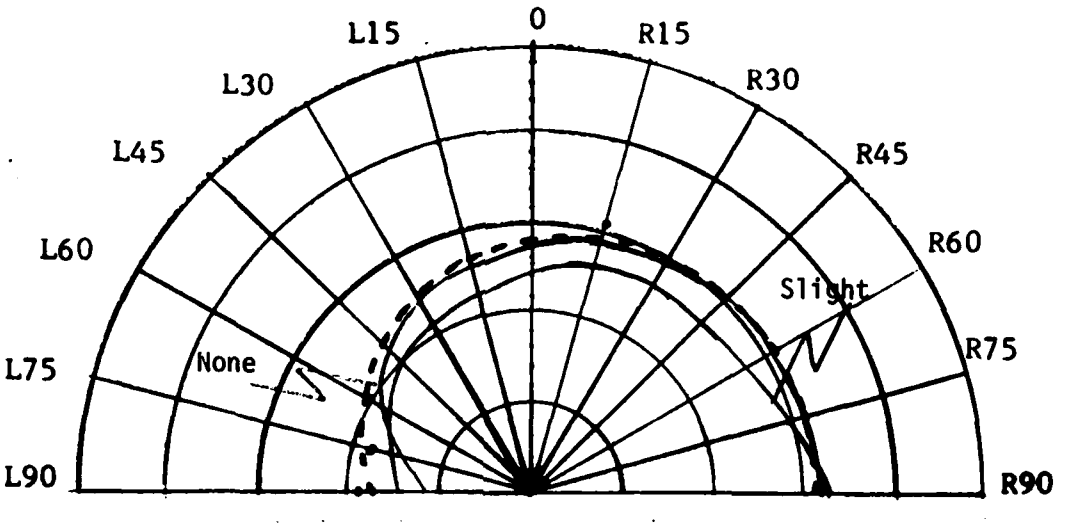


Figure B1 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position T.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	17.27	12.72	18.41
L75	19.66	18.37	14.77
L60	22.50	21.04	18.21
L45	23.45	22.52	20.38
L30	25.25	25.03	21.79
L15	27.35	26.31	23.26
0	28.07	27.68	25.50
R15	29.26	30.86	25.59
R30	30.22	29.68	27.46
R45	30.90	30.82	27.29
R60	31.45	25.44	26.79
R75	31.25	31.32	29.43
R90	31.32	31.62	32.44

Table B1 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position T.

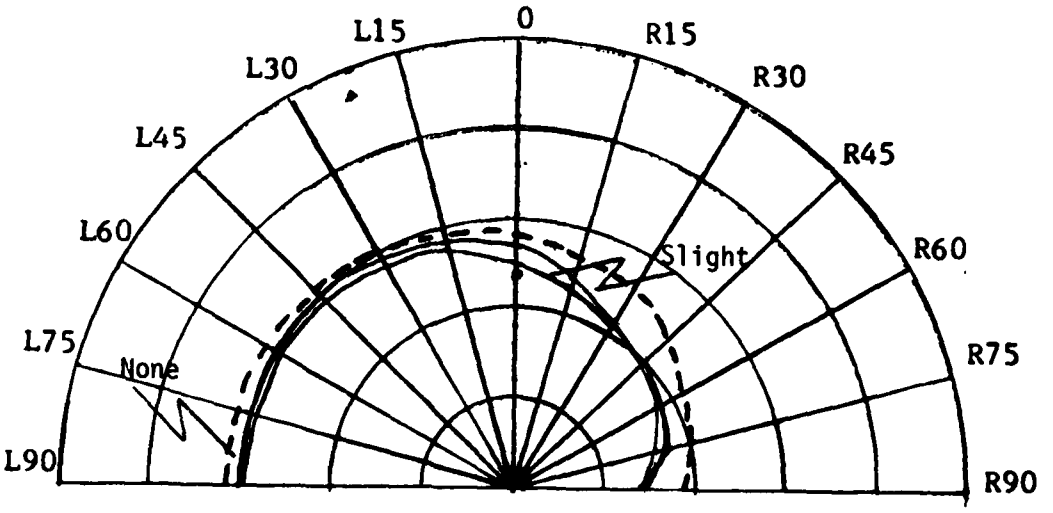


Figure B2 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position T.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	31.36	30.02	30.01
L75	31.84	30.18	29.93
L60	31.60	30.55	29.54
L45	31.19	30.43	29.54
L30	30.32	29.59	28.71
L15	29.42	28.16	27.26
0	28.54	27.13	25.25
R15	27.16	24.71	24.59
R30	26.72	23.45	23.29
R45	24.30	21.67	21.37
R60	22.67	19.83	18.62
R75	20.61	18.23	17.09
R90	18.51	15.72	15.02

Table B2 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position T.

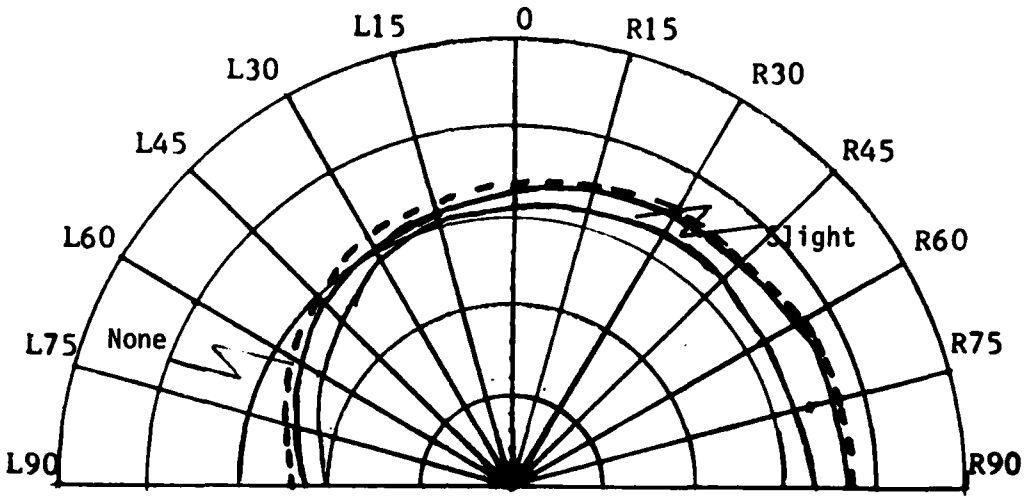


Figure B3 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 0.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	24.92	23.22	21.19
L75	26.91	25.82	22.77
L60	28.90	27.79	25.79
L45	30.15	29.42	27.79
L30	32.0	31.48	29.21
L15	33.69	33.01	30.84
0	34.74	34.43	33.25
R15	35.76	35.61	33.09
R30	36.75	36.58	34.88
R45	37.61	37.42	34.13
R60	37.98	37.39	33.79
R75	38.49	38.17	36.27
R90	38.57	39.12	37.11

Table B3 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 0.

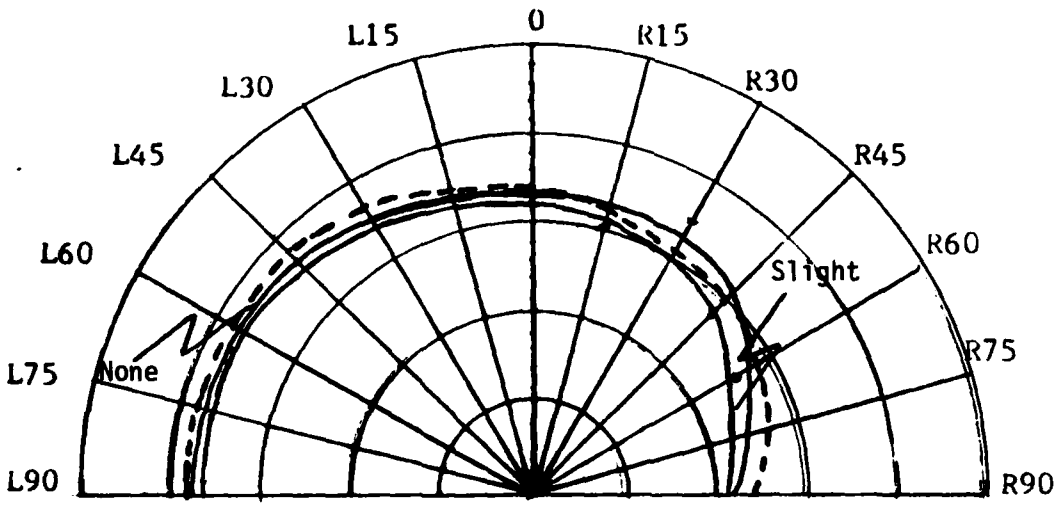


Figure B4 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 0.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	38.36	38.12	37.35
L75	38.79	37.73	37.26
L60	38.15	37.65	37.12
L45	38.02	37.07	37.13
L30	37.07	36.27	35.79
L15	35.69	34.86	34.48
0	34.88	33.78	33.07
R15	34.26	31.76	31.84
R30	32.90	36.21	30.37
R45	31.40	28.72	28.62
R60	29.37	27.45	25.79
R75	27.48	25.33	24.34
R90	25.16	22.92	22.52

Table B4 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 0.

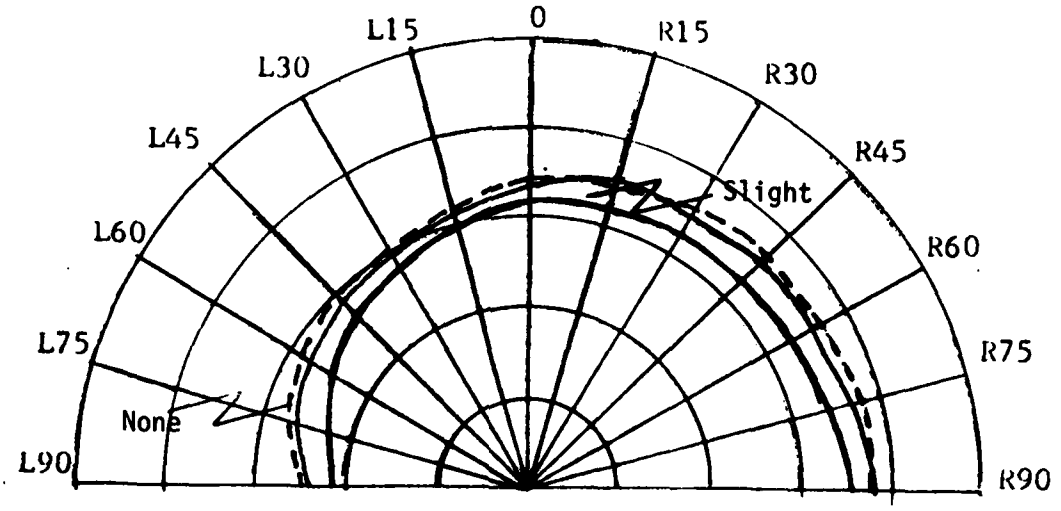


Figure B5 Comparison of the Able, None and Slight Group Averages. *Horizontal Grasping Reach, Right Arm, Vertical Position 15.*

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	24.49	24.31	21.02
L75	26.91	26.17	23.10
L60	28.75	28.49	25.88
L45	30.25	29.47	27.88
L30	31.85	31.58	29.13
L15	33.54	33.31	30.59
0	34.78	34.0	33.05
R15	35.66	36.31	33.18
R30	36.62	36.28	34.04
R45	37.41	37.07	33.79
R60	37.73	37.19	33.04
R75	38.11	37.72	35.68
R90	38.32	38.47	35.94

Table B5 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 15.

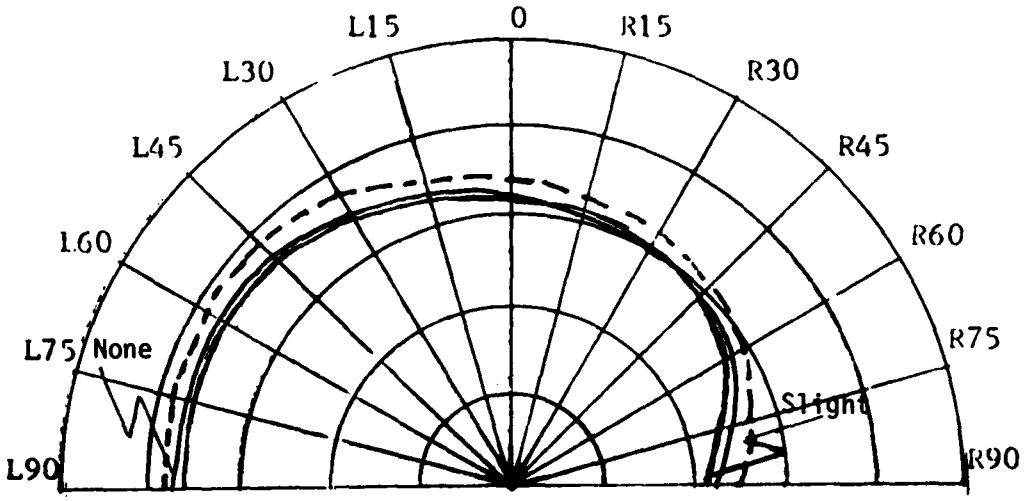


Figure B6 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 15.

Horizontal Angle	Average		
	Able N = 10	None N = 3	Slight N = 5
L90	38.41	38.02	36.02
L75	38.44	37.63	36.51
L60	38.02	37.10	36.37
L45	37.95	36.82	36.71
L30	36.92	36.34	35.46
L15	35.59	34.71	34.67
0	34.86	33.73	33.42
R15	33.94	31.96	32.17
R30	33.00	30.95	30.29
R45	31.00	29.03	29.12
R60	29.62	27.25	26.20
R75	27.60	25.48	24.59
R90	25.86	23.42	22.35

Table B6 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 15.

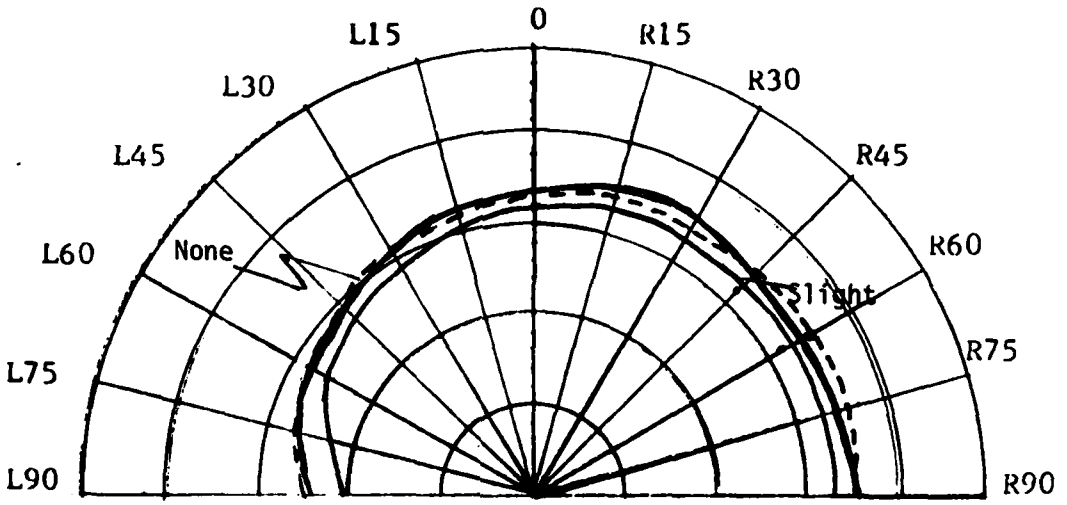


Figure B7 Comparison of the Able, None and Slight Group Averages. *Horizontal Grasping Reach, Right Arm, Vertical Position 30.*

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	24.67	25.47	21.77
L75	27.09	26.92	23.52
L60	28.53	28.94	25.96
L45	30.02	29.82	27.46
L30	31.85	31.83	28.96
L15	32.89	33.76	30.68
0	34.19	34.33	32.75
R15	35.09	35.41	33.18
R30	35.8	36.08	33.71
R45	36.81	36.47	33.21
R60	36.93	36.64	32.13
R75	37.21	36.52	34.68
R90	36.92	37.25	34.27

Table B7 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 30.

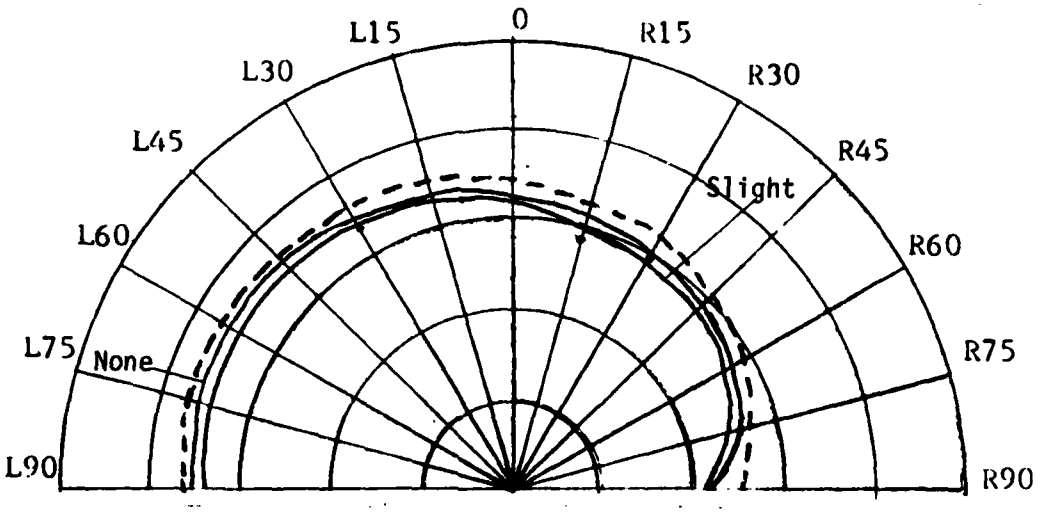


Figure B8 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 30.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	36.89	36.52	34.77
L75	37.21	36.53	35.18
L60	37.17	36.40	35.29
L45	36.77	36.22	35.79
L30	36.20	35.59	34.79
L15	35.59	34.31	34.09
0	34.34	33.93	32.92
R15	33.66	28.61	31.59
R30	32.70	31.00	30.37
R45	30.87	29.55	28.87
R60	29.24	27.40	26.29
R75	27.39	25.43	24.84
R90	26.16	23.82	22.94

Table B8 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 30.

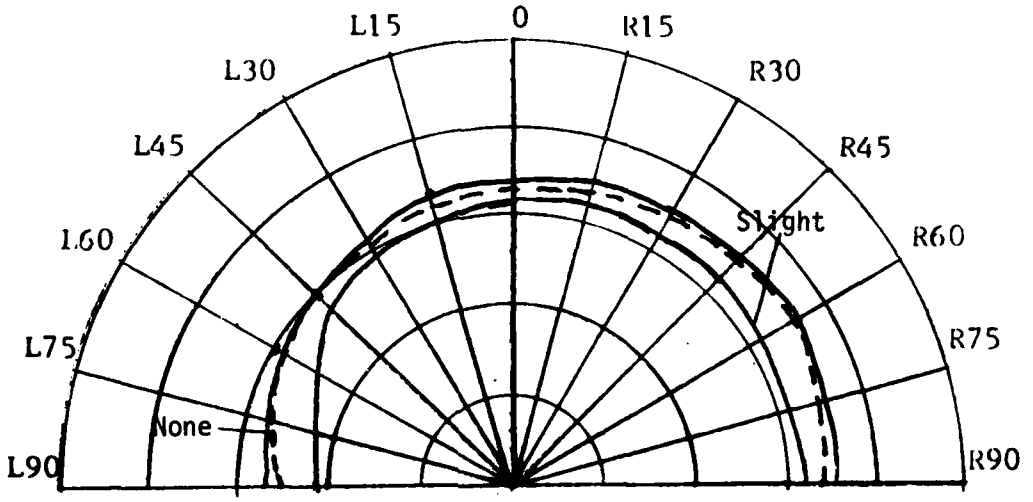


Figure B9 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 45.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	25.34	27.02	22.11
L75	27.26	27.62	23.68
L60	28.60	29.34	25.71
L45	30.05	29.87	28.29
L30	31.37	31.88	29.13
L15	32.81	33.91	30.51
0	33.87	34.23	32.25
R15	34.24	35.46	32.68
R30	34.82	35.68	32.21
R45	35.31	35.82	32.54
R60	35.27	35.69	31.71
R75	35.01	35.17	32.68
R90	34.87	35.42	32.02

Table B9 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 45.

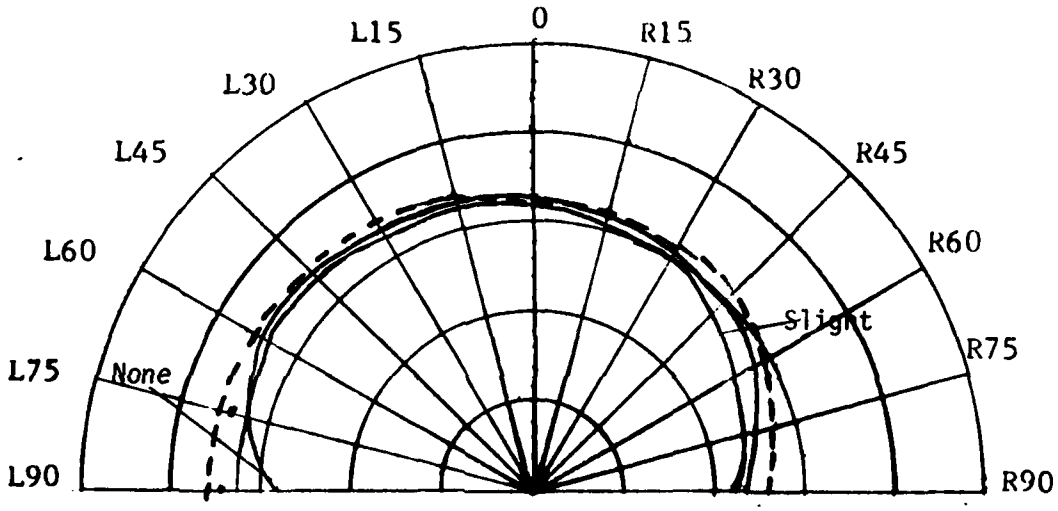


Figure B10 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 45.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	34.99	27.96	33.35
L75	35.61	34.83	34.01
L60	35.72	35.00	34.04
L45	35.50	35.37	34.87
L30	35.25	35.39	33.96
L15	35.19	33.96	33.34
0	33.89	33.93	33.09
R15	33.37	32.26	31.67
R30	32.45	31.40	30.29
R45	30.87	29.87	27.87
R60	29.50	28.60	25.79
R75	27.54	25.93	24.93
R90	26.39	24.37	23.27

Table B10 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 45.

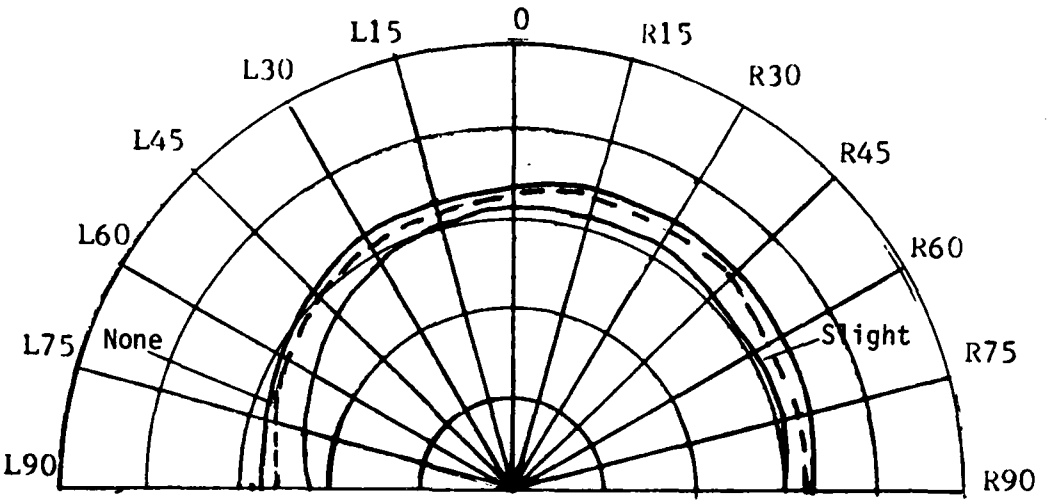


Figure B11 Comparison of the Able, None and Slight Group Averages Horizontal Grasping Reach, Right Arm, Vertical Position 60.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	26.82	27.52	22.61
L75	27.61	27.72	24.37
L60	28.68	29.84	25.46
L45	30.02	30.42	27.71
L30	30.25	32.23	29.38
L15	32.39	33.96	30.43
0	33.03	33.98	32.17
R15	33.69	34.36	32.26
R30	33.90	34.93	32.21
R45	33.96	34.87	31.65
R60	33.65	34.49	30.41
R75	32.97	33.64	31.10
R90	32.59	32.87	30.02

Table B11 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 60.

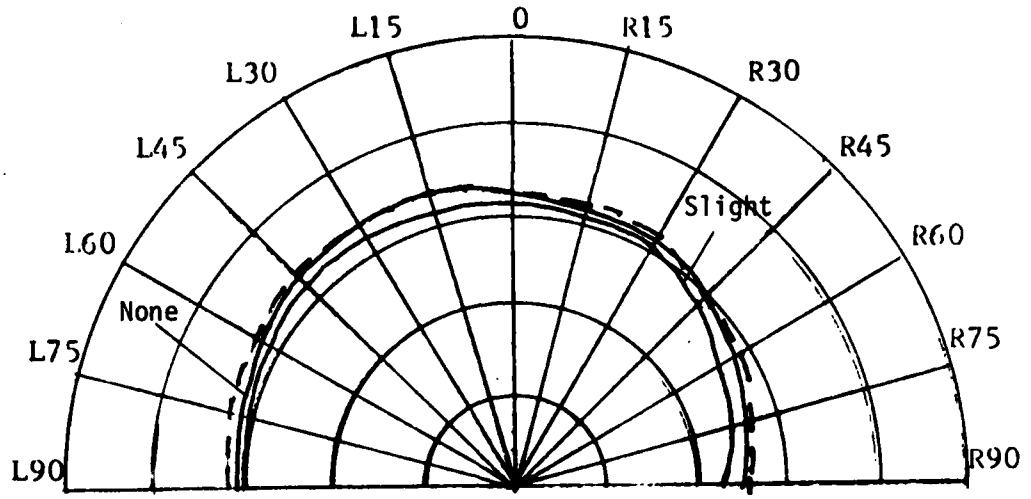


Figure B12 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 60.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	32.71	32.37	31.52
L75	33.51	32.64	32.26
L60	34.20	33.60	32.95
L45	34.50	34.07	33.54
L30	34.42	34.44	33.54
L15	34.56	34.01	33.17
0	33.51	33.73	32.67
L15	33.21	32.56	31.76
R30	32.40	31.35	30.12
R45	30.85	30.62	29.04
R60	29.50	28.65	26.70
R75	28.31	26.53	25.84
R90	26.55	24.92	24.19

Table B12 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 60.

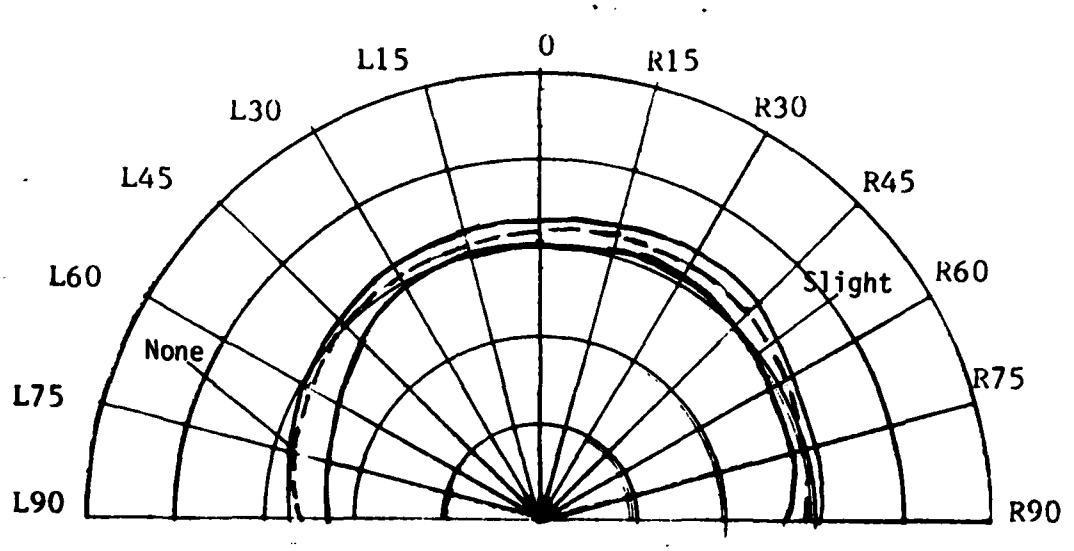


Figure B13 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 75.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	26.04	27.32	23.44
L75	27.51	27.67	24.43
L60	28.69	29.79	25.21
L45	30.13	30.42	27.79
L30	31.27	32.48	29.13
L15	32.19	33.51	30.43
0	32.66	33.58	31.42
R15	32.91	33.26	31.76
R30	33.02	34.08	31.38
R45	32.48	33.82	30.46
R60	31.65	32.94	29.04
R75	30.81	31.27	29.27
R90	29.52	30.32	27.61

Table B13 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 75.

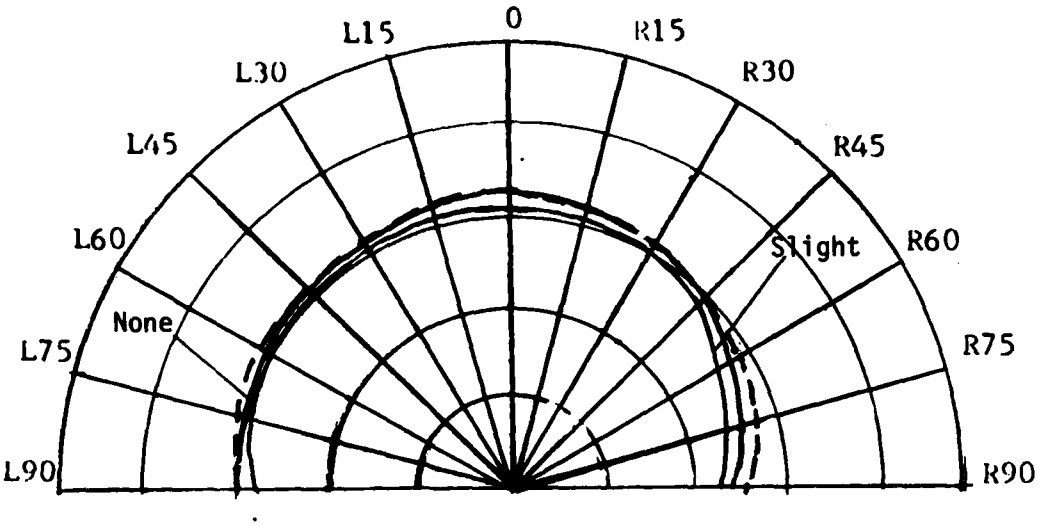


Figure B14 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 75.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	30.04	29.72	29.19
L75	31.51	30.63	30.43
L60	32.32	31.85	31.62
L45	32.95	32.77	32.46
L30	33.20	33.54	32.54
L15	33.99	33.41	32.84
0	33.16	33.73	32.42
R15	33.04	32.46	32.01
R30	32.35	31.95	30.54
R45	30.75	30.62	29.54
R60	29.55	28.90	27.20
R75	28.41	27.03	25.59
R90	26.71	25.27	24.52

Table B14 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 75.

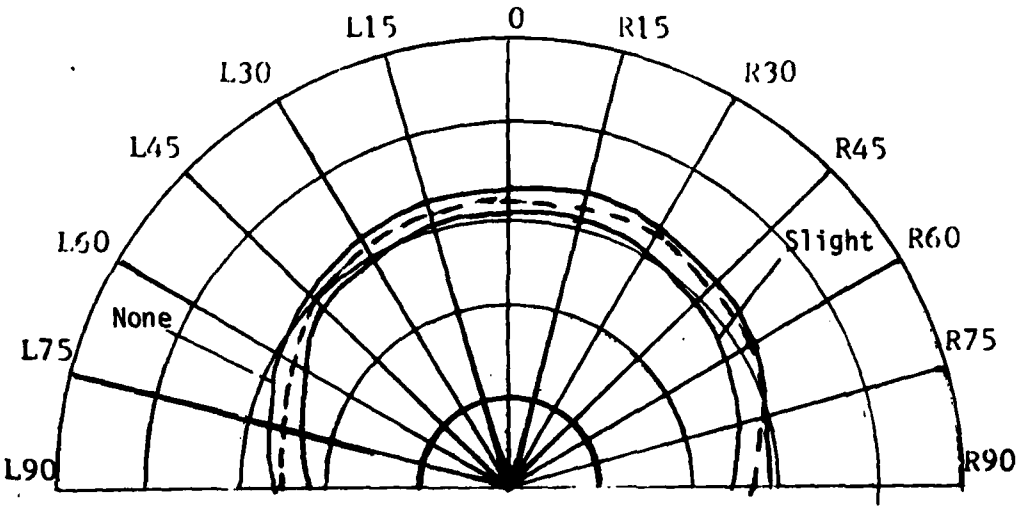


Figure B15 Comparison of the Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 90.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	25.64	26.93	22.86
L75	27.64	27.62	24.43
L60	27.81	29.64	26.38
L45	30.25	30.87	28.29
L30	31.37	32.73	28.96
L15	31.99	33.46	30.09
0	32.31	33.53	30.67
R15	32.63	33.31	31.09
R30	32.61	33.84	30.21
R45	31.36	32.77	29.13
R60	30.48	31.79	27.71
R75	28.94	29.97	27.10
R90	27.57	28.87	25.44

Table B15 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Right Arm, Vertical Position 90.

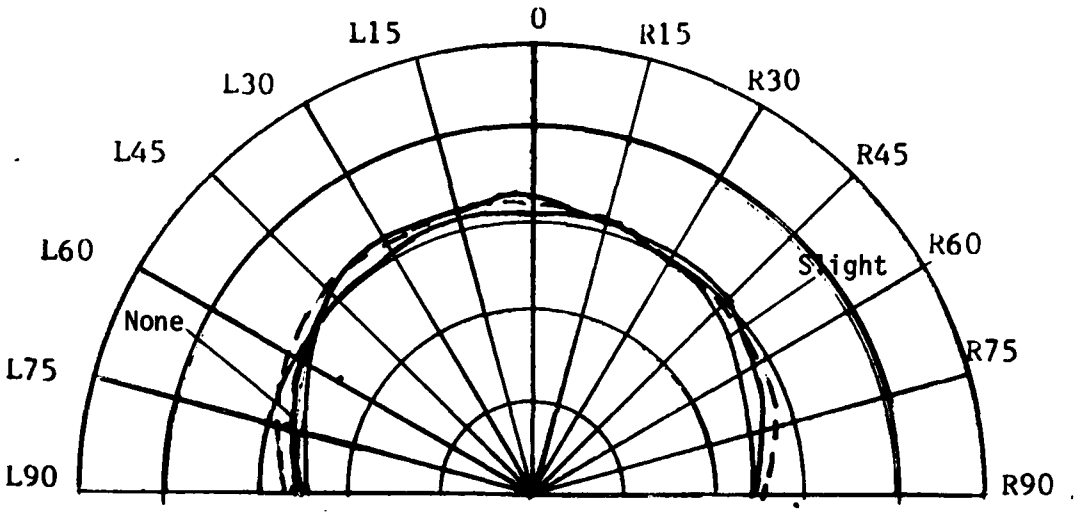


Figure B16 Comparison of the Able, None and Slight Group Averages Horizontal Grasping Reach, Left Arm, Vertical Position 90.

Horizontal Angle	Average		
	Able N = 10	None N = 5	Slight N = 3
L90	27.56	26.27	26.52
L75	28.91	28.43	28.18
L60	30.30	24.59	29.45
L45	31.30	31.57	30.96
L30	32.10	32.79	31.46
L15	32.86	33.21	32.26
0	32.89	33.58	32.09
R15	32.81	31.26	32.17
R30	31.55	31.60	30.87
R45	30.87	30.62	30.04
R60	29.72	29.05	26.01
R75	28.51	27.18	25.93
R90	26.79	25.87	25.26

Table B16 Values of Able, None and Slight Group Averages. Horizontal Grasping Reach, Left Arm, Vertical Position 90.

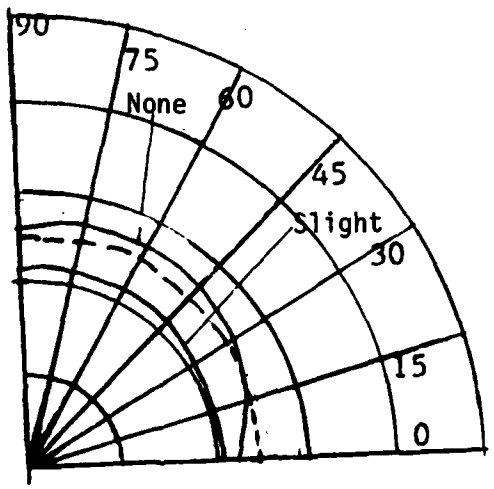


Figure B17 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L90.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	24.92	23.22	21.19
15	24.49	24.31	21.09
30	24.67	25.47	21.77
45	25.34	27.02	22.11
60	26.82	27.52	22.61
75	26.04	27.32	23.44
90	25.64	26.93	22.86

Table B17 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L90.

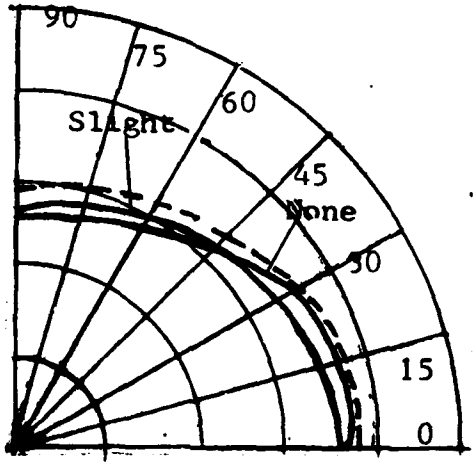


Figure B18 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Left Arm. Horizontal Position L90.*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.36	38.12	37.35
15	38.41	38.02	36.02
30	36.89	36.52	34.77
45	34.99	27.96	33.35
60	32.71	32.37	31.52
75	30.04	29.72	29.19
90	27.56	26.27	26.52

Table B18 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L90.

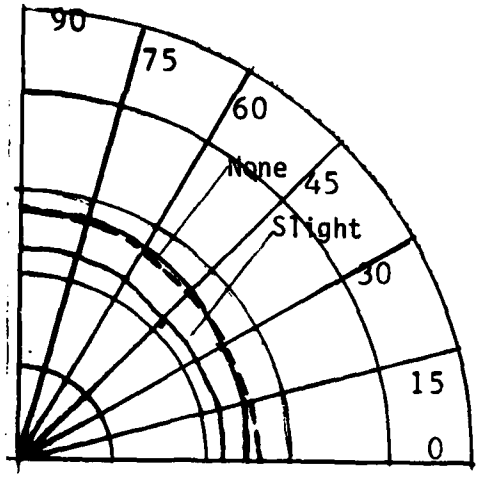


Figure B19 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L75.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	26.91	25.82	22.77
14	26.91	26.17	23.10
30	27.09	26.92	23.52
45	27.26	27.62	23.68
60	27.61	27.72	24.37
75	27.51	27.67	24.43
90	27.64	27.62	24.43

Table B19 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L75.

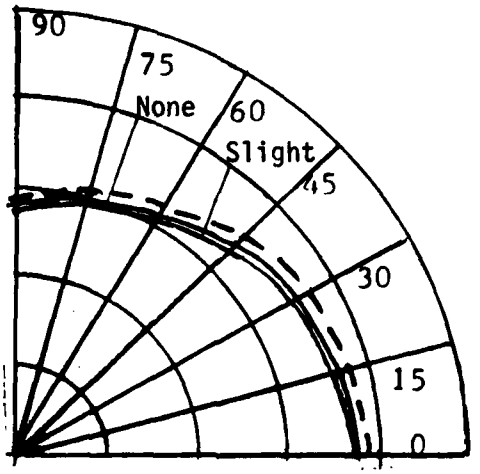


Figure B20 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L75.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.78	37.73	37.26
15	38.44	37.63	36.51
30	37.21	36.53	35.18
45	35.61	34.83	34.01
60	33.51	32.64	32.26
75	31.51	30.63	30.43
90	28.91	28.43	28.18

Table B20 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L75.

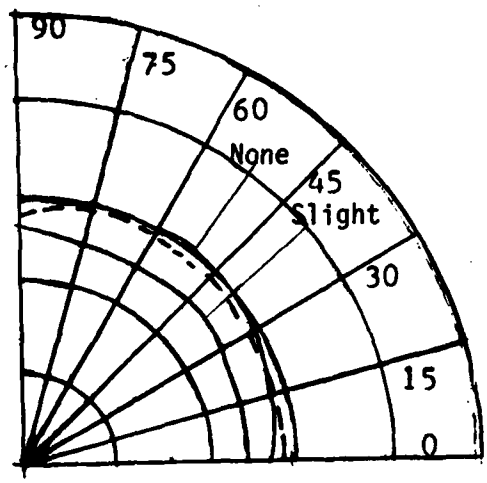


Figure B21 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L60.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	28.90	27.79	25.79
15	28.75	28.49	25.88
30	28.53	28.94	25.96
45	28.60	29.34	25.71
60	28.68	29.84	25.46
75	28.69	29.79	25.21
90	27.81	29.64	26.38

Table B21 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L60.

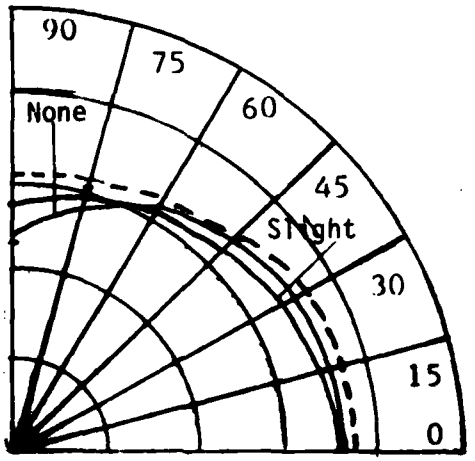


Figure B22 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Left Arm. Horizontal Position L60.*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.15	37.65	37.12
15	38.02	37.10	36.37
30	37.17	36.40	35.29
45	35.72	35.00	34.04
60	34.20	33.60	32.95
75	32.32	31.85	31.62
90	30.30	24.59	29.45

Table B22 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L60.

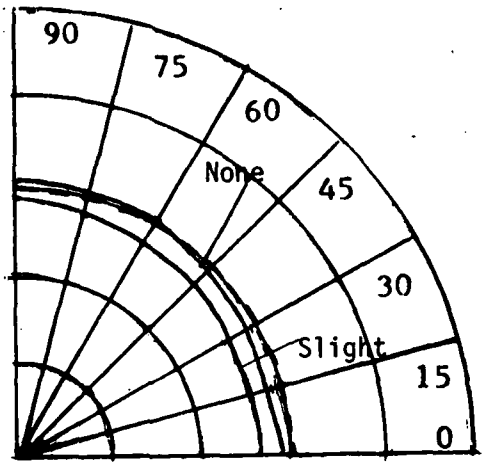


Figure B23 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L45.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	30.15	29.42	27.79
15	30.25	29.47	27.88
30	30.02	29.82	27.46
45	30.05	29.87	28.29
60	30.02	30.42	27.71
75	30.13	30.42	27.79
90	30.25	30.87	28.29

Table B23 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L45.

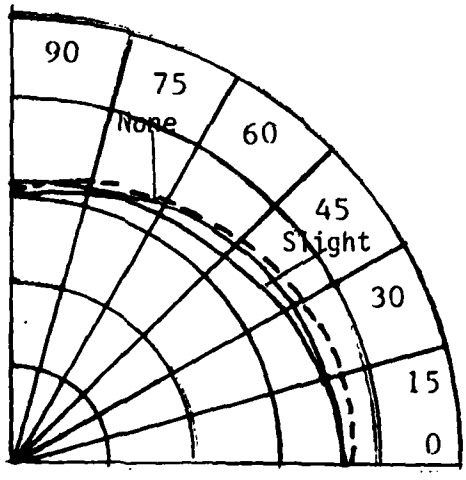


Figure B24 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L45.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.02	37.07	37.13
15	37.95	36.82	36.71
30	36.77	36.22	35.79
45	35.50	35.37	34.87
60	34.50	34.07	33.54
75	32.95	32.77	32.46
90	31.30	31.57	30.96

Table B24 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L45.

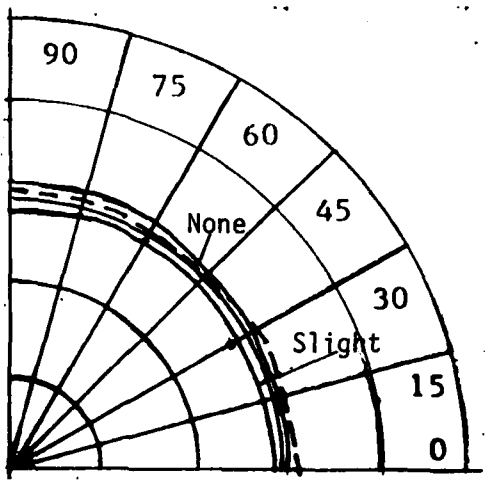


Figure B25 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Right Arm, Horizontal Position L30.*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	32.0	31.48	29.21
15	31.85	31.58	29.13
30	31.85	31.83	28.96
45	31.37	31.88	29.13
60	30.25	32.23	29.38
75	31.27	32.48	29.13
90	31.37	32.73	28.96

Table B25 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L30.

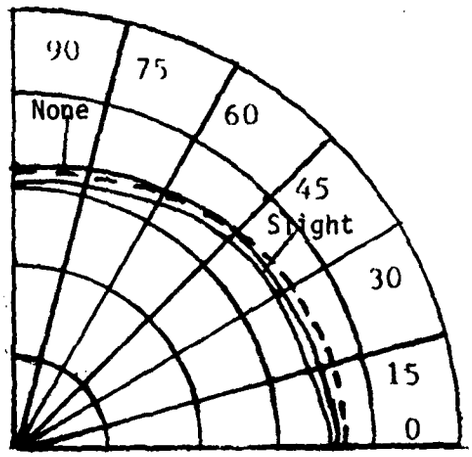


Figure B26 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L30.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	37.07	36.27	35.79
15	36.92	36.34	35.46
30	36.20	35.59	34.79
45	35.25	35.39	33.96
60	34.42	34.44	33.54
75	33.20	33.54	32.54
90	32.10	32.79	31.46

Table B26 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L30.

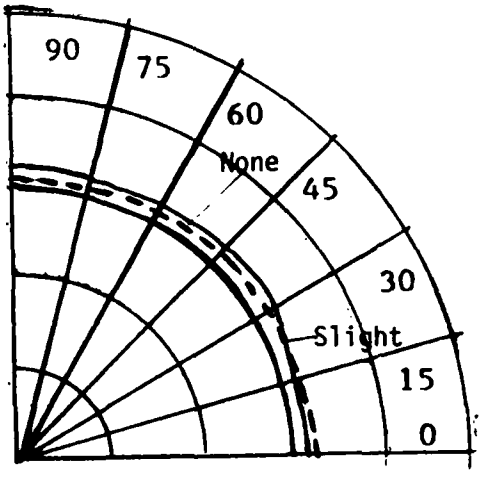


Figure B27 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L15.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	33.69	33.01	30.84
15	33.54	33.31	30.59
30	32.89	33.76	30.68
45	32.81	33.91	30.51
60	32.39	33.96	30.43
75	32.19	33.51	30.43
90	31.99	33.46	30.09

Table B27 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position L15.

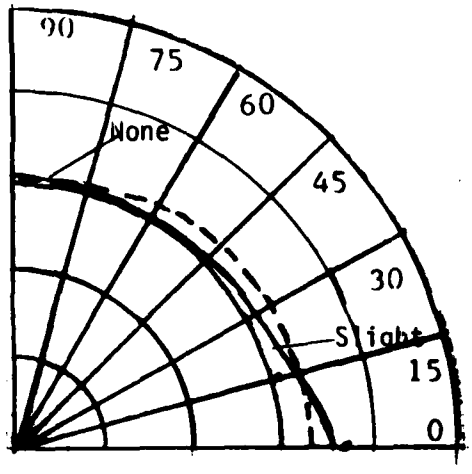


Figure B28 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R30.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	32.90	36.31	30.37
15	33.00	30.95	30.29
30	32.70	31.00	30.37
45	32.45	31.40	30.29
60	32.40	31.35	30.12
75	32.35	31.95	30.54
90	31.55	31.60	30.87

Table B28 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R30.

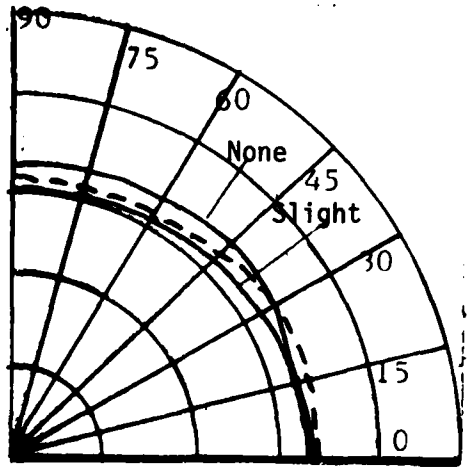


Figure B29 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position 0.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	34.74	34.43	33.25
15	34.78	34.00	33.05
30	34.19	34.33	32.75
45	33.87	34.23	32.25
60	33.03	33.98	32.17
75	32.66	33.58	31.42
90	32.31	33.53	30.67

Table B29 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position 0

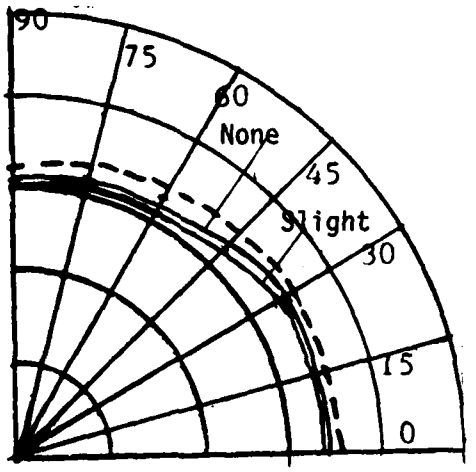


Figure B30 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Left Arm. Horizontal Position L15.*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	35.69	34.86	34.48
15	35.59	34.71	34.67
30	35.59	34.31	34.09
45	35.19	33.96	33.34
60	34.56	34.01	33.17
75	33.99	33.41	32.84
90	32.86	33.21	32.26

Table B30 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L15.

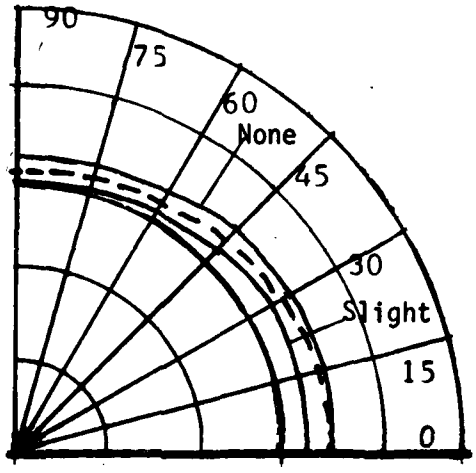


Figure B31 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Right Arm, Horizontal Position R15*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	35.76	35.61	33.09
15	35.66	36.31	33.18
30	35.09	35.41	33.18
45	34.24	35.46	32.68
60	33.69	34.36	32.26
75	32.91	33.26	31.76
90	32.63	33.31	31.09

Table B31 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R15.

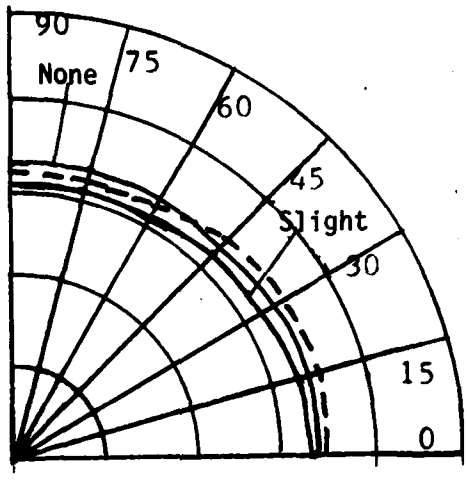


Figure B32 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position 0.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	34.88	33.78	33.07
15	34.86	33.73	33.42
30	34.34	33.93	32.92
45	33.89	33.93	33.09
60	33.51	33.73	32.67
75	33.16	33.73	32.42
90	32.89	33.58	32.09

Table B32 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position 0.

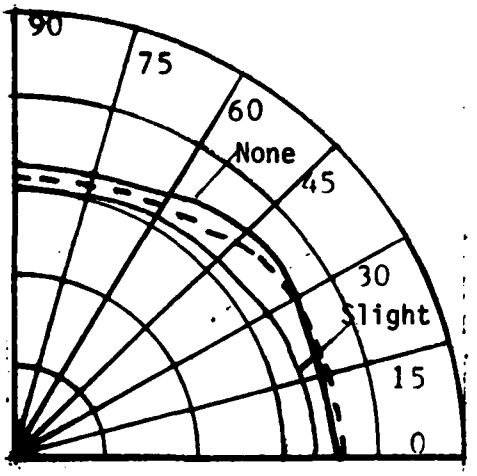


Figure B33 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R30

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	36.75	36.58	34.88
15	36.62	36.28	34.04
30	35.8	36.08	33.71
45	34.82	35.68	32.21
60	33.90	34.93	32.21
75	33.02	34.08	31.38
90	32.61	33.84	30.21

Table B33 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R30.

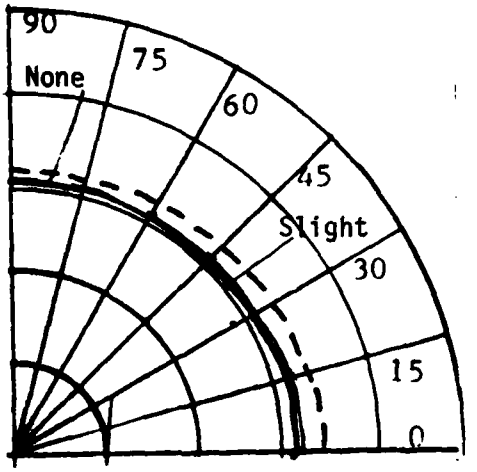


Figure B34 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R15.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	34.26	31.76	31.84
15	33.94	31.96	32.17
30	33.66	28.61	31.59
45	33.37	32.26	31.67
60	33.21	32.56	31.76
75	33.04	32.46	32.01
90	32.81	31.26	32.17

Table B34 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R15.

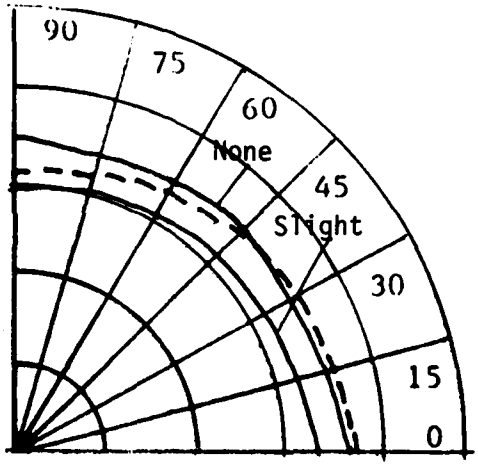


Figure B35 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R45.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	37.61	37.42	34.13
15	37.41	37.07	33.79
30	36.81	36.47	33.21
45	35.31	35.82	32.54
60	33.96	34.87	31.65
75	32.48	33.82	30.46
90	31.36	32.77	29.13

Table B35 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R45.

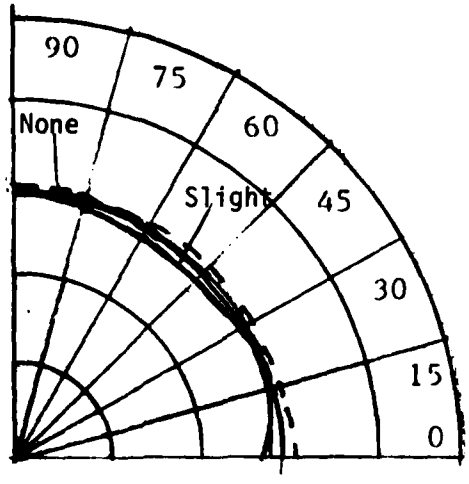


Figure B36 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R45.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	31.40	28.72	28.62
15	31.00	29.03	29.12
30	30.87	29.55	28.87
45	30.87	29.87	27.87
60	30.85	30.62	29.04
75	30.75	30.62	29.54
90	30.87	30.62	30.04

Table B36 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R45.

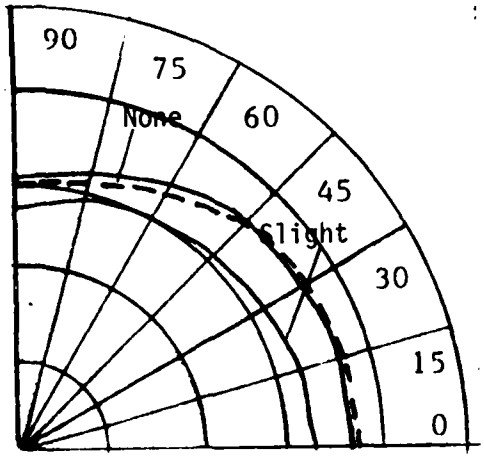


Figure B37 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R60.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	37.98	37.39	33.79
15	37.73	37.19	33.04
30	36.93	36.64	32.13
45	35.27	35.69	31.71
60	33.65	34.49	30.41
75	31.65	32.94	29.04
90	30.48	31.79	27.71

Table B37 Values of Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm, Horizontal Position R60.

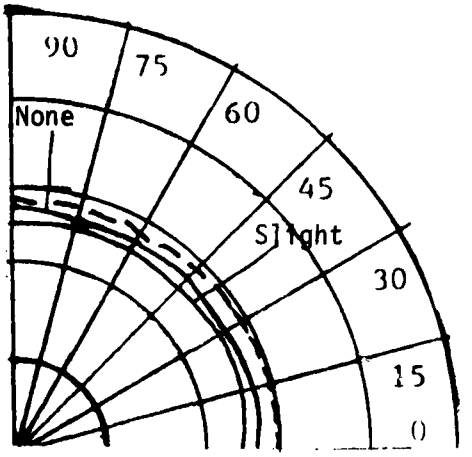


Figure B38 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R60.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	29.37	27.45	25.79
15	29.62	27.75	26.20
30	29.24	27.40	26.29
45	29.50	28.60	25.79
60	29.50	28.65	26.70
75	29.55	28.90	27.20
90	29.72	29.05	26.01

Table B38 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R60.

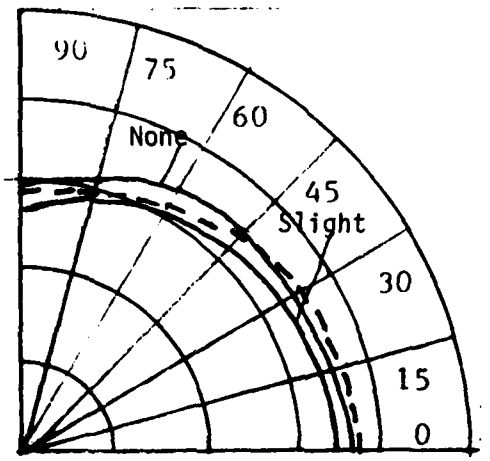


Figure B39 Comparison of the Able, None and Slight Group Averages. *Vertical Grasping Reach, Right Arm. Horizontal Position R75.*

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.49	38.17	36.27
15	38.11	37.72	35.68
30	37.21	36.52	34.68
45	35.01	35.17	32.68
60	32.97	33.64	31.10
75	30.81	31.27	29.27
90	28.94	29.97	27.10

Table B39 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R75.

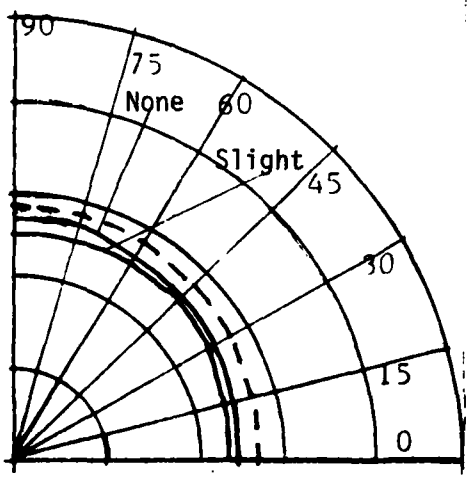


Figure B40 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R75.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	27.48	25.33	24.34
15	27.60	25.48	24.59
30	27.39	25.43	24.84
45	27.54	25.93	24.93
60	28.31	26.53	25.84
75	28.41	27.03	25.59
90	28.51	27.18	25.93

Table B40 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R75.

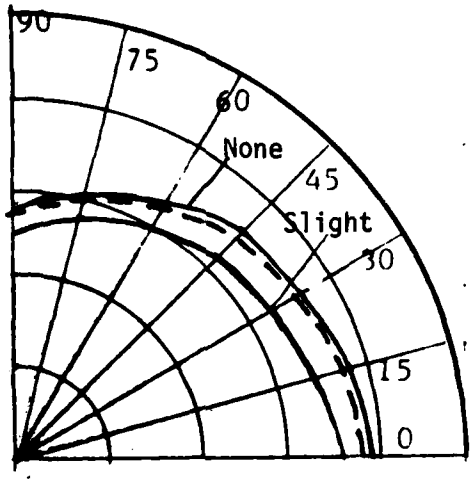


Figure B41 Comparison of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R90.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	38.57	39.12	37.11
15	38.32	38.47	35.94
30	36.92	37.25	34.27
45	34.87	35.42	32.02
60	32.59	32.87	30.02
75	29.52	30.32	27.61
90	27.57	38.87	25.44

Table B41 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R90.

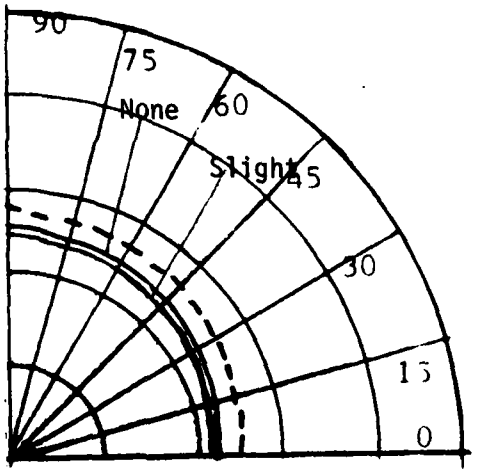


Figure B42 Comparison of the Able, None and Slight Group Averages Vertical Grasping Reach, Left Arm. Horizontal Position R90.

Vertical Position	Average		
	Able N = 10	None N = 5	Slight N = 3
0	25.16	22.92	22.52
15	25.86	23.42	22.35
30	26.16	23.82	22.94
45	26.39	24.37	23.27
60	26.55	24.92	24.19
75	26.71	25.27	24.52
90	26.79	25.87	25.26

Table B42 Values of the Able, None and Slight Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R90.

APPENDIX C

HORIZONTAL AND VERTICAL REACH

(ABLE GROUP AND DISABLED SUBGROUPS:

MEDIUM AND SEVERE)

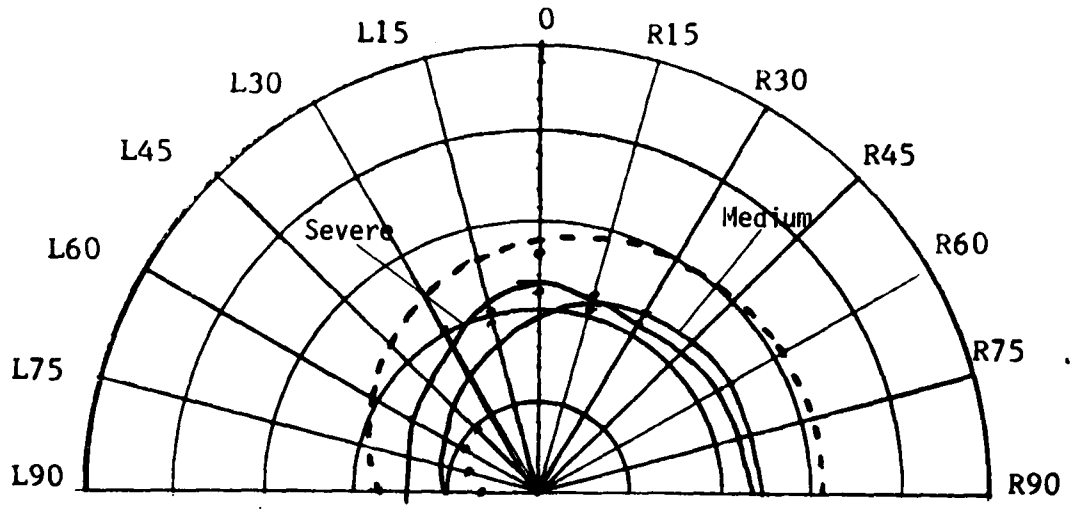


Figure C1 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position T.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	17.27	6.52	18.85
L75	19.66	7.71	14.38
L60	22.50	8.19	16.12
L45	23.45	9.55	17.03
L30	25.25	20.16	18.76
L15	27.35	21.27	19.53
0	28.07	22.94	26.65
R15	29.26	23.77	21.33
R30	30.22	23.79	21.91
R45	30.90	23.49	22.38
R60	31.45	25.06	23.07
R75	31.25	24.81	22.99
R90	31.32	25.03	23.34

Table C1 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position T.

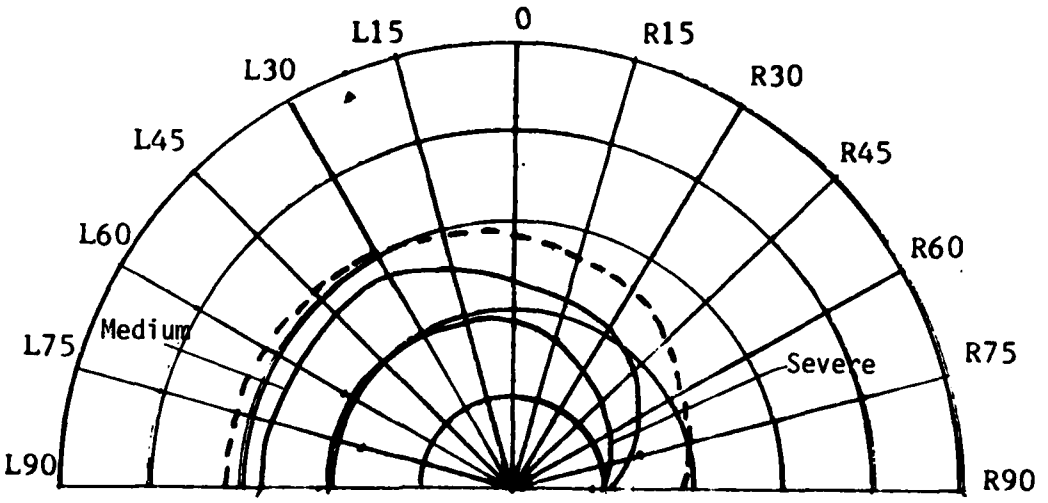


Figure C2 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position T.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	31.36	27.78	21.49
L75	31.84	27.56	16.35
L60	31.60	27.69	21.17
L45	31.19	27.49	20.53
L30	30.32	27.16	19.96
L15	29.42	25.02	18.93
0	28.54	23.32	18.63
R15	27.16	21.65	17.53
R30	26.72	21.29	16.31
R45	24.30	18.62	15.28
R60	22.67	16.94	13.77
R75	20.61	14.93	15.13
R90	18.51	11.41	9.24

Table C2 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position T.

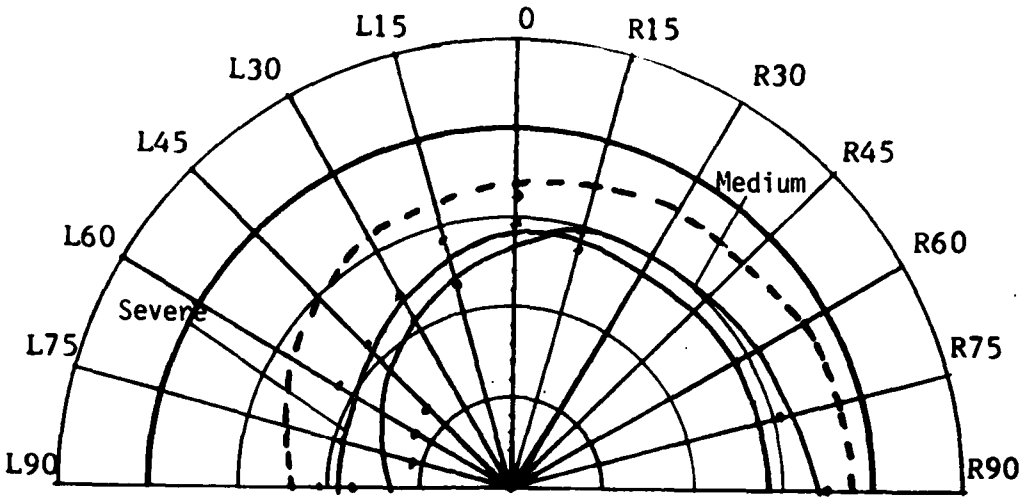


Figure C3 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 0.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	24.92	17.66	21.31
L75	26.91	11.09	19.44
L60	28.90	11.94	22.57
L45	30.15	13.17	23.13
L30	32.0	25.79	22.46
L15	33.69	28.77	24.83
0	34.74	29.57	32.2
R15	35.76	29.90	27.68
R30	36.75	30.54	27.91
R45	37.61	30.12	27.58
R60	37.98	32.06	28.32
R75	38.49	31.18	28.37
R90	38.57	35.66	28.59

Table C3 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 0.

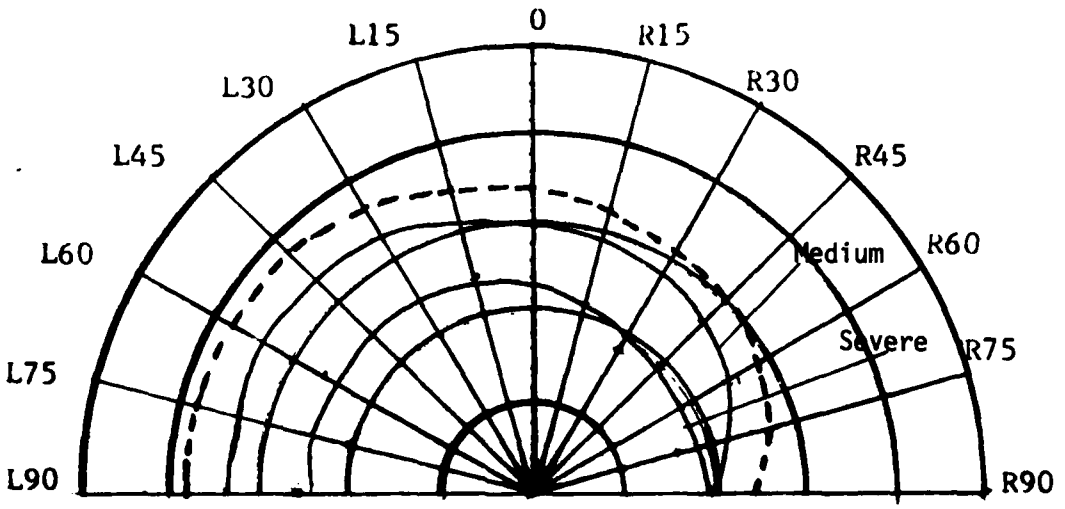


Figure C4 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 0.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	38.36	34.66	26.54
L75	38.79	34.31	20.30
L60	38.15	34.81	26.12
L45	38.02	34.49	25.83
L30	37.07	34.66	25.51
L15	35.69	31.90	24.98
0	34.88	29.94	23.23
R15	34.26	28.77	22.84
R30	32.90	28.04	17.11
R45	31.40	26.33	19.93
R60	29.37	23.81	18.42
R75	27.48	21.93	16.24
R90	25.16	19.53	19.24

Table C4 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 0.

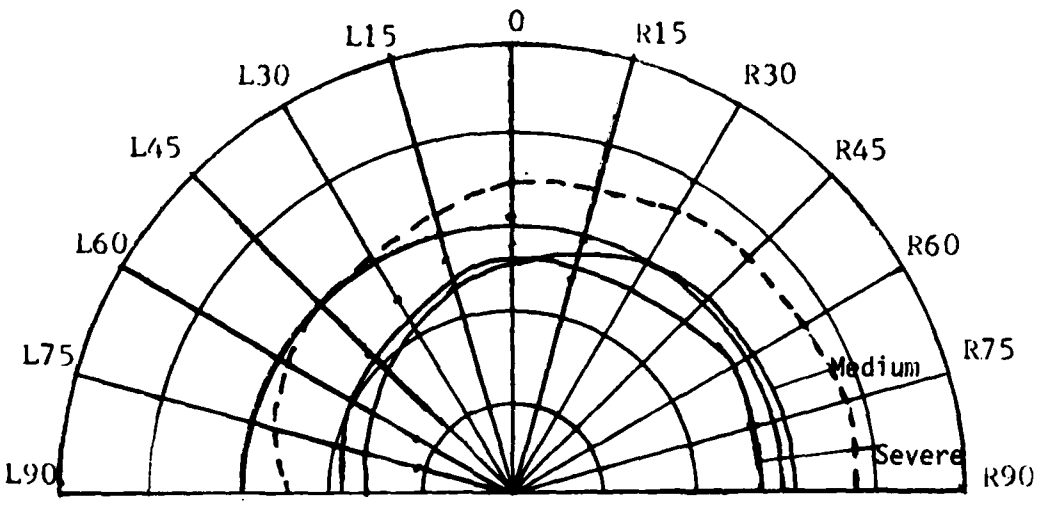


Figure C5 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 15.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	24.49	16.91	19.31
L75	26.91	11.21	19.54
L60	28.75	12.06	21.42
L45	20.25	23.87	22.13
L30	31.85	25.79	23.01
L15	33.54	26.90	24.51
0	34.78	27.69	31.40
R15	35.66	29.40	25.53
R30	36.62	29.79	26.46
R45	37.41	31.37	26.06
R60	37.73	30.94	27.62
R75	38.11	31.06	27.36
R90	38.32	30.91	27.49

Table C5 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 15.

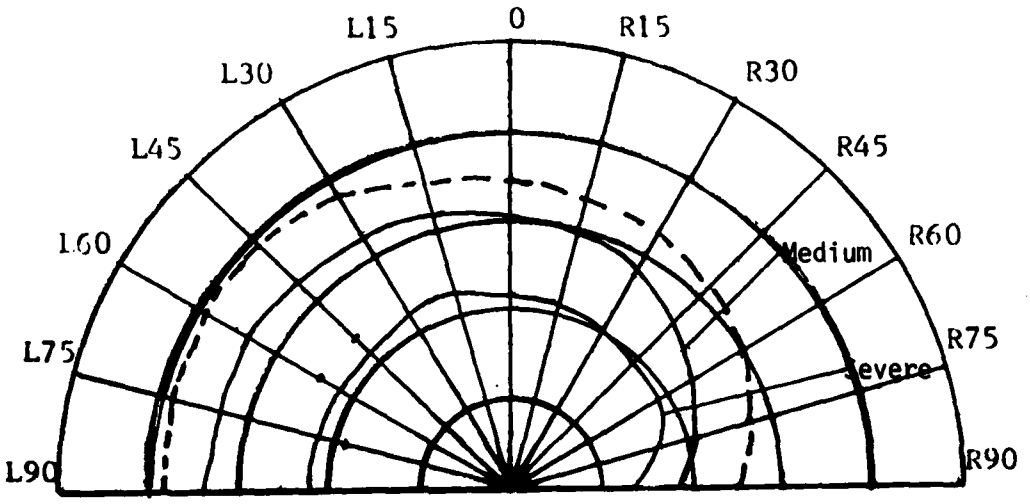


Figure C6 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 15.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	38.41	34.16	25.49
L75	38.44	33.68	18.80
L60	38.02	34.19	24.47
L45	37.95	34.49	24.28
L30	36.92	34.29	24.31
L15	35.59	32.15	23.18
0	34.86	29.12	22.23
R15	33.94	28.52	21.23
R30	33.00	27.04	20.91
R45	31.00	25.12	19.40
R60	29.62	23.06	17.92
R75	27.60	21.56	15.89
R90	25.86	19.78	13.84

Table C6 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 15.

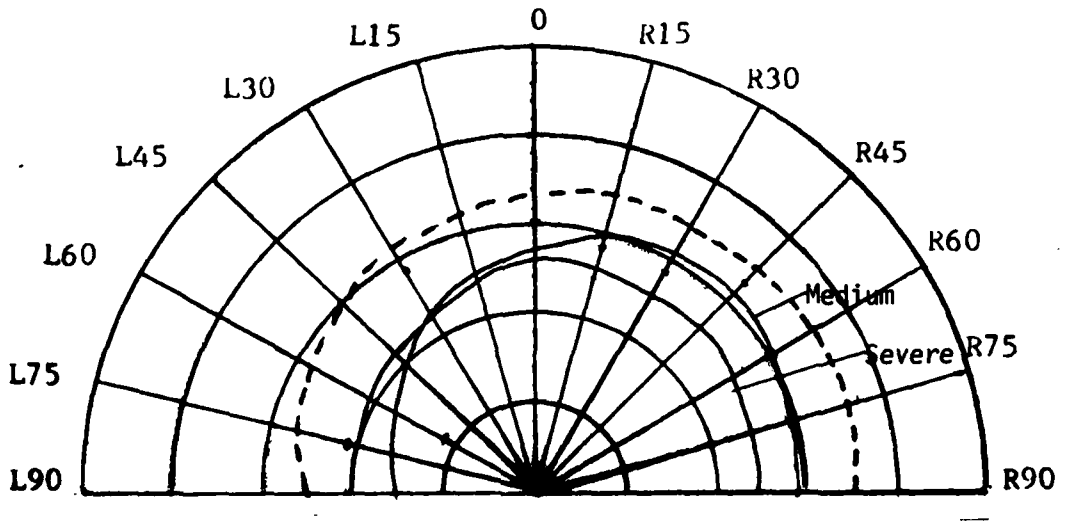


Figure C7 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 30.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	24.67	16.28	20.39
L75	27.09	20.18	19.24
L60	28.53	12.31	20.57
L45	30.02	25.53	21.43
L30	31.85	29.54	22.76
L15	32.89	26.65	24.38
0	34.19	27.57	30.15
R15	35.09	28.65	25.13
R30	35.8	28.79	25.91
R45	36.81	33.99	25.63
R60	36.93	30.69	26.62
R75	37.21	29.93	25.69
R90	36.92	29.53	25.84

Table C7 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 30.

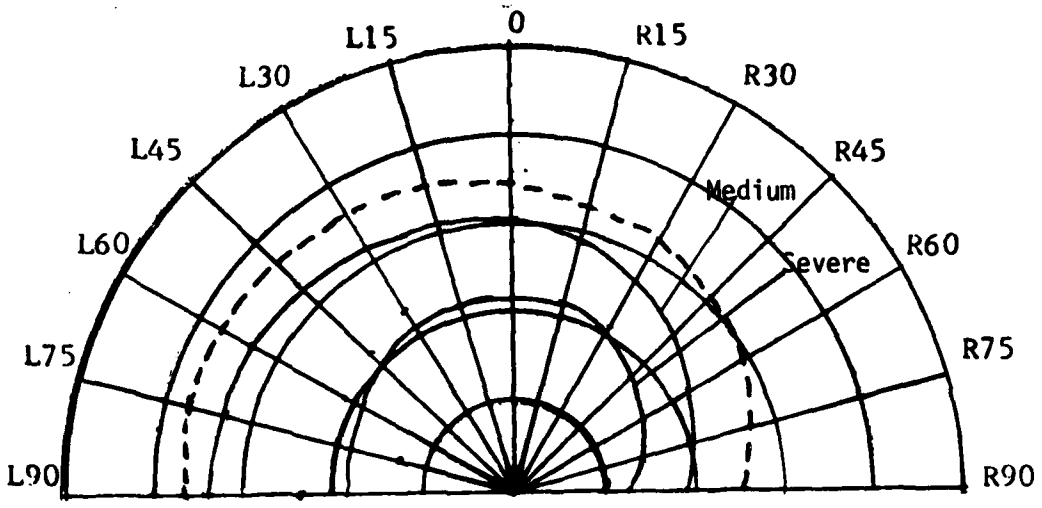


Figure C8 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 30.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	36.89	33.03	23.64
L75	37.21	32.56	14.71
L60	37.17	33.31	22.07
L45	36.77	33.74	22.68
L30	36.20	32.91	23.20
L15	35.59	31.65	21.93
0	34.34	30.57	20.78
R15	33.66	29.15	20.43
R30	32.70	27.29	20.32
R45	30.87	25.24	18.83
R60	29.24	23.81	16.97
R75	27.39	21.18	15.39
R90	26.16	19.03	13.14

Table C8 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 30.

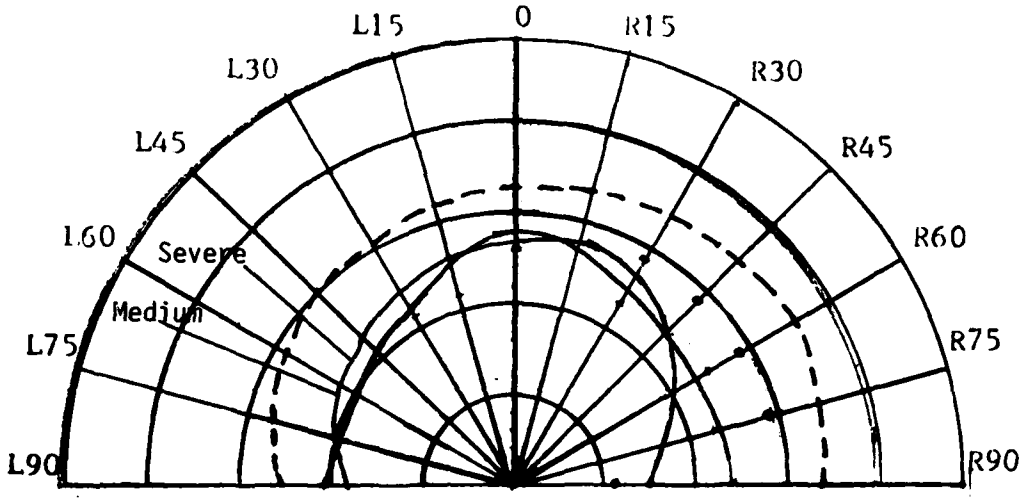


Figure C9 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 45.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	25.34	18.28	20.49
L75	27.26	20.31	18.74
L60	28.60	22.06	19.62
L45	30.05	23.62	21.18
L30	31.37	25.41	22.06
L15	32.81	26.27	22.13
0	33.87	25.94	30.00
R15	34.24	28.52	26.46
R30	34.82	29.29	24.46
R45	35.31	29.24	25.78
R60	35.27	29.44	26.22
R75	35.01	29.43	32.94
R90	34.87	12.76	25.24

Table C9 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 45.

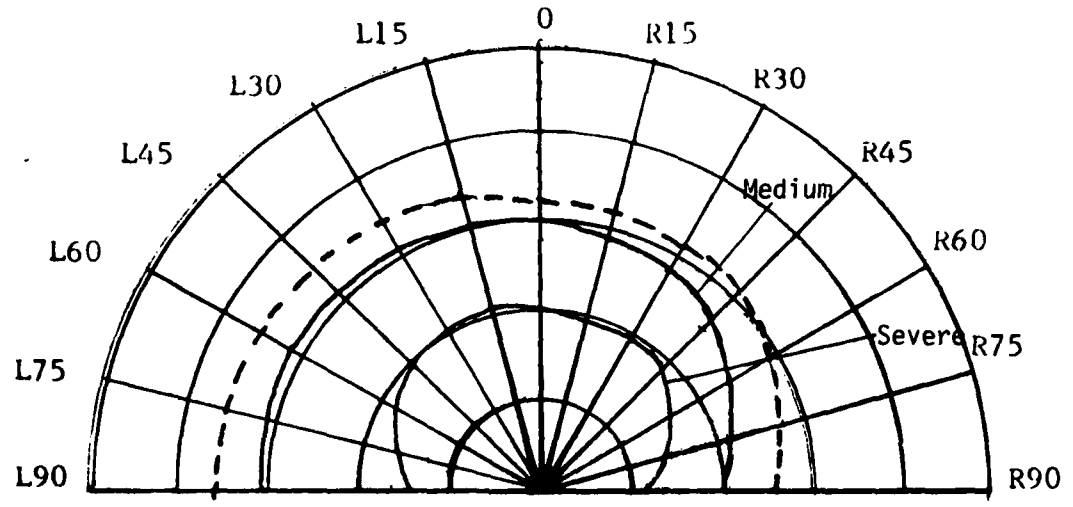


Figure C10 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 45.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	34.99	30.66	16.18
L75	35.61	30.06	13.81
L60	35.72	32.31	18.72
L45	35.50	32.24	18.75
L30	35.25	32.41	22.01
L15	35.19	31.77	21.28
0	33.89	30.69	20.38
R15	33.37	28.77	19.53
R30	32.45	27.41	19.66
R45	30.87	25.49	18.28
R60	29.50	24.56	16.57
R75	27.54	21.81	15.19
R90	26.39	20.66	12.14

Table C10 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 45.

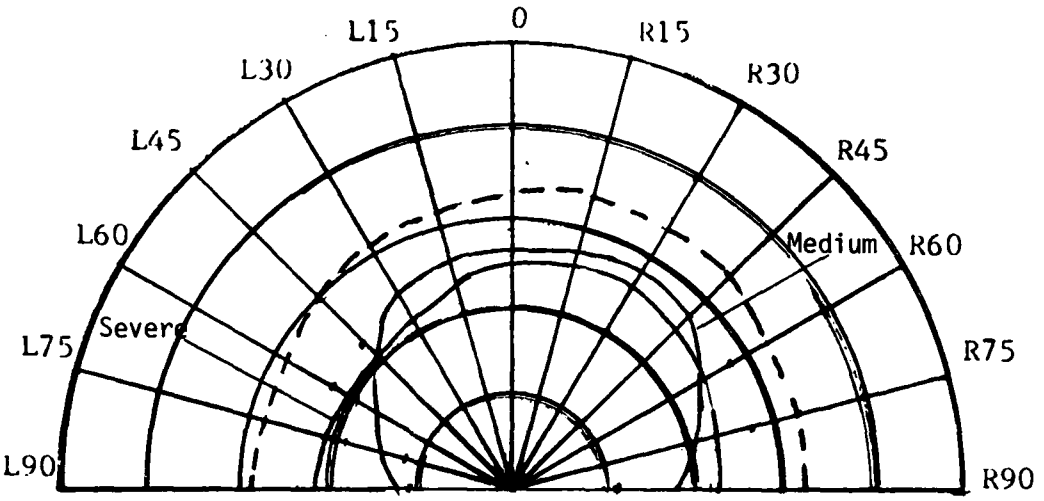


Figure C11 Comparison of the Able, Medium and Severe Group Averages. *Horizontal Grasping Reach*, Right Arm. Vertical Position 60.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	26.82	10.90	23.59
L75	27.61	11.84	18.74
L60	28.68	23.19	19.37
L45	30.02	24.74	21.18
L30	30.25	26.29	21.61
L15	32.39	26.88	21.48
0	33.03	26.69	29.85
R15	33.69	27.52	25.23
R30	33.90	28.29	25.61
R45	33.96	27.99	25.33
R60	33.65	28.06	25.07
R75	32.97	27.68	24.44
R90	32.59	12.01	23.59

Table C11 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 60.

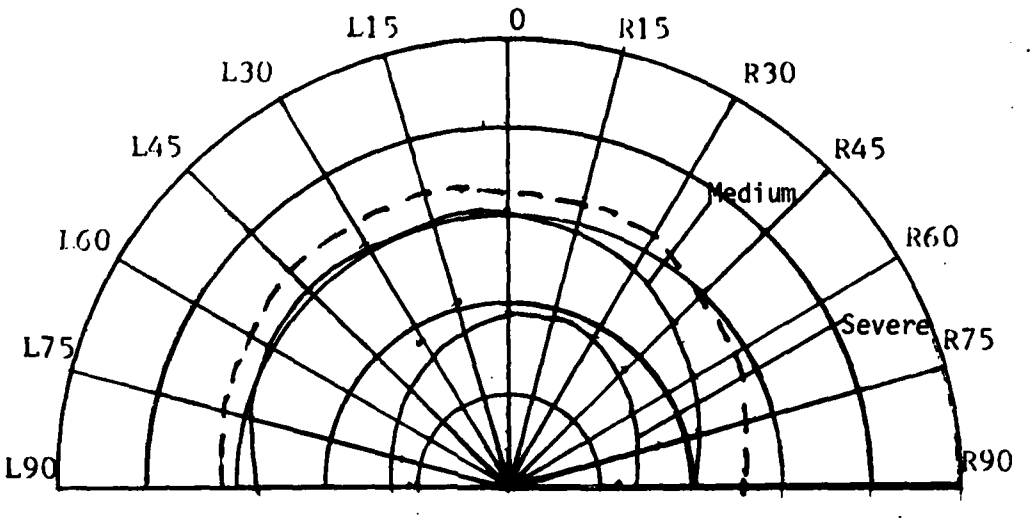


Figure C12 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 60.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	32.71	28.66	12.56
L75	33.51	28.93	12.96
L60	34.20	30.69	13.40
L45	34.50	30.87	13.28
L30	34.42	31.54	18.35
L15	34.56	30.77	20.68
0	33.51	30.44	19.88
R15	33.21	28.90	19.53
R30	32.40	27.91	19.21
R45	30.85	25.37	18.28
R60	29.50	24.94	16.07
R75	28.31	22.18	19.78
R90	26.55	21.16	12.44

Table C12 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 60.

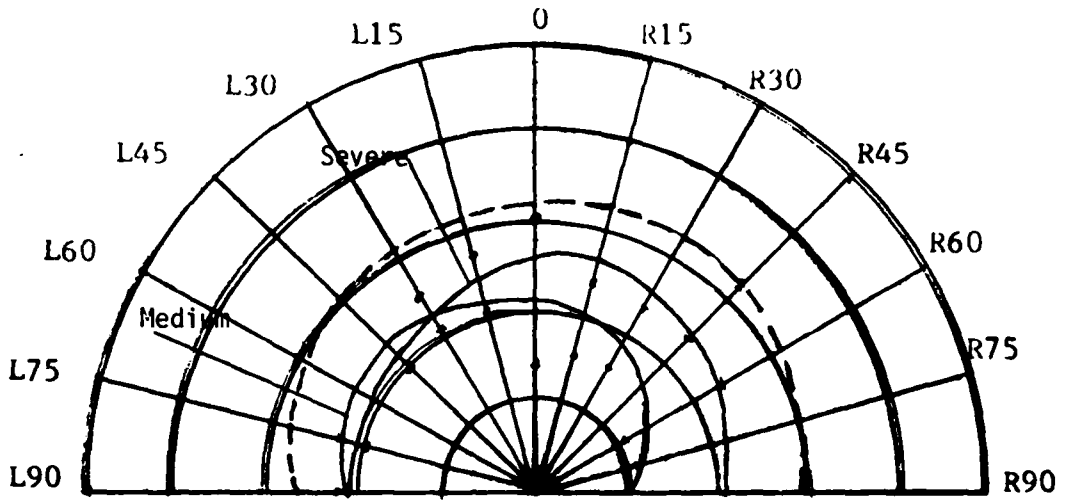


Figure C13 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 75.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	26.04	20.91	22.24
L75	27.51	22.56	18.24
L60	28.69	23.44	22.42
L45	30.13	24.37	19.93
L30	31.27	25.91	21.31
L15	32.19	27.65	22.73
0	32.66	14.63	30.80
R15	32.91	15.53	24.83
R30	33.02	15.50	24.76
R45	32.48	32.37	24.50
R60	31.65	12.63	24.19
R75	30.81	12.10	22.87
R90	29.52	11.51	21.74

Table C13 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 75.

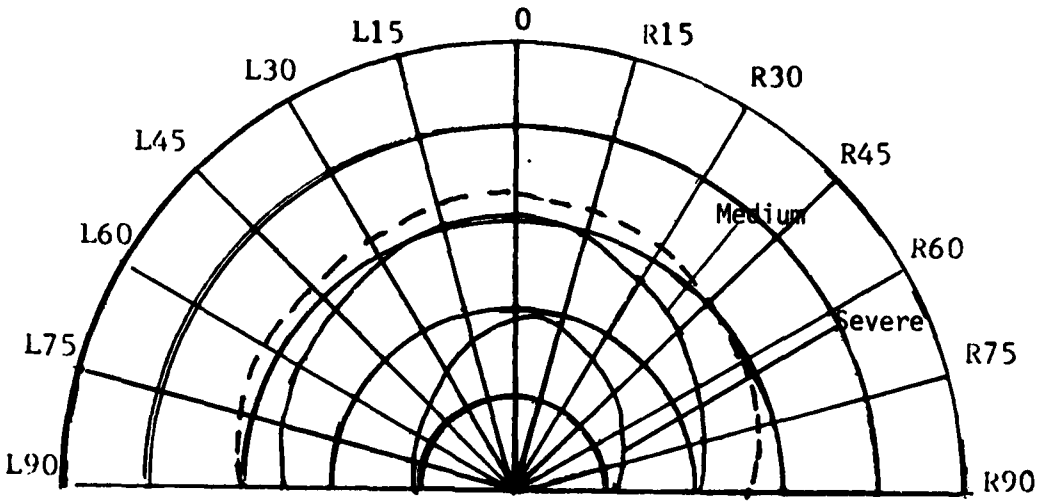


Figure C14 Comparison of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 75.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	30.04	25.03	11.01
L75	31.51	26.18	11.91
L60	32.32	27.81	12.65
L45	32.95	28.74	12.93
L30	33.20	29.79	13.00
L15	33.99	30.40	21.03
0	33.16	30.07	19.38
R15	33.04	29.02	19.08
R30	32.35	27.91	19.36
R45	30.75	26.37	18.38
R60	29.55	24.94	12.31
R75	28.41	23.43	14.84
R90	26.71	21.66	12.49

Table C14 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 75.

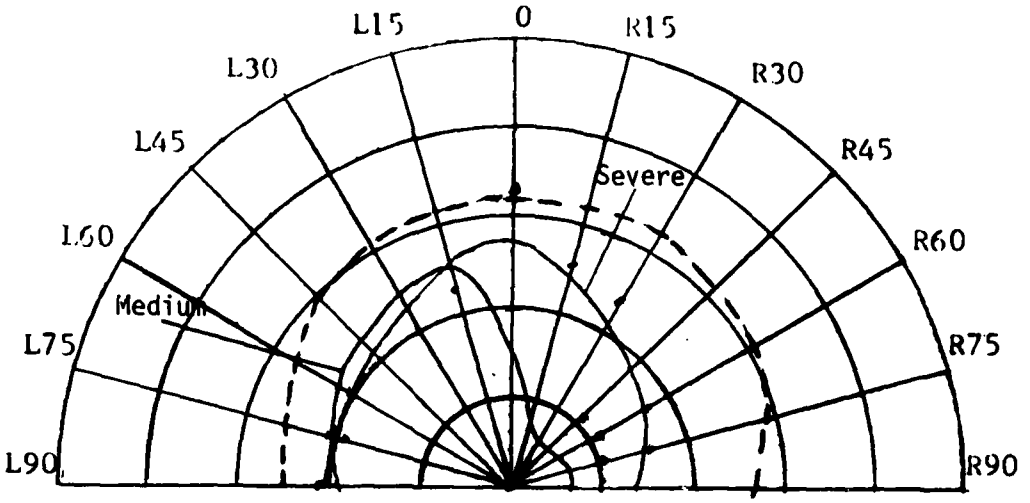


Figure C15 Comparison of the Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 90.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	25.64	19.78	21.19
L75	27.64	21.43	19.29
L60	27.81	22.81	21.37
L45	30.25	24.29	21.68
L30	31.37	25.91	23.41
L15	31.99	26.77	24.28
0	32.31	15.00	33.05
R15	32.63	0	25.03
R30	32.61	0	24.51
R45	31.36	12.45	18.31
R60	30.48	12.13	17.30
R75	28.94	11.60	16.00
R90	27.57	10.39	14.93

Table C15 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Right Arm. Vertical Position 90.

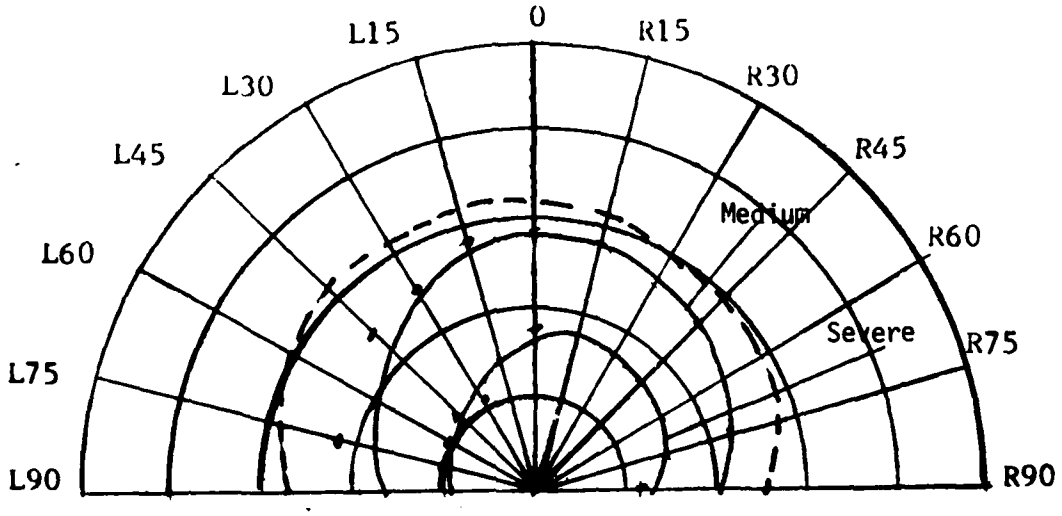


Figure C16 Comparison of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 90.

Horizontal Angle	Average		
	Able N = 10	Medium N = 2	Severe N = 5
L90	27.56	19.53	9.12
L75	28.91	22.18	11.16
L60	30.30	12.75	11.65
L45	31.30	25.62	12.73
L30	32.10	26.39	12.80
L15	32.86	28.02	15.47
0	32.89	29.57	18.93
R15	32.81	28.77	18.68
R30	31.55	27.41	18.66
R45	30.87	26.12	17.58
R60	29.72	25.19	16.37
R75	28.51	23.55	15.14
R90	26.79	21.16	12.94

Table C16 Values of Able, Medium and Severe Group Averages. Horizontal Grasping Reach, Left Arm. Vertical Position 90.

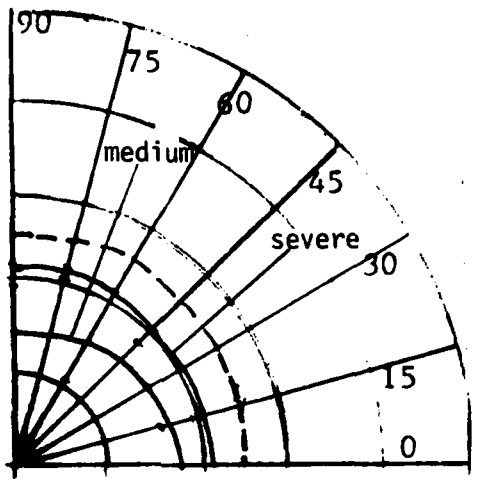


Figure C17 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L90.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	24.92	17.66	21.31
15	24.49	16.91	19.31
30	24.67	16.28	20.39
45	25.34	18.28	20.49
60	26.82	10.90	23.59
75	26.04	20.91	22.24
90	25.64	19.78	21.19

Table C17 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L90.

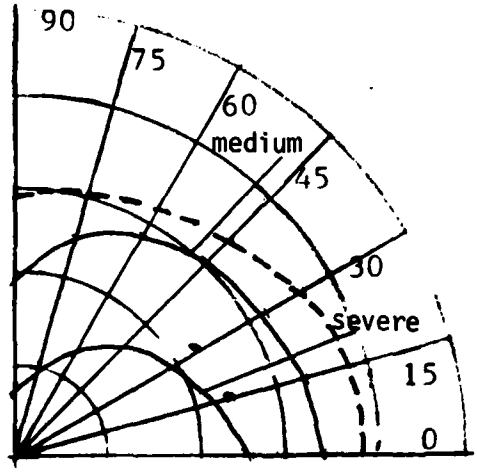


Figure C18 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L90.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.36	34.66	26.54
15	38.41	34.16	25.49
30	36.89	33.03	23.64
45	34.99	30.66	16.18
60	32.71	28.66	12.56
75	30.04	25.03	11.01
90	27.56	19.53	9.12

Table C18 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L90.

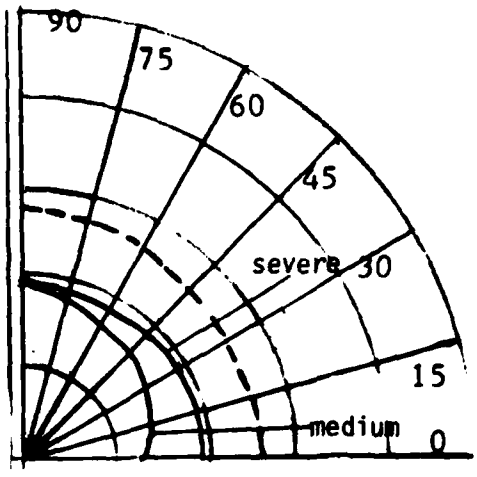


Figure C19 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L75.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	26.91	11.09	19.44
15	26.91	11.21	19.54
30	27.09	20.18	19.24
45	27.26	20.31	18.74
60	27.61	11.84	18.74
75	27.51	22.56	18.24
90	27.64	21.43	19.29

Table C19 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L75.

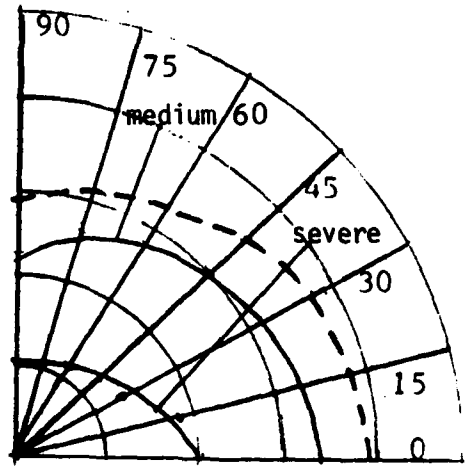


Figure C20 Comparison of the Able, *Medium* and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L75.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.79	34.31	20.30
15	38.44	33.68	18.80
30	37.21	32.56	14.71
45	35.61	30.06	13.81
60	33.51	28.93	12.96
75	31.51	26.18	11.91
90	28.91	22.18	11.16

Table C20 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L75.

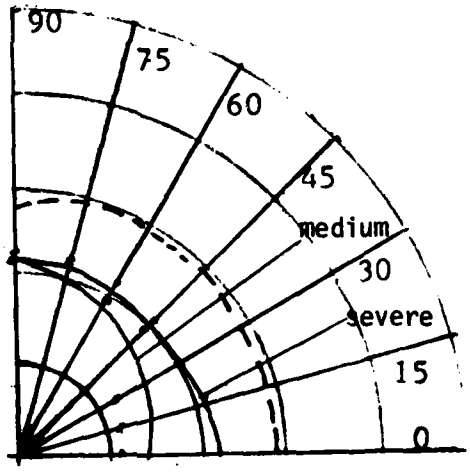


Figure C21 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L60.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	28.90	11.94	22.57
15	28.75	12.06	21.42
30	28.53	12.31	20.57
45	28.60	22.06	19.62
60	28.68	23.19	19.37
75	28.69	23.44	22.42
90	27.81	22.81	21.37

Table C21 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L60.

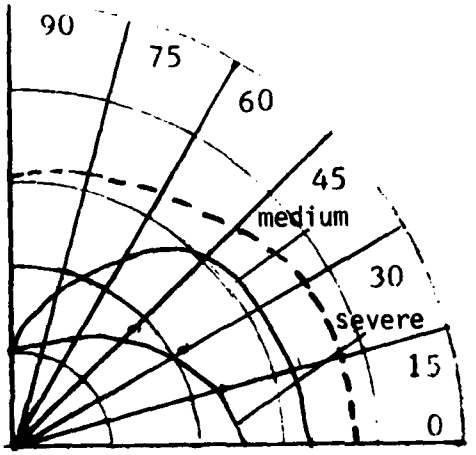


Figure C22 Comparison of the Able, Medium and Severe Group Averages. *Vertical Grasping Reach*, Left Arm. Horizontal Position L60.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.15	34.81	26.12
15	38.02	34.19	24.47
30	37.16	33.31	22.07
45	35.72	32.31	18.72
60	34.20	30.69	13.40
75	32.32	27.81	12.65
90	30.30	12.75	11.65

Table C22 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L60.

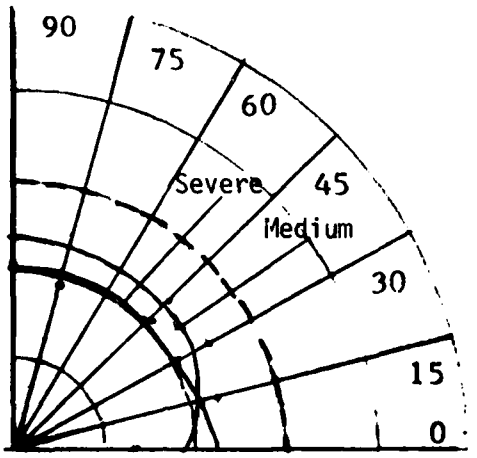


Figure C23 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L45.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	30.15	13.17	23.13
15	30.25	23.87	22.13
30	30.02	25.53	21.43
45	30.05	23.62	21.18
60	30.02	24.74	21.18
75	30.13	24.37	19.93
90	30.25	24.49	21.68

Table C23 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L45.

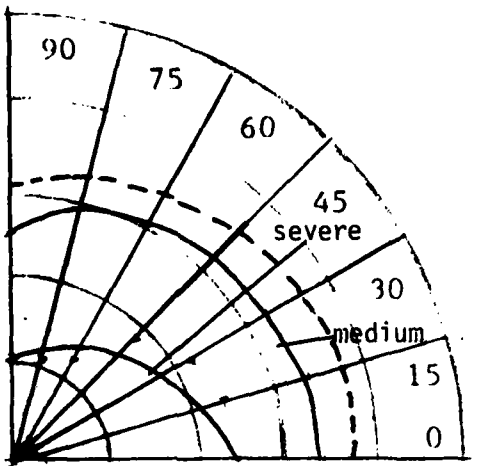


Figure C24 Comparison of the Able, Medium and Severe Group Averages Vertical Grasping Reach, Left Arm. Horizontal Position L45.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.02	34.49	25.83
15	37.95	34.49	24.28
30	36.77	33.74	22.68
45	35.50	32.24	18.75
60	34.50	30.87	13.28
75	32.95	28.74	12.93
90	31.30	25.62	12.73

Table C24 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L45.

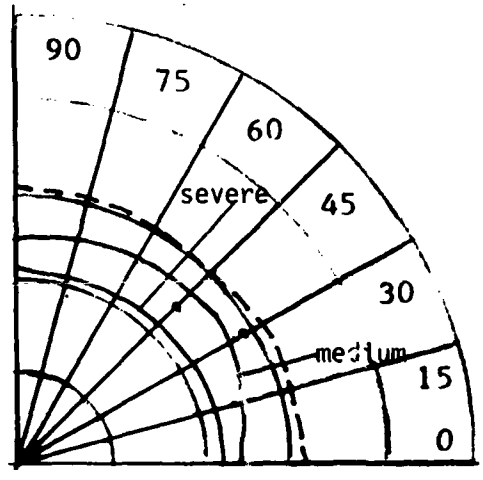


Figure C25 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L30.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	32.0	25.79	22.46
15	31.85	25.79	23.01
30	31.85	29.54	22.76
45	31.37	25.41	22.06
60	30.25	26.29	21.61
75	31.27	25.91	21.31
90	31.37	25.91	23.41

Table C25 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L30.

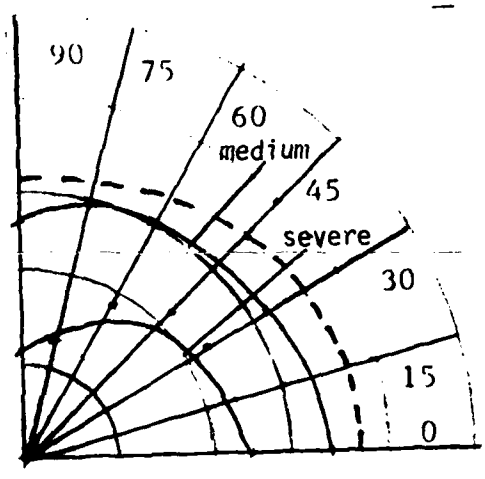


Figure C26 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L30.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	37.07	34.66	25.51
15	36.92	34.29	24.31
30	36.20	32.91	23.20
45	35.25	32.41	22.01
60	34.42	31.54	18.35
75	33.20	29.79	13.00
90	32.10	26.29	12.80

Table C26 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L30.

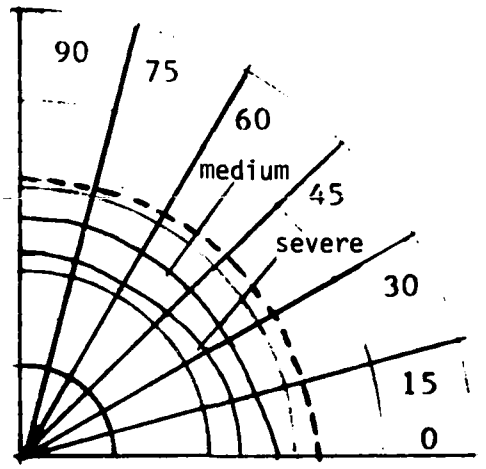


Figure C27 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L15.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	33.69	28.77	24.83
15	33.54	26.90	24.51
30	32.89	26.65	24.38
45	32.81	26.27	22.13
60	32.39	26.88	21.48
75	32.19	27.65	22.73
90	31.99	26.77	24.28

Table C27 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position L15.

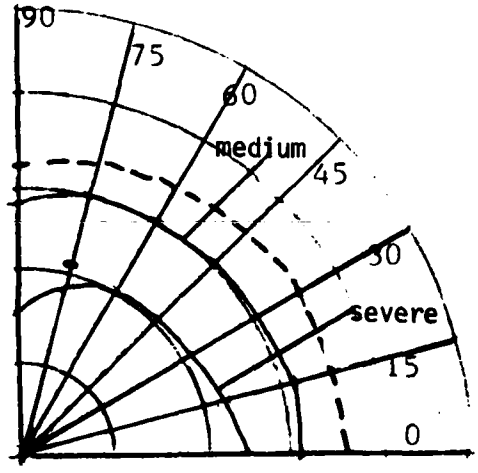


Figure C28 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L15.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	35.69	31.90	24.98
15	35.59	32.15	23.18
30	35.59	31.65	21.93
45	35.19	31.77	21.28
60	34.56	30.77	20.68
75	33.99	30.40	21.03
90	32.86	28.02	15.47

Table C28 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position L15.

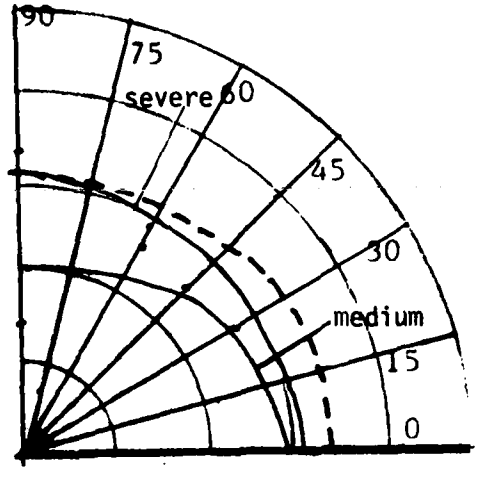


Figure C29 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position 0.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	34.74	29.57	32.2
15	34.78	27.69	31.40
30	34.19	27.57	30.15
45	33.87	25.94	30.00
60	33.03	26.69	29.85
75	32.66	14.63	30.80
90	32.31	15.00	33.05

Table C29 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position 0.

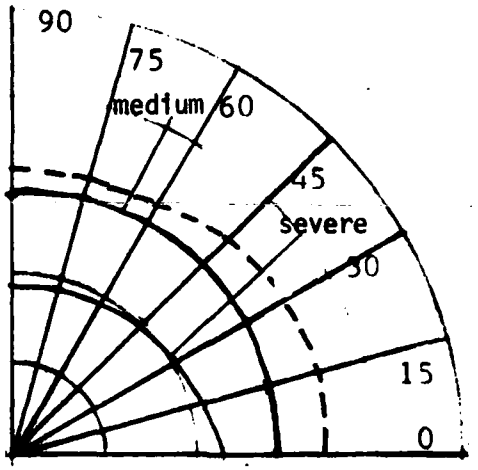


Figure C30 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. *Horizontal Position 0*

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	34.88	29.94	23.23
15	34.86	29.12	22.23
30	34.34	30.57	20.78
45	33.89	30.69	20.38
60	33.51	30.44	19.88
75	33.16	30.07	19.38
90	32.89	29.57	18.93

Table C30 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position 0.

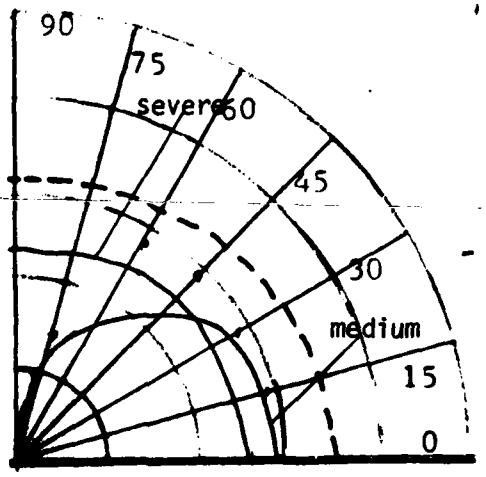


Figure C31 Comparison of the Able, Medium and Severe Group Averages. *Vertical Grasping Reach, Right Arm. Horizontal Position* R15.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	35.76	29.90	27.68
15	35.66	29.40	25.53
30	35.09	28.65	25.13
45	34.24	28.52	26.46
60	33.69	27.52	25.23
75	32.91	15.53	24.83
90	32.63	0	25.03

Table C31 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R15.

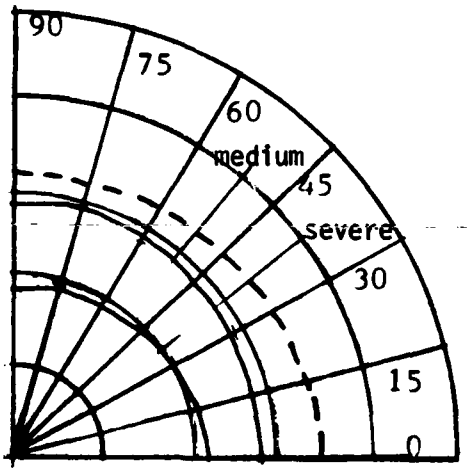


Figure C32 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R15.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	34.26	28.77	22.84
15	33.94	28.52	21.23
30	33.66	29.15	20.43
45	33.37	28.77	19.53
60	33.21	28.90	19.53
75	33.04	29.02	19.08
90	32.81	28.77	18.68

Table C32 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R15.

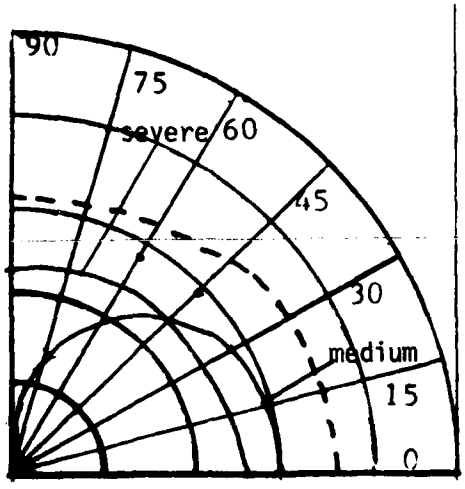


Figure C33 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R30.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	36.75	30.54	27.91
15	36.62	29.79	26.46
30	35.8	28.79	25.91
45	34.82	29.29	24.46
60	33.90	28.29	25.61
75	33.02	15.50	24.76
90	32.61	0	24.51

Table C33 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R30.

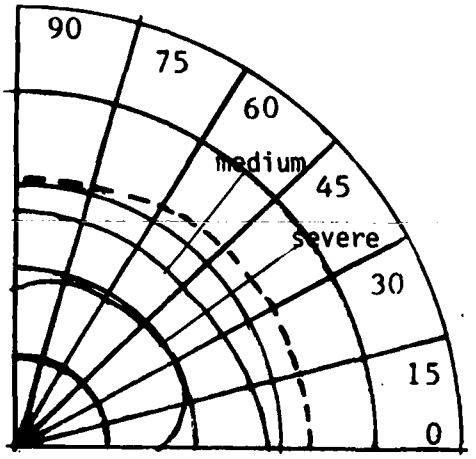


Figure C34 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R30.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	32.90	28.04	17.11
15	33.00	27.04	20.91
30	32.70	27.29	20.32
45	32.45	27.41	19.66
60	32.40	27.91	19.21
75	32.35	27.91	19.36
90	31.55	27.41	18.66

Table C34 Values of Able, Medium and Severe Group Average. Vertical Grasping Reach, Left Arm. Horizontal Position R30.

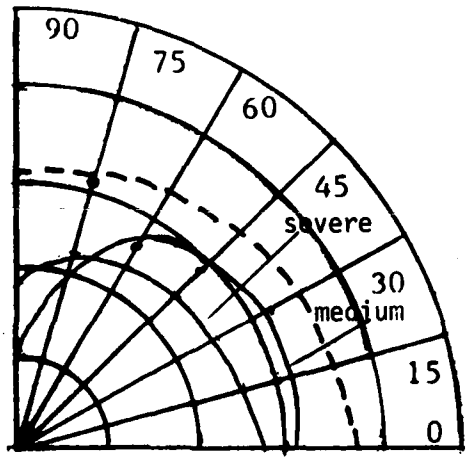


Figure C35 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R45.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	37.61	30.12	27.58
15	37.41	31.37	26.06
30	36.81	33.99	25.63
45	35.31	29.24	25.78
60	33.96	27.99	25.33
75	32.48	32.37	24.50
90	31.36	12.45	18.31

Table C35 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R45.

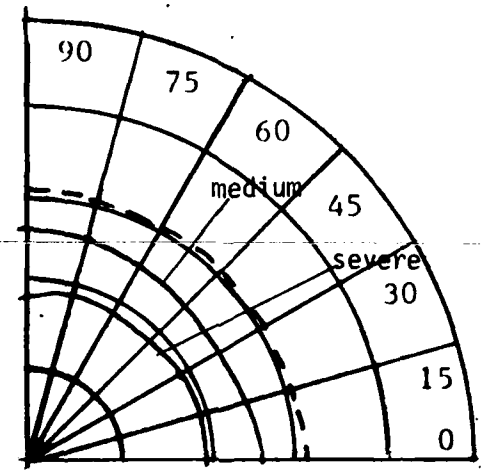


Figure C36 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R45.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	31.40	26.33	19.93
15	31.00	25.12	19.40
30	30.87	25.24	18.83
45	30.87	25.49	18.28
60	30.85	25.37	18.28
75	30.75	26.37	18.38
90	30.87	26.12	17.58

Table C36 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R45.

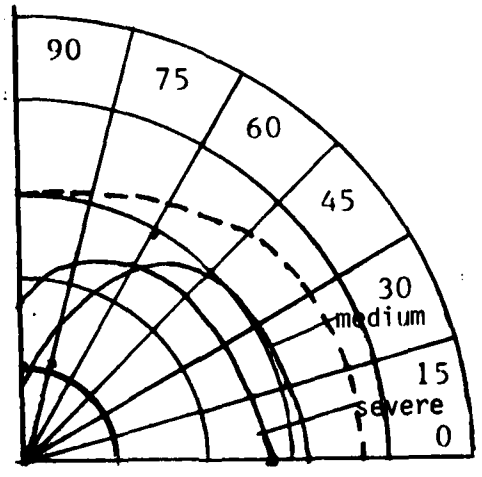


Figure C37 Comparison of the Able, Medium and Severe Group Averages. *Vertical Grasping Reach, Right Arm. Horizontal Position R60.*

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	37.98	32.06	28.32
15	37.73	30.94	27.62
30	36.93	30.69	26.62
45	35.27	29.44	26.22
60	33.65	28.06	25.07
75	31.65	12.63	24.19
90	30.48	12.13	17.30

Table C37 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R60.

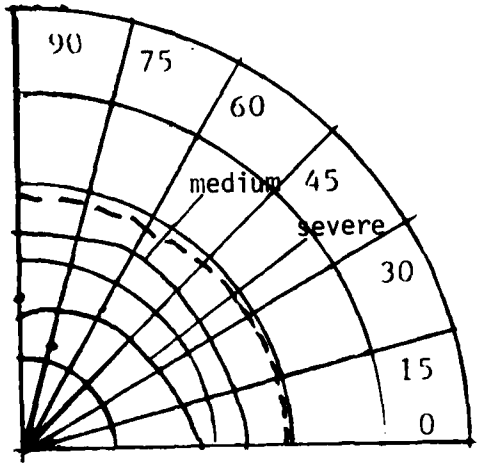


Figure C38 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R60.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	29.37	23.81	18.42
15	29.62	23.06	17.92
30	29.24	23.81	16.97
45	29.50	24.56	16.57
60	29.50	24.94	16.07
75	29.55	24.94	12.31
90	29.72	25.19	16.37

Table C38 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R60.

AD-A090 853 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 5/5
MAXIMUM GRASPING REACH OF OPERATORS POSSESSING FUNCTIONAL IMPAI--ETC(U)
DEC 78 L A GOEBEL
UNCLASSIFIED AFIT-CI-79-181T NL

END
DATE FILMED
12-80
DTIC

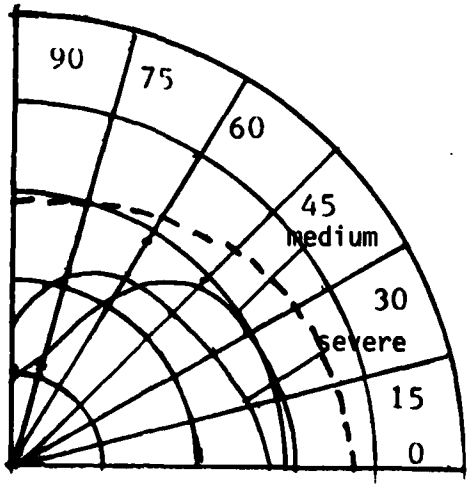


Figure C39 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R75.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.49	31.18	28.37
15	38.11	31.06	27.36
30	37.21	29.93	25.69
45	35.01	29.43	23.94
60	32.97	27.68	24.44
75	30.81	12.10	22.87
90	28.94	11.60	16.00

Table C39 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R75.

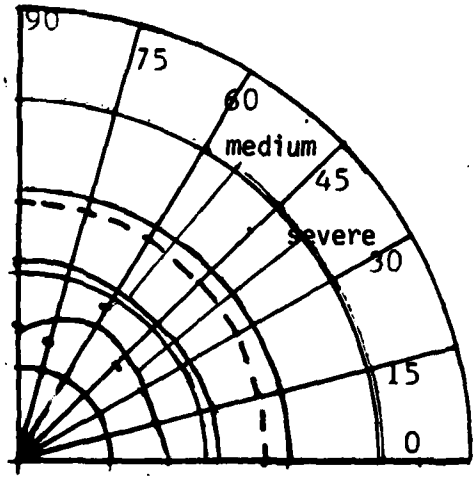


Figure C40 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R75.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	27.48	21.93	16.24
15	27.60	21.56	15.89
30	27.39	21.18	15.39
45	27.54	21.81	15.19
60	28.31	22.18	19.78
75	28.41	23.43	14.84
90	28.51	23.55	15.14

Table C40 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R75.

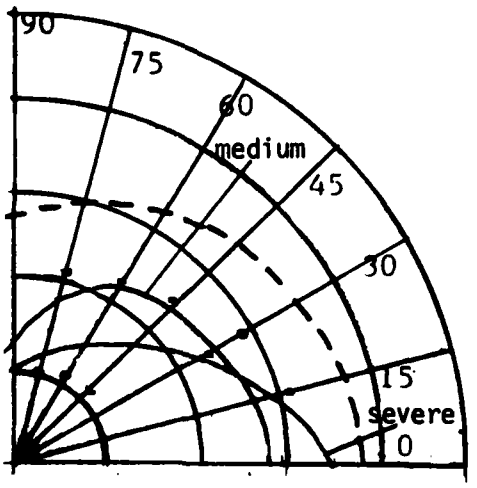


Figure C41 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R90.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	38.57	35.66	28.59
15	38.32	30.91	27.49
30	36.92	29.53	25.84
45	34.87	12.76	25.24
60	32.59	12.01	23.59
75	29.52	11.51	21.74
90	27.57	10.39	14.93

Table C41 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Right Arm. Horizontal Position R90.

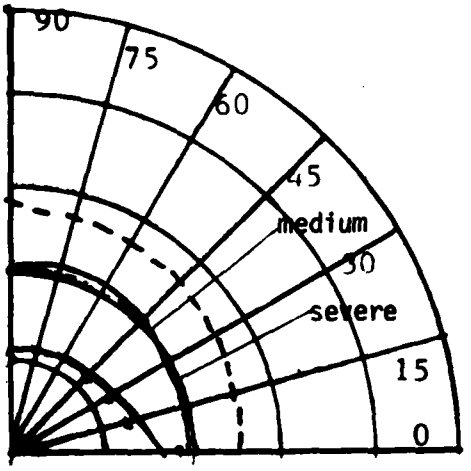


Figure C42 Comparison of the Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R90.

Vertical Position	Average		
	Able N = 10	Medium N = 2	Severe N = 5
0	25.16	19.53	19.24
15	25.86	19.78	13.84
30	26.16	19.03	13.14
45	26.39	20.66	12.14
60	26.55	21.16	12.44
75	26.71	21.66	12.49
90	26.79	21.16	12.94

Table C42 Values of Able, Medium and Severe Group Averages. Vertical Grasping Reach, Left Arm. Horizontal Position R90.

APPENDIX D

MEAN AND STANDARD DEVIATION

(ABLE GROUP)

APPENDIX D

MEAN AND STANDARD DEVIATION

OF GRASPING REACH (INCHES) OF THE ABLE GROUP

Right Arm

Horz. Angle		Vertical							
		T	0	15	30	45	60	75	90
L90	$\bar{X}$	17.27	24.92	24.49	24.67	25.34	26.82	26.04	25.64
	S_x	3.136	3.193	3.640	3.387	3.521	5.094	2.699	2.378
L75	$\bar{X}$	19.66	26.91	26.91	27.09	27.26	27.61	27.51	27.64
	S_x	2.647	2.827	2.827	3.125	3.130	2.996	2.225	1.703
L60	$\bar{X}$	22.5	28.90	28.75	28.53	28.60	28.68	28.69	27.81
	S_x	2.951	1.868	2.307	2.613	2.805	2.608	2.595	4.230
L45	$\bar{X}$	23.45	30.15	30.25	30.02	30.05	30.02	30.13	30.25
	S_x	2.309	26.43	2.641	2.551	2.371	2.353	2.137	2.009
L30	$\bar{X}$	25.25	32.0	31.85	31.85	31.37	30.25	31.27	31.37
	S_x	1.818	1.761	1.798	1.798	2.097	2.730	1.938	1.770
L15	$\bar{X}$	27.35	33.69	33.54	32.89	32.81	32.39	32.19	31.99
	S_x	2.349	1.493	1.527	1.753	1.813	1.929	1.877	1.859
0	$\bar{X}$	28.07	34.74	34.78	34.19	33.87	33.03	32.66	32.31
	S_x	1.208	1.377	1.749	1.619	1.752	1.715	1.715	1.82
R15	$\bar{X}$	29.26	35.76	35.66	35.09	34.24	33.69	32.91	32.63
	S_x	1.325	1.528	1.504	1.761	1.796	1.763	1.903	1.709
R30	$\bar{X}$	30.22	36.75	36.62	35.8	34.82	33.9	33.02	32.61
	S_x	1.139	1.245	1.462	1.448	1.668	1.706	1.840	2.899
R45	$\bar{X}$	30.90	37.61	37.41	36.81	35.31	33.96	32.48	31.36
	S_x	1.449	1.699	1.829	2.054	1.840	1.766	1.891	1.890
R60	$\bar{X}$	31.45	37.98	37.73	36.93	35.27	33.65	31.65	30.48
	S_x	2.185	2.470	2.064	2.174	2.113	2.049	2.193	2.406
R75	$\bar{X}$	31.25	38.49	38.11	37.21	35.01	32.97	30.81	28.94
	S_x	2.237	2.766	2.528	2.492	1.926	1.819	2.017	2.396
R90	$\bar{X}$	31.32	38.57	38.32	36.92	34.87	32.59	39.52	27.57
	S_x	19.94	2.137	2.250	2.127	1.979	2.069	2.018	2.501

(continued)

Left Arm

Horz. Angle		Vertical							
		T	0	15	30	45	60	75	90
L90	$\bar{X}$	31.36	38.36	38.41	36.89	34.99	32.71	30.04	27.56
	S_x	1.533	2.480	2.031	2.226	2.068	2.091	2.321	2.942
L75	$\bar{X}$	31.84	38.79	38.44	37.21	35.61	33.51	31.51	28.91
	S_x	1.979	2.214	2.472	2.446	2.323	2.197	2.150	2.836
L60	$\bar{X}$	31.6	38.15	38.02	27.17	35.72	34.20	32.32	30.30
	S_x	1.686	1.879	3.231	2.343	2.398	2.361	2.221	2.648
L45	$\bar{X}$	31.19	38.02	37.95	36.77	35.50	34.50	32.95	31.30
	S_x	1.982	2.102	2.244	2.079	2.382	2.273	2.219	2.420
L30	$\bar{X}$	30.32	37.07	36.92	36.20	35.25	34.42	33.20	32.10
	S_x	1.713	1.767	1.879	2.200	2.395	2.344	2.356	2.742
L15	$\bar{X}$	29.42	35.69	35.59	35.59	35.19	34.56	33.99	32.86
	S_x	1.758	2.245	1.948	1.922	1.732	1.987	2.340	2.469
0	$\bar{X}$	28.54	34.88	34.86	34.34	33.89	33.51	33.16	32.89
	S_x	1.569	1.631	1.356	1.676	1.816	1.809	1.974	2.088
R15	$\bar{X}$	27.16	34.26	33.94	33.66	33.37	33.21	33.04	32.81
	S_x	2.273	2.165	2.163	2.165	2.057	2.194	2.265	2.056
R30	$\bar{X}$	26.72	32.90	33	32.70	32.45	32.40	32.35	31.55
	S_x	2.085	2.184	2.324	2.225	2.144	2.082	2.146	2.804
R45	$\bar{X}$	24.30	31.40	31.00	30.87	30.87	30.85	30.75	30.87
	S_x	2.591	2.594	2.716	2.828	2.463	2.465	2.373	2.295
R60	$\bar{X}$	22.67	29.37	29.62	29.24	29.50	29.50	29.55	29.72
	S_x	2.707	2.814	2.782	2.829	2.678	2.573	2.615	2.612
R75	$\bar{X}$	20.61	27.48	27.60	27.39	27.54	28.31	28.41	28.51
	S_x	3.537	3.729	3.426	3.233	3.003	3.213	2.164	2.109
R90	$\bar{X}$	18.51	25.16	25.86	26.16	26.39	26.55	26.71	26.79
	S_x	2.503	2.732	2.655	2.987	3.182	2.922	2.648	2.144

APPENDIX E

MEAN

(COMPOSITE EXPERIMENTAL GROUP)

APPENDIX E

MEAN OF GRASPING REACH (INCHES)

OF THE DISABLED GROUP

Right Arm

Horizontal Angle	Vertical							
	T	0	15	30	45	60	75	90
L90	18.78	21.43	20.74	21.27	22.38	23.23	22.49	21.63
L75	16.25	23.79	24.42	23.56	23.78	24.37	23.35	23.88
L60	18.87	26.08	26.03	25.70	24.67	25.17	25.1	25.78
L45	20.69	27.40	26.25	25.97	26.00	26.29	25.93	27.32
L30	22.20	28.63	27.63	27.67	27.31	27.67	27.81	29.27
L15	23.06	30.00	29.41	29.56	28.85	29.60	29.17	30.21
0	26.09	30.95	30.27	29.99	29.56	29.16	31.13	32.96
R15	22.46	31.85	31.35	30.96	30.88	31.03	31.83	31.49
R30	26.35	33.60	32.49	31.70	32.24	31.45	31.68	31.06
R45	27.25	33.86	32.50	32.14	32.22	31.50	30.50	29.82
R60	27.85	34.81	33.67	32.78	32.39	31.00	29.53	28.47
R75	28.42	34.74	33.56	32.31	30.20	30.13	28.06	26.80
R90	28.74	36.49	34.13	32.56	31.31	29.02	27.09	25.52

Left Arm

L90	27.82	34.95	33.21	31.60	29.28	30.57	27.82	25.27
L75	27.30	34.55	32.88	34.47	32.52	30.97	28.82	26.97
L60	26.67	33.57	32.39	29.96	31.71	31.92	30.12	28.90
L45	26.07	32.97	31.97	30.50	32.06	30.65	31.26	30.11
L30	25.56	32.38	31.60	30.45	29.78	31.27	31.92	31.07
L15	24.03	31.49	30.49	29.35	28.96	28.76	28.10	28.31
0	22.29	29.13	28.70	28.34	28.13	27.84	27.41	27.02
R15	21.21	29.33	27.47	25.21	26.71	26.81	26.74	26.67
R30	20.07	26.82	26.28	25.74	25.74	25.07	29.32	24.82
R45	18.86	25.22	25.07	24.93	24.57	25.15	25.18	24.61
R60	16.92	23.78	23.64	23.35	23.17	23.28	23.28	23.21
R75	15.49	22.35	21.78	21.49	21.6	21.60	21.49	21.49
R90	13.03	23.71	20.07	19.67	20.21	19.67	19.53	20.10

APPENDIX F

T-TEST

(ABLE vs. DISABLED)

APPENDIX F

RESULTS OF T-TEST PERFORMED

ON THE ABLE GROUP AND DISABLED GROUP

Right Arm — Horizontal Reach

Horizontal Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
L90	2.880	1.767	7	4.5335	*
L75	3.399	0.487	7	19.7246	*
L60	3.133	.634	7	13.9836	*
L45	3.559	.633	7	15.9002	*
L30	3.378	.775	7	12.3303	*
L15	4.249	2.472	7	4.8608	*
0	2.943	1.825	7	4.5603	*
R15	3.424	1.860	7	5.2065	*
R30	2.896	1.103	7	7.427	*
R45	3.256	1.217	7	7.568	*
R60	3.068	.799	7	10.8574	*
R75	3.571	1.076	7	9.3918	*
R90	3.103	0.931	7	9.4232	

Right Arm — Vertical Reach

Vertical Position	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
T	3.149	1.816	12	6.2533	*
0	3.295	.525	12	22.6468	*
15	3.998	.683	12	21.1193	*
30	3.987	.571	12	25.1856	*
45	3.618	.640	12	20.3734	*
60	3.072	.524	12	21.153	*
75	2.709	1.055	12	9.2592	*
90	2.03	1.164	12	6.2900	*

(continued)

Left Arm — Horizontal Reach

Horizontal Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
L90	3.725	1.490	7	7.0724	*
L75	3.043	1.708	7	5.0390	*
L60	2.78	2.700	7	2.9127	*
L45	4.074	1.888	7	6.1025	*
L30	3.931	1.887	7	5.8928	*
L15	5.449	.761	7	20.2404	*
0	5.901	.213	7	78.2514	*
R15	6.413	.979	7	18.5185	*
R30	6.276	1.357	7	13.0843	*
R45	5.915	.323	7	51.8353	*
R60	6.068	.316	7	54.3880	*
R75	6.07	.749	7	22.9162	*
R90	5.768	1.832	7	8.9032	*

Left Arm — Vertical Reach

Vertical Position	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
T	5.302	.795	12	24.0531	*
0	4.714	1.260	12	13.4894	*
15	5.82	.472	12	44.4967	*
30	5.318	2.735	12	7.0117	*
45	5.525	1.215	12	16.4019	*
60	4.212	3.922	12	3.8725	*
75	4.413	2.171	12	7.3294	*
90	4.432	2.446	12	6.5328	*

APPENDIX G

T-TESTS, HORIZONTAL REACH

(ABLE vs. DISABLED SUBGROUPS)

APPENDIX G

RESULTS OF T-TEST PERFORMED ON THE HORIZONTAL REACH OF THE ABLE GROUP AND THE SUBGROUPS OF IMPAIRED

ABLE/NONE

Right Arm

Vertical Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
T	1.119	2.030	12	1.9864	*
0	.539	.558	12	3.4861	*
15	.312	.393	12	2.8621	*
30	- .111	.453	.2	- .8821	
45	- .638	.486	12	-4.7280	*
60	- .867	0.508	12	-6.1537	*
75	- .891	.433	12	-7.4117	*
90	-1.133	.469	12	-8.7152	*

Left Arm

T	1.89	.867	12	7.8561	*
0	1.045	1.557	12	2.4209	*
15	1.405	.683	12	7.4232	*
30	.683	3.228	12	.7630	
45	1.339	1.817	12	2.6557	*
60	.672	.579	12	4.1889	*
75	.469	.574	12	2.9460	*
90	.781	1.665	12	1.6910	

(continued)

ABLE/SLIGHT

Right Arm

Vertical Angle	$\overline{\Delta}$	S_{Δ}	DF	t	5% Significance
T	2.818	1.948	12	5.2154	*
0	2.797	.916	12	11.0046	*
15	2.931	.781	12	13.5307	*
30	2.748	.862	12	11.4938	*
45	2.562	.676	12	13.6728	*
60	2.675	1.315	12	7.3355	*
75	2.116	.693	12	11.0165	*
90	2.172	.531	12	14.7565	*

Left Arm

T	2.617	.886	12	10.6503	*
0	1.989	.905	12	7.9246	*
15	2.102	.836	12	9.0703	*
30	1.266	2.890	12	1.5798	
45	1.984	.908	12	7.8757	*
60	1.61	0.662	12	8.7637	*
75	1.314	.739	12	6.4088	*
90	1.152	.155	12	4.3472	*

(continued)

ABLE/MEDIUM

Right Arm

Vertical Angle	$\overline{\Delta}$	S_{Δ}	DF	t	5% Significance
T	8.128	3.355	12	8.7359	*
0	8.386	4.832	12	6.2581	*
15	8.194	3.588	12	8.2332	*
30	6.797	3.342	12	7.3330	*
45	7.558	4.426	12	6.1574	*
60	7.292	5.001	12	5.2565	*
75	10.752	7.237	12	5.3567	*
90	14.449	9.996	12	5.2274	*

Left Arm

T	4.883	1.1327	12	15.5437	*
0	4.488	1.038	12	15.5914	*
15	4.927	1.273	12	13.9558	*
30	3.902	3.244	12	4.3366	*
45	4.418	1.068	12	14.9201	*
60	4.298	0.959	12	16.1578	*
75	4.356	.681	12	23.0703	*
90	3.847	9.210	12	1.5060	*

(continued)

ABLE/SEVERE

Right Arm

Vertical Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
T	6.278	3.054	12	7.4113	*
0	7.852	2.449	12	11.5627	*
15	8.66	2.358	12	13.2430	*
30	8.789	2.380	12	13.3142	*
45	8.654	2.111	12	14.7840	*
60	8.036	2.242	12	12.9219	*
75	7.563	2.393	12	11.3972	*
90	7.712	5.168	12	5.3800	*

Left Arm

T	9.994	2.133	12	16.8937	*
0	11.942	2.854	12	15.0854	*
15	13.02	2.095	12	22.4083	*
30	13.085	3.622	12	13.0239	*
45	13.911	4.435	12	11.3092	*
60	15.524	3.941	12	14.2015	*
75	16.125	3.168	12	18.353	*
90	15.765	2.549	12	22.2971	*

APPENDIX H

T-TESTS, VERTICAL REACH

(ABLE vs. DISABLED SUBGROUPS)

APPENDIX H

RESULTS OF T-TEST PERFORMED ON THE VERTICAL REACH OF THE ABLE GROUP AND SUBGROUPS OF IMPAIRED

Able/None

Right Arm

Horizontal Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
L90	0.085	2.098	7	0.1146	
L95	0.335	0.621	7	1.5261	
L60	0.301	1.154	7	-0.7382	
L45	0.189	0.588	7	0.9076	
L30	0.504	0.915	7	-1.5578	
L15	0.548	1.037	7	-1.4927	
0	0.264	.726	7	-1.0280	
R15	0.668	.543	7	-3.4759	*
R30	0.426	.707	7	-1.7055	
R45	0.403	0.742	7	-1.5352	
R60	0.446	2.376	7	.5213	
R75	-0.124	.581	7	- .6028	
R90	-0.533	.372	7	-4.0537	

Left Arm

L90	1.415	2.312	7	1.7308	
L75	0.903	.349	7	7.3179	*
L60	0.093	4.158	7	.0629	
L45	0.508	.486	7	2.9564	*
L30	0.191	.561	7	.9648	
L15	0.783	.543	7	4.0748	*
0	0.316	0.819	7	1.0923	
R15	1.984	1.444	7	3.8869	*
R30	0.758	1.971	7	1.0871	
R45	1.276	1.057	7	3.4143	*
R60	1.443	.792	7	5.1509	*
R75	1.839	.380	7	13.7006	*
R90	1.978	.610	7	9.1702	*

(continued)

Able/Slight

Right Arm

Horizontal Angle	$\bar{\Delta}$	S_{Δ}	DF	t	5% Significance
L90	2.723	1.648	7	4.6724	*
L75	3.69	.596	7	17.5049	*
L60	2.983	.813	7	10.3710	*
L45	2.341	.390	7	16.9829	*
L30	3.065	1.208	7	7.1765	*
L15	2.503	0.772	7	9.1637	*
0	1.574	.488	7	9.1154	*
R15	2.051	0.837	7	6.9289	*
R30	2.205	.441	7	14.1461	*
R45	2.955	.698	7	11.9697	*
R60	3.815	.889	7	12.1400	*
R75	2.073	.352	7	16.6510	*
R90	1.854	1.281	7	4.0917	*

Left Arm

L90	1.449	.557	7	7.3632	*
L75	1.508	0.459	7	9.2851	*
L60	0.138	3.368	7	.1155	*
L45	0.898	.421	7	6.025	*
L30	1.154	.375	7	8.7003	*
L15	1.348	.498	7	7.6508	*
0	1.393	.863	7	4.5649	*
R15	1.706	.660	7	7.3090	*
R30	2.241	.789	7	8.0363	*
R45	1.603	1.592	7	2.8478	*
R60	3.321	.569	7	16.5221	*
R75	2.838	.363	7	22.1001	*
R90	2.758	.702	7	11.1117	*

(continued)

Able/Medium

Right Arm

Horizontal Angle	$\bar{\Delta}$	S_Δ	DF	t	5% Significance
L90	8.494	3.442	7	6.9804	*
L75	10.533	4.780	7	6.2329	*
L60	10.808	5.671	7	5.3903	*
L45	8.123	4.632	7	4.9601	*
L30	5.051	1.318	7	10.8420	*
L15	5.711	.779	7	20.7445	*
0	9.203	5.311	7	4.9009	*
R15	10.744	9.705	7	3.1312	*
R30	10.969	9.604	7	3.2305	*
R45	6.853	5.476	7	3.5397	*
R60	9.266	5.828	7	4.4973	*
R75	9.375	5.403	7	4.9078	*
R90	4.813	7.483	7	4.8133	*

Left Arm

L90	4.601	1.456	7	8.9416	*
L75	5.045	.805	7	17.7314	*
L60	4.24	6.406	7	1.8720	
L45	3.813	.829	7	13.0044	*
L30	3.304	1.066	7	8.7624	*
L15	3.901	0.492	7	22.4076	*
0	4.044	1.085	7	10.5465	*
R15	4.738	.642	7	20.8776	*
R30	4.971	0.610	7	23.0603	*
R45	5.281	.511	7	29.2350	*
R60	5.24	.715	7	20.7407	*
R75	5.66	.484	7	33.0984	*
R90	5.968	.766	7	22.0378	*

(continued)

Able/Severe

Right Arm

Horizontal Angle	$\bar{\Delta}$	S_{Δ}	DF	t	5% Significance
L90	3.478	2.143	7	4.5908	*
L75	7.873	1.238	7	17.9837	*
L60	7.375	1.245	7	16.7612	*
L45	8.329	1.170	7	20.1346	*
L30	8.729	1.087	7	22.7199	*
L15	9.123	1.188	7	21.7194	*
0	2.444	1.583	7	4.3671	*
R15	8.503	.985	7	24.4067	*
R30	9.026	0.952	7	26.8151	*
R45	10.034	1.727	7	16.4329	*
R60	9.591	1.732	7	15.6645	*
R75	10.141	1.771	7	16.1989	*
R90	9.865	1.640	7	17.0146	*

Left Arm

L90	15.536	3.975	7	11.0536	*
L75	19.478	2.255	7	24.4354	*
L60	14.65	5.369	7	7.7176	*
L45	15.896	3.828	7	11.7440	*
L30	14.543	3.609	7	11.3972	*
L15	13.176	2.170	7	17.1760	*
0	12.829	1.403	7	25.868	*
R15	12.825	1.564	7	23.2008	*
R30	12.816	1.489	7	24.3395	*
R45	11.869	1.291	7	26.0116	*
R60	12.596	2.397	7	14.8631	*
R75	11.031	2.730	7	11.4291	*
R90	12.083	3.006	7	11.3671	

APPENDIX I

DATA TRANSLATION

APPENDIX I

TRANSFORMATION OF MEASUREMENTS TO THE STANDARD REFERENCE VERTICAL

In order to standardize the data, the initial calibrating measurement that resulted in SA distance was transformed to the standard reference vertical (SRV). This was accomplished by converting or transforming the SA distance to a parallel position which passes through the center of the seat, as can be seen in figure I1. Note that the seat reference point (SRP), point P, is located in the 0 degree horizontal position at the time SA distance is translated. This is done for convenience of explanation only, and should not be considered a necessary condition for translating SA. Part B of figure I1 illustrates this point.

In the 0 degree horizontal position, transforming SA to the SRV is accomplished by adding length SA to length OP. Length OP is constant for the type of chair being used. For the regular chair, OP is 4.625 inches, and for the wheelchair OP is 6.5 inches. The following is an example of the translation of SA to the SRV. Assume length SA is measured to be 40 inches, and we are using the standard chair where OP is 4.625 inches. Following the procedure just mentioned, we have (OP) + (SA) = 4.625 + 40 = 44.625 inches. This new quantity is designated R in order to distinguish it from the original shoulder to arc distance measurement SA. For other horizontal positions, the transformation is not achieved so readily.

In horizontal positions other than 0 degrees, a slightly more complicated transformation is required. By translating SA in the same manner as indicated, and by using the constant SRP value for each type of

chair, the transformation equation takes the form of the conventional Law of Cosines. Lengths SA and OP, when geometrically joined, form two sides of a triangle. A resultant is produced by joining the other end points of SA and OP, thus forming the third side of the triangle. This resultant, we have designated R, is the distance from the SRV to the leading edge of the 0 degree vertical block. It is also the distance for all vertical blocks 0 through 90 degrees. The length of resultant R may be calculated by using the known information, the two sides, and an included angle. This allows the use of the Law of Cosines for calculating $R = \sqrt{a^2 + b^2 - 2ab \cos c}$, R is the distance of the resultant, a is the distance OP, b is the distance SA, and c is the angle formed by the intersections of OP and SA. Using the same example as we did earlier, where the distance (SA) = b was assumed to be 40 inches, (OP) = a = 4.625 inches, and c, the angle formed by (OP) and (SA) = 180 degrees.

$$
\begin{aligned}
R &= \sqrt{(OP)^2 + (SA)^2 - 2[(OP)(SA)]\cos c} \\
&= \sqrt{(4.625)^2 + (40)^2 - 2(4.625)\ (40)\cos 180} \\
&= \sqrt{1621.391 - 370(-1)} \\
&= \sqrt{1991.391} \\
&= \quad 44.625 \text{ inches}
\end{aligned}
$$

This is the same distance arrived at earlier. To obtain R for the other horizontal positions, the angle used will vary according to the chair position under study as shown in the table I1. Note the symmetry that is present. For example, the cosine of 270 degrees equals the cosine of 90 degrees.

Chair Position (degrees)	Angle c (degrees)
Left 90	270
75	255
60	240
45	225
30	210
15	195
0	180
Right 15	165
30	150
45	135
60	120
75	105
90	90

Note: observe the symmetry that is involved.

Table I1. Values of Angle c for Chair Positions Shown.

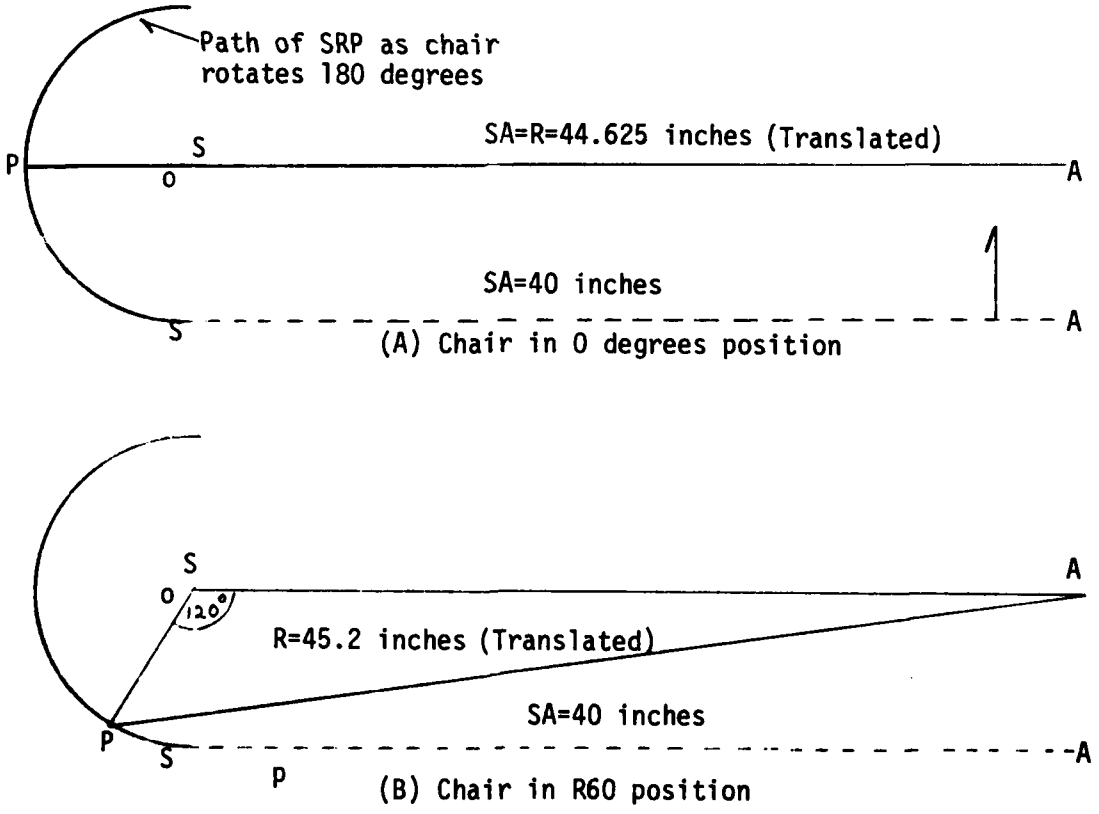


Figure I1 Geometric presentation of Translation Method

VITA

LUCKY ARLAN GOEBEL

Born: January 16, 1943 Place of Birth: Scottsbluff, Nebraska

Parents: Ms. Grace Bartlett
Mr. William Goebel

Educational Background:

Texas A&M University, College Station, Texas
Master of Science--Industrial Engineering,
December 1978

New Mexico State University, Las Cruces, New Mexico
Bachelor of Science--Industrial Engineering,
December 1973

University of Alaska, Anchorage, Alaska

Honors:

Alpha Pi Mu (Industrial Engineering honor fraternity),
New Mexico State University

Military Service:

Enlisted in the United States Air Force June, 1961.
Commissioned as a Second Lieutenant April 2, 1974.
Currently serving in the grade of Captain in the
Regular Component of the U.S.A.F.

Typist: Jan Bertch