HUMAN DIMENSION & INTERIOR SPACE

A SOURCE BOOK OF DESIGN REFERENCE STANDARDS

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DEDICATION

To that small group of anthropologists specializing in the field of engineering anthropometry, without whose expertise, vision, and sensitivity to the importance of human dimension and its relationship to the design process this book certainly could not have been written.

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FOREWORD

Over the past 30 years, physical anthropologists have been concerned with the documentation and description of human body size variability and its application to design. A significant problem continues to exist, however, in the communication of such knowledge to the wide variety of potential users, the design community.

The diversity of this group of users is broad, ranging from designers of workspaces such as aircraft cockpits or offices, through pattern makers and clothiers, to designers of respirators and other personal protective equipment. Equally as diverse are the needs of the users. For example, a designer of an office has little use for a dimension such as neck circumference, while a clothier or pattern maker may consider it vital. Furthermore, users often need information about different segments of the population, perhaps about children, coal miners, college students, office workers, factory workers, etc., and each user may require a different type of analysis or data presentation. It is, therefore, extremely helpful for the anthropologist to communicate effectively with each of the many specialists within the specific framework of their particular design problems.

It is thus very gratifying to find that the authors of this book, both experienced professionals in their field, have taken on the complex task of bridging the gap not only by bringing to architects and interior designers much valuable anthropometric information in usable form but, more importantly, by conveying so persuasively the concept that untapped resources of relevant body size information exist and that its use has much potential impact on the improvement of workspace and residential design. In their presentation, the authors strike an excellent balance, avoiding the pitfalls of overwhelming the reader with needless technical complexities and resisting the simple-minded approach which has so often in the past conveyed the mistaken impression that a few tables of summary values will provide the answers to specific design problems.

I have long been an advocate of relating the basic anthropometric data to a specific designer's needs, and the authors' clear treatment for a special audience is particularly gratifying. The real beneficiaries, ultimately, will be office workers, small children, and handicapped persons, to name but a few of the many consumer groups with specialized needs.

John T. McConville, Ph.D.
Anthropology Research Project, Inc.

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Without certain published anthropometric information, this book could not have been written. For this, we would like to express our appreciation to Dr. Howard Stoudt, formerly of the Harvard School of Public Health, and his colleagues, who in conjunction with Jean Roberts of the U.S. Public Health Service prepared a study of the weight, height, and selected body dimensions of adults. This study now constitutes one of the most current and comprehensive sources of published anthropometric data on the civilian population. Our adaptation and metrication of this survey serves as the basis for many of the design reference standards developed in Part C of the book. We would also like to thank Dr. Stoudt, presently a member of the faculty of the department of community health science at Michigan State University, for the additional data he shared with us and for the encouragement he provided during the early stages of the preparation of this book.

With respect to published anthropometric information, we would be remiss in our acknowledgment if we did not mention the three-volume Anthropometric Source Book, brilliantly compiled and edited for the National Aeronautics and Space Administration by Dr. John McConville and his colleagues at the Anthropology Research Project, Inc., Yellow Springs, Ohio.

The Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, has also served as a fountainhead of information. We are indebted to Charles E. Clauser, who is presently responsible for the U.S. Air Force's Anthropometry Program, and his colleagues, Dr. Kenneth Kennedy and Milton Alexander, for their comments and encouragement and for making some of their data available to us.

We would also like to express our appreciation to three distinguished human factors engineers whose stimulating articles and books relating to anthropometry and human factors roused our interest and curiosity in investigating the architectural and interior design applications of anthropometric data: Archie Kaplan, Charles Mauro, and Wesley Woodson.

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On a more personal note, our amazement and gratitude must be expressed to Jamie Panero, the young son of one of the authors, who with the tenacity of purpose of a graduate research assistant helped in gathering data and was responsible for the metrication of much of the data. A special tribute must also be made to a former student of interior design of both authors, Pamela Kingsbury, who has shouldered the major responsibility for the illustrations, graphics, charts, and layouts. Not only has her technical skill and resourcefulness been of the highest quality, but her unending allegiance to the development of this project has transcended any human understanding of the term "dedication."

PREFACE

A potential danger in writing a book of this type is dealing with an area of study too large to be treated satisfactorily. Human dimension and interior space, by its very nature, is quite conducive to such an error in judgment. No great leap of the imagination is required to acknowledge the multitude of disciplines implied: ergonomics, anthropometry, biomechanics, architecture, interior design, environmental psychology. The list is almost endless. Each discipline and subareas of those disciplines could in themselves all qualify as legitimate topics for an entire network of books.

The problem, therefore, is to avoid erring in the direction of too large an area of study and risking superficiality or to treat the subject within too narrow a frame of reference by limiting the material too severely. We are hopeful that we have avoided these obvious pitfalls. The measure of success, however, can best be determined within the context of the purpose of this book.

The architectural and interior design professions have an abundance of reference material dealing with general planning and design criteria. Not enough of this material, however, addresses itself specifically to the actual physical fit, or interface, between the human body and the various individual components of interior spaces. Of the available material, much is based almost exclusively on trade practices, many of which are outdated, or on the personal judgments of those preparing the standards. With few exceptions, most reference standards are simply not predicated on enough hard anthropometric data.

This is understandable, given the minimal amount of such data available, the form in which most of these data are presented, the general inaccessibility of such data to the interior designer and architect, and, until very recently, the lack of centralized reference sources for such information. In partial defense, however, of the pragmatic approach underlying the preparation of much of the design standards currently in use, it should be recognized that the use of anthropometric data is no substitute for good design or sound professional judgment. It should be viewed as one of many design tools.

Within recent years and arising out of the pressing need for such information on the part of the equipment designer, industrial designer, and human factors engineer, anthropometric data have become more available. Not all the data are necessarily presented in the form most appropriate for use by the architectural or interior design professions. Nor are all the data necessarily applicable to the nature of the particular design problems peculiar to these professions. Moreover, its availability is still in terms of sources relatively foreign to the architect and interior designer and requires referral to a large variety of such sources for what data there are.

The important fact, however, is that anthropometric data are slowly becoming more available, both on a national and international basis. As the world population continues to grow, as our explorations of outer space increase, as international trade and marketing of services and products expands, and as society generally places more priority on the quality of life, it is expected that the inventory of such data will become even more abundant. Architects and interior designers should avail themselves of these data and become more knowledgeable concerning its applicability to the design process. In addition, they should provide the anthropometrist with input, relative to the type and form of data the profession requires.

In elaborating on the role industrial designers will play in the future development of engineering anthropometry, Mauro indicates the thrust of that role "is in defining their needs in terms that the research anthropometrist can understand." The same should apply to the architect and interior designer.

The general objectives of this book, therefore, are as follows:

1. To develop an awareness on the part of the architect, interior designer, builder, manufacturer, and user of the importance of anthropometry as it relates to human fit and interior space.
2. To provide the architect and interior designer with a basic understanding of anthropometry and the nature, origins, limitations, and proper application of the data involved.
3. To provide the architect and interior designer with a source of the anthropometric data relevant to the nature of those design problems most frequently encountered by those professions and to present those data in an appropriate form.
4. Based on these anthropometric data, to provide the architect and interior designer with a series of graphic design reference standards, involving the interface of the human body with the physical components of some of the prototypical interior spaces in which people live, work, or play.

Accordingly, the book is divided into three major sections. *Part A* familiarizes the architect and interior designer with the elements of anthropometry in terms of theory, limitations, and application. In addition, the special anthropometric problems of physically handicapped and elderly people and of seating are also discussed. *Part B* consists exclusively of hard anthropometric data in the form of tables and related illustrations. *Part C* consists of a series of design reference standards. These standards are in the form of plans and sections of prototypical interior spaces, showing the proper anthropometric relationship between the user and the space.

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During the course of developing the necessary research for this book, we found that many of our reasons concerning the need for the architect and interior designer to utilize anthropometric data as a tool in the design process were continually and in some instances, dramatically, reinforced. The urgency for so doing became ever more apparent. We wanted to share some of what we learned and also offer some suggestions for appropriate action that might be taken. Accordingly, the Epilogue contains some jolting examples of how insensitivity to human dimension in the design of various aspects of interior space can result not only in discomfort to the user but, in certain cases, in bodily injury and even death.

INTRODUCTION

The fascination of philosophers, artists, theoreticians, and architects with human body size dates back many centuries. In the only complete treatise on architecture surviving from antiquity, Vitruvius, who lived in 1st century B.C. Rome, wrote:

> For the human body is so designed by nature that the face, from the chin to the top of the forehead and the lowest roots of the hair, is a tenth part of the whole height; the open hand from the wrist to the tip of the middle finger is just the same; the head from the chin to the crown is an eighth, and with the neck and shoulder from the top of the breast to the lowest roots of the hair is a sixth; from the middle of the breast to the summit of the crown is a fourth. If we take the height of the face itself, the distance from the bottom of the chin to the underside of the nostrils is one third of it; the nose from the underside of the nostrils to a line between the eyebrows is the same; from there to the lowest roots of the hair is also a third, comprising the forehead. The length of the foot is one sixth of the height of the body; of the forearm, one fourth; and the breadth of the breast is also one fourth. The other members, too, have their own symmetrical proportions, and it was by employing them that the famous painters and sculptors of antiquity attained to great and endless renown.
>
> . . . Then again, in the human body the central point is naturally the navel. For if a man be placed flat on his back, with his hands and feet extended, and a pair of compasses centred at his navel, the fingers and toes of his two hands and feet will touch the circumference of a circle described therefrom. And just as the human body yields a circular outline, so too a square figure may be found from it. For if we measure the distance from the soles of the feet to the top of the head, and then apply that measure to the outstretched arms, the breadth will be found to be the same as the height as in the case of plane surfaces which are perfectly square.[1]

Not only was Vitruvius concerned with proportions of the body, but with their metrological implications. In alluding to Greek temple design he tells us, "Moreover, they collected from members of the human body the proportionate dimensions which appear necessary in all building operations, the finger or inch, the palm, the foot, the cubit.[2]

During the Middle Ages, Dionysius, monk of Phourna of Agrapha, wrote of man's body size as "nine heads tall,"[3] and Cennino Cennini,

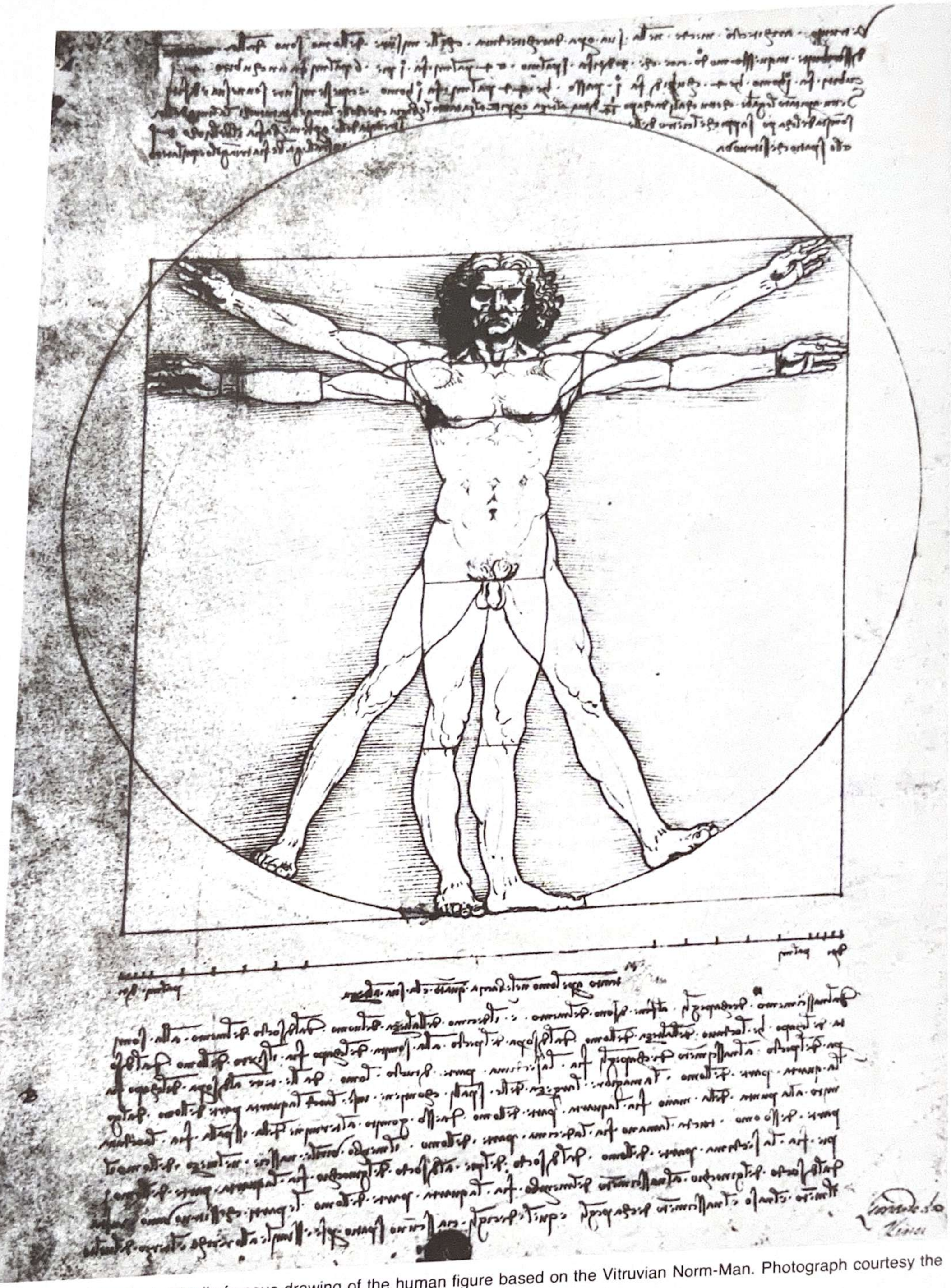


Figure I–1. Leonardo da Vinci's famous drawing of the human figure based on the Vitruvian Norm-Man. Photograph courtesy the Bettmann Archive, Inc.

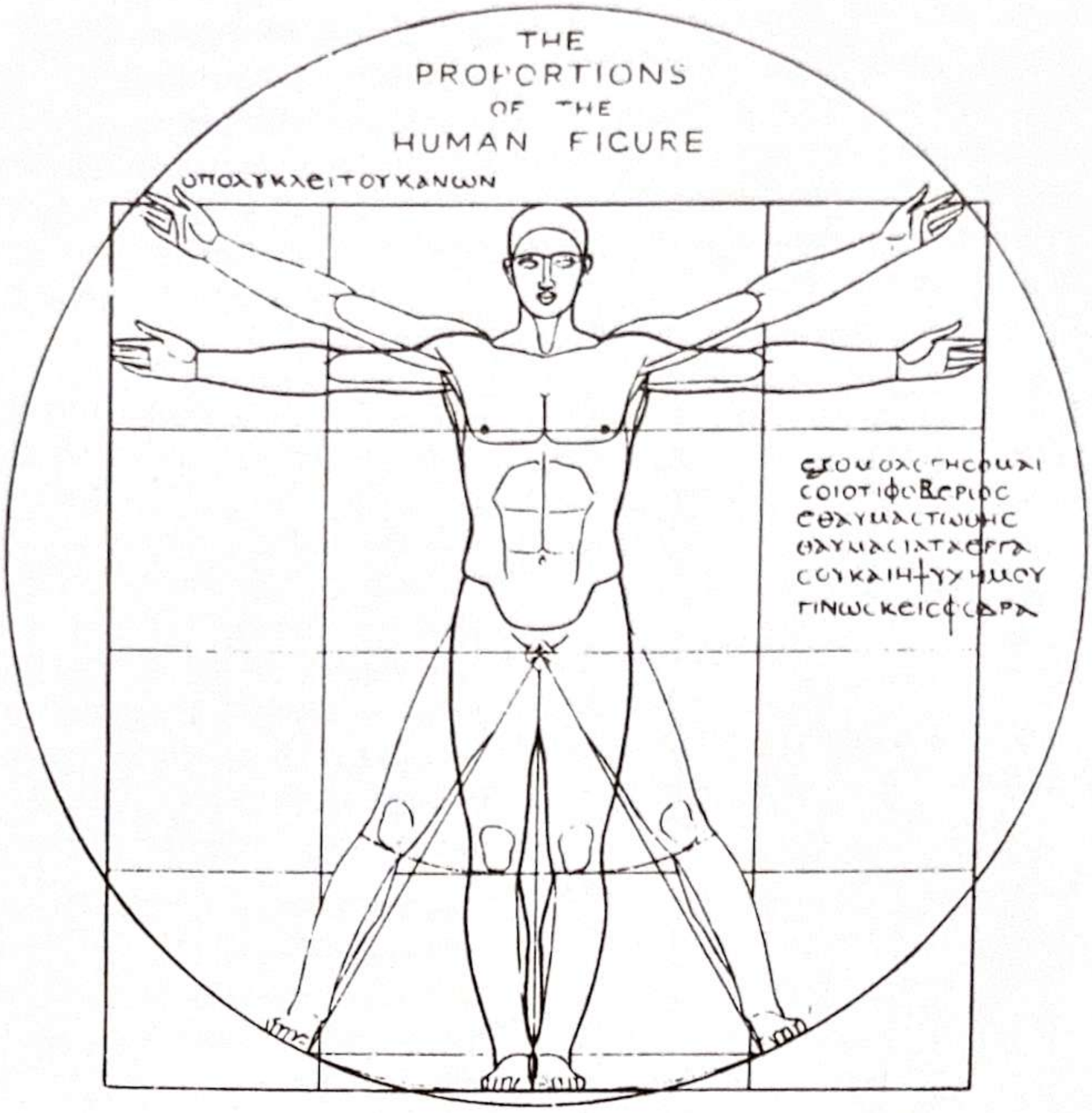


Figure I–2. Vitruvian Man by John Gibson and J. Bonomi, London, 1857.

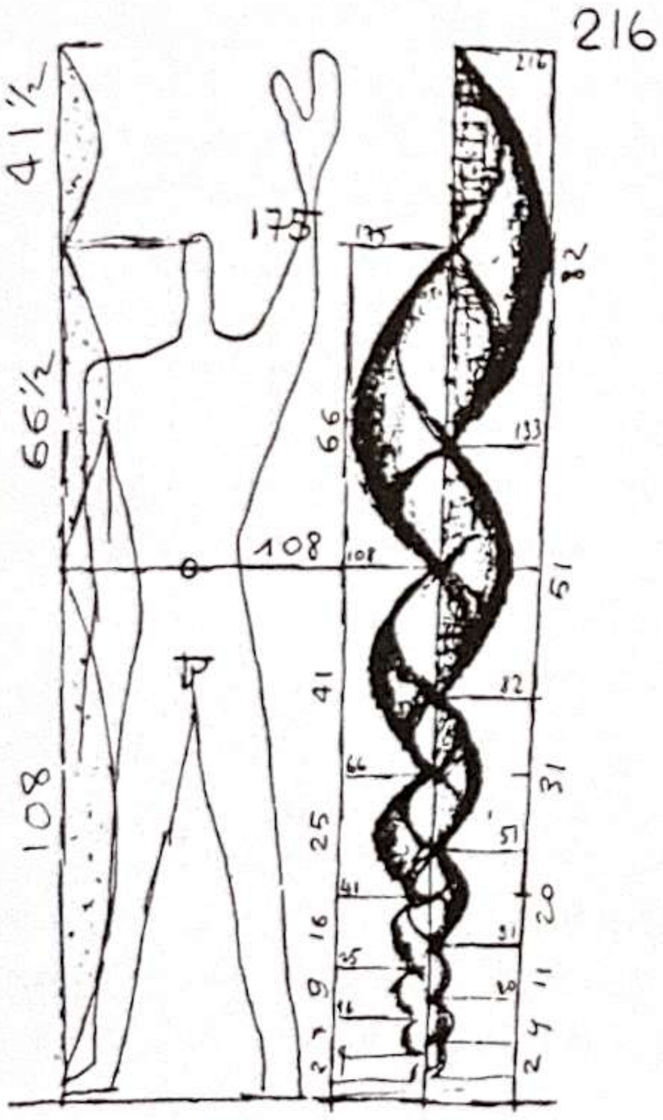


Figure I–3. Modular figure by Le Corbusier.

a 15th-century Italian, described the length of a man as equal to his width with arms extended.[4] During the Renaissance, Leonardo da Vinci created his famous drawing of the human figure, based on the Vitruvian norm-man (Figure I-1). In the mid-19th century John Gibson and J. Bonomi were also to reconstruct the Vitruvian figure (Figure I-2), and later, more than 2000 years after Vitruvius wrote his ten books on architecture, Le Corbusier was to revive interest in the Vitruvian norm with his creation of Modular No. 1 (Figure I-3).

No discussion of body size and proportion, however, would be complete without mention of the so-called Golden Section, the name given in the 19th century to the proportion derived from the divisions of a line into what Euclid in 300 B.C. Greece called "extreme and mean ratio."[5] According to Euclid, a line is cut in such a ratio only when the "whole line is to the greater segment, so is the greater to the less." Although three terms, at least, are required for any proportion, what is unique about the Golden Section is that the third term of the proportion is equal to the sum of the other two.

So fascinating was this notion of the Golden Section that in the early part of the 16th century, Luca Paccoli, a close friend of Leonardo and probably the most famous mathematician of the time, wrote a book about it called *Divina Proportione*[6] (divine proportion) in which he endowed the Golden Section with many varied mystical properties in both science and art. He contended, for example, that he could detect "an aesthetic principle which is found in architectural forms, in the human body, and even in the letters of the Latin alphabet."[7]

It has been claimed that the proportion of the so-called Golden Section is far superior to all other proportions. Actual experiments are

said to indicate a preference, on the part of most people, for those proportions closest to Euclid's extreme and mean ratio. While it was employed as a conscious element in architectural design during the Renaissance, the architecture of antiquity, as well as that of the Middle Ages, may also have been designed according to the proportion of the Golden Section. More recently, its most enthusiastic supporter was Le Corbusier, who in 1948 wrote a book dealing with proportions based on it.

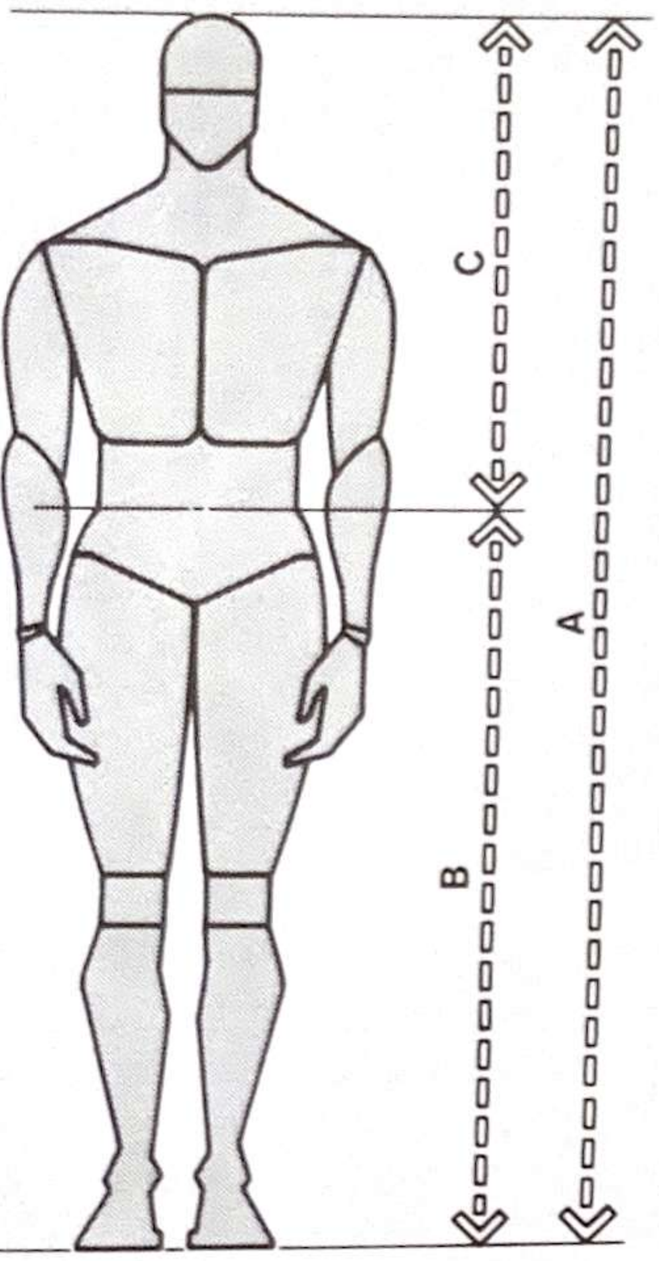


Figure I–4. The human body and the Golden Section.

The most fascinating observation about the Golden Section, however, involves the human figure. If a horizontal line is drawn through the navel, three different body measurements are produced, as illustrated in Figure I-4. One represents stature, or the distance from the top of the head to the floor. Another represents the distance from the navel to the floor, while the third represents the distance from the top of the head to the navel. It is contended that if actual measurements are substituted for the letters indicated, the ratio of stature to the height of the navel above the floor usually approximates 1.618. The proportion of the three measurements conforms fairly closely to Euclid's extreme and mean ratio.

Despite Vitruvius's attempts to relate the human body to the system of measurements employed by the Greeks in the design of temples, humanity's basic concern with the human figure historically has been more aesthetic than metrological, more involved with proportion than with absolute measurements and function. Over the last several decades, however, concern for human dimensions and body size, as critical factors in the design process, has steadily increased. Nowhere has this concern been greater than in the field of *human factors engineering*, as it is called in the United States, or *ergonomics*, as it is referred to in Europe. It should be noted, however, that concern for body size is only one of several areas of interest to the human factors engineer, or ergonomist, due to the extremely complex nature of those disciplines. According to one definition, "human engineering (human factors engineering, ergonomics, biotechnology) is not a single scientific discipline but a synthesis which integrates the biological sciences—psychology, anthropology, physiology, and medicine—with engineering."[8]

Ergonomics has been defined in one instance as "the technology of work design" that "is based on the human biological sciences: anatomy, physiology and psychology."[9] In another instance, it is defined more simply as "an interdisciplinary science which studies the relationships between people and their environments."[10] Most agree that both terms "human engineering" and "ergonomics" may be used interchangeably, and during the course of this book, both terms will be so used.

The application of human factors engineering has been typically associated with highly complex and limited technological problems in machine and equipment design. The problems have usually involved relatively sophisticated man-machine interface situations: the design of control centers, aircraft cockpits, electronic consoles, and endless numbers and types of military air, ground, and sea vehicles. Yet today human factors engineering relates to the civilian sector as well. The design of consumer products, work environments, transportation vehicles, to name a few, all require human factors input.

The field was given enormous impetus during the Second World War due to the compelling need to reconcile human capabilities with the technological sophistication of military equipment. The possibility of human error had to be eliminated. Equipment had to be operated at maximum efficiency under the most trying of circumstances. Problems facing the ergonomist ranged in complexity from a simple control, such as the push button, to complicated console designs for use under battle conditions. More recently, the ergonomist has had to cope with physiological, psychological, and anthropometric (the study of human body measurement, which will be thoroughly discussed in Part A) aspects of design problems inherent in space travel. Of greatest significance, however, was the basic realization and acceptance of the idea that consideration of human factors constituted an integral part of the design process.

Among the most important of these human factors is body size and dimension as it relates to the so-called ergonomic fit, or the *ergofitting*, of the user to the environment—one aspect of the so-called man-machine interface to which the ergonomist constantly alludes.

Most applications of human engineering have, in fact, been in the industrial and military sectors. Unfortunately, the more mundane applications, such as those found in the design of the interior spaces within our homes, offices, health facilities, schools, etc., have been relatively ignored. This is particularly ironic since much of the underlying philosophy of human engineering is based on the premise that everything is designed for people. Where else can the concept of "designing from the man, out" make more sense than in the field of architecture and interior design?

It is the purpose of this book, therefore, to focus on the anthropometric aspects of ergonomics and to apply the related data to the design of interior spaces. The application will take the form of anthropometrically oriented design reference standards structured to ensure a proper ergofitting of people to the interior environments in which they may live, work, or play. These interior environments are all utilized by individuals of varying body sizes, weight, age, and physical condition. On a global basis, users may also reflect a wide range of races, cultures, and ethnic backgrounds.

Despite the variables involved, however, the interface between the user and the designed interior environment, or ergofit, must ensure comfortable, safe, and efficient enjoyment of that environment. Work surface heights in a kitchen, office, or home workshop; allowances for seating around a dining or conference table; heights for shelves in an apartment or library; corridor widths in a home or public building—all must reflect the human factor of body size. In certain situations, we are, for a number of reasons, required to design for a large mixed user population. At the other extreme, we may be obligated to design for a single user. In still other situations, the user may constitute a specific group—young children, elderly people, college students, physically disabled people, etc. It is obvious that if we are tc respond responsibly and sensitively to the design needs of the user, we must become more aware of the metrology of body size and its ergonomic implications.

A HUMAN DIMENSION/ ANTHROPOMETRICS

1 ANTHROPOMETRIC THEORY

1.1 ANTHROPOMETRY

People's historic involvement with body size was discussed in the Introduction. However, the science dealing specifically with the measurement of the human body to determine differences in individuals, groups, etc., is termed *anthropometry*. Pioneering work in this field dates back to the Belgian mathematician, Quetlet, who in 1870 published his *Anthropometrie* and is credited not only with founding and formalizing the science, but also with having created the term "anthropometry" itself. The origins of physical anthropology can be traced even further back to the late 18th century and Linne, Buffon, and White, who first developed the science of comparative racial anthropometry.

During the course of time, a significant amount of anthropometric data has been amassed. Unfortunately for the designer, however, the thrust of much of the efforts in this area was for taxonomic purposes, physiological studies, etc., and not primarily for the ergonomic implications of body size. It was not until the 1940s that the need for anthropometric data, generated in a variety of industrial fields, but primarily in the aircraft industry, began to develop and increase. The Second World War naturally provided much of the impetus, and even today it is in the military-industrial sector that much of the anthropometric research is generated. Although the discipline has fallen within the purview of the anthropometrist, anatomist, or ergonomist, it is time for the architect and interior designer to become more aware of the data available and its applicability to the design of interior spaces.

If anthropometry is viewed mainly as exercises in simple measurement and nothing more, one might conclude that the dimensional data could be gathered simply and effortlessly. Nothing, however, could be further from the truth. There are many complicating factors and difficulties involved. One such factor is that body sizes vary with age, sex, race, and even occupational group. For example, Chart 1-1 shows statistics on the statures (body height) of samples from various national groups. The variation in stature is quite significant, ranging from 160.5 cm, or 63.2 in, for the Vietnamese to a high of 179.9 cm, or 70.8 in, for the Belgian—a range of 19.4 cm, or slightly more than 7.5 in.

Sample	Date	N	Age[a]	Stature	
				Mean	SD
Republic of Vietnam Armed Forces	1964	2,129	27.2	160.5	5.5
Thailand Armed Forces	1964	2,950	24.0	163.4	5.3
Republic of Korea Army	1970	3,473	24.7	164.0	5.9
Latin America Armed Forces (18 countries)	1967	733	23.1	166.4	6.1
Iran Armed Forces	1970	9,414	23.8	166.8	5.8
Japan JASDF pilots	1962	239	24.1	166.9	4.8
India Army	1969	4,000	27.0	167.5	6.0
Republic of Korea ROKAF pilots	1961	264	28.0	168.7	4.6
Turkey Armed Forces	1963	915	24.1	169.3	5.7
Greece Armed Forces	1963	1,084	22.9	170.5	5.9
Italy Armed Forces	1963	1,358	26.5	170.6	6.2
France Flight personnel	1955	7,084	18-45	171.3	5.8
U.S. Army WWI demobilization	1921	96,596	24.9	172.0	6.7
Australia Army	1970	3,695	21.0	173.0	6.0
U.S. civilian men Nat'l. Health Survey	1965	3,091	44.0	173.2	7.2
U.S. Army WWII separatees	1951	24,508	24.3	173.9	6.4
U.S. Army Ground troops	1971	6,682	22.2	174.5	6.6
U.S. Army Aviators	1971	1,482	26.2	174.6	6.3
Fed. Rep. of Germany Army tank crews	1965	300	22.8	174.9	6.1
U.S. Air Force Flight personnel	1954	4,062	27.9	175.5	6.2
United Kingdom RAF and RN air crew	1968	200	28.7	177.0	6.1
United Kingdom RAF pilots	1965	4,357	—	177.2	6.2
U.S. Air Force Flight personnel	1972	2,420	30.0	177.3	6.2
Canada RCAF pilots	1965	314	—	177.4	6.1
Norway Young men	1964	5,765	20.0	177.5	6.0
Belgium Flight personnel	1954	2,450	17-50	179.9	5.8

[a] Mean values except where ranges are given.

Chart 1–1. Statistics on the statures in centimeters and certain other characteristics of 26 samples. From Chapanis, *Ethnic Variables in Human Factors Engineering*.

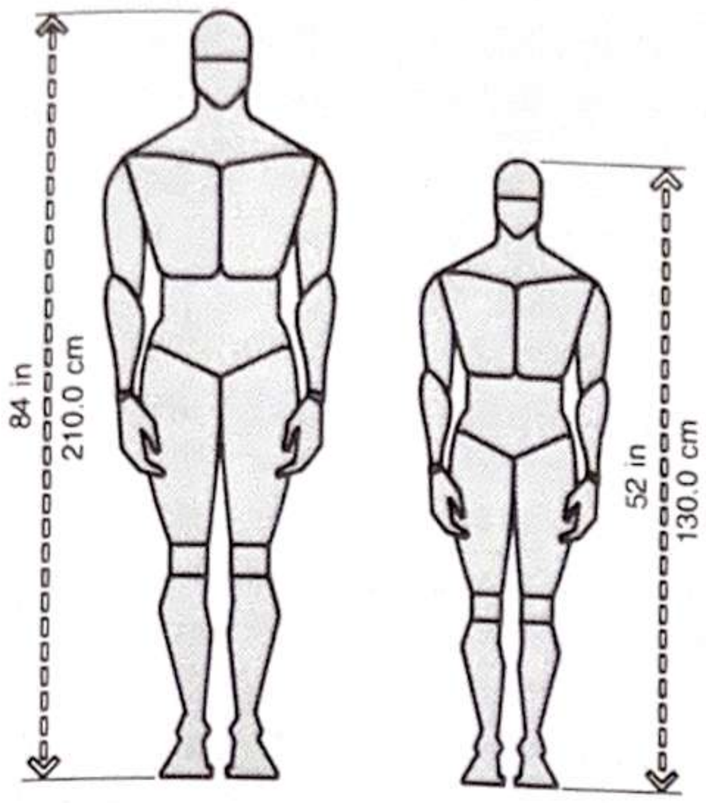


Figure 1–1. Comparison of difference in stature of the tallest Northern Nilote of Southern Sudan with the stature of the smallest Pigmy of Central Africa. Data from Chapanis, *Ethnic Variables in Human Factors Engineering.*

Perhaps an even more dramatic example of ethnic variability, however, is a comparison of the difference in stature of the smallest males on record with the largest, as shown in Figure 1-1. D.F. Roberts notes that the former, the Pigmies of Central Africa, have a mean stature of 143.8 cm, or about 56.6 in, while the tallest males, for whom records are available, are the Northern Nilotes of Southern Sudan, with a mean stature of 182.9 cm, or 72 in—a range of 39.1 cm, or about 15.4 in.[1]

Age is another significant factor in body size. Full growth, with respect to body dimensions, peaks in the late teens and early twenties for males and usually a few years earlier for females. Subsequent to maturity, body dimension for both sexes actually decreases with age, as illustrated in Figure 1-2. In terms of the anthropometry of elderly people, a study in England suggested that body size of elderly women was smaller than the body size of young women. It was also pointed out, however, that to some extent the difference could be attributable not only to the fact that the elderly sample was obviously drawn from an earlier generation but to the aging process itself. Another conclusion of the study was the reduction in upward reach among elderly people.

Socioeconomic factors also impact significantly on body dimensions. The nutrition available to those with higher incomes creates, for example, freedom from childhood disease and contributes to body growth, as illustrated in Figure 1-3. Socioeconomic status also reflects a relationship to the availability of higher education. Accordingly, studies made of college students almost always indicate higher statures than noncollege individuals. Yet, within the same group, variations in body size are so significant that "averages" are not necessarily meaningful or sufficient. To all this must be added such other considerations as the actual physical conditions under which

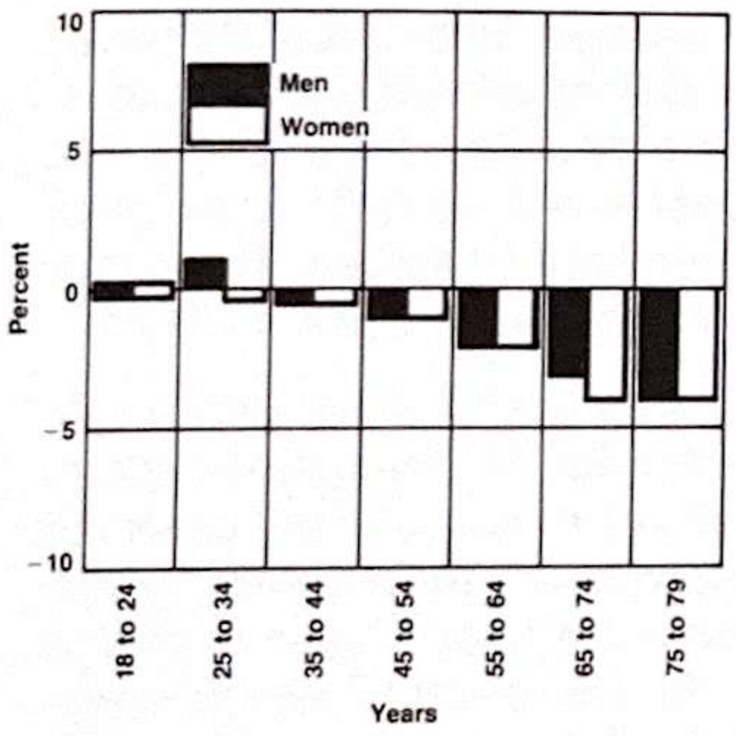


Figure 1–2. Relative change in height with age over the mean for men and women aged 18–24 years. Data from National Health Survey.

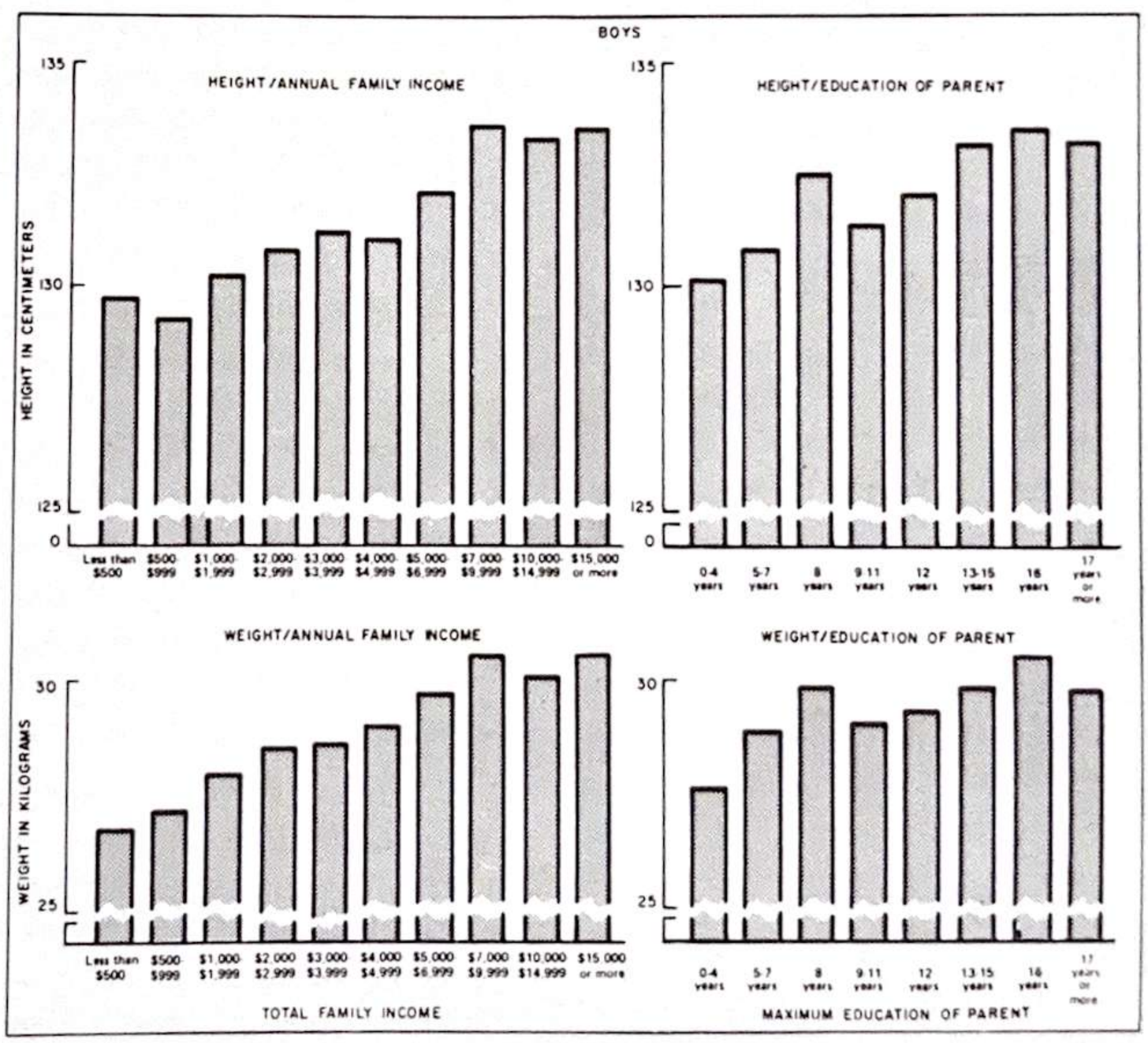


Figure 1–3. Bar graphs showing mean height and weight for U.S. children 6 to 11 years by annual family income and education of parents. Data from National Health Survey.

data are recorded. Was the subject clothed or nude? If clothed, was the clothing light or heavy? Was the subject barefooted?

Although there have been some national and international attempts at standardization among anthropometrists, with regard to terminology and definitions, the lack thereof very often complicates the interpretation and significance of the data recorded. Studies, therefore, must often include descriptions of techniques used and diagrams necessary to clearly define the actual points from which measurements were taken. There is no doubt that anthropometric studies are no less sophisticated or tedious than other investigations in the biological sciences. When one considers that the anthropometrist must also be knowledgeable in the area of statistical methodology, the complexity and tediousness of the discipline is underscored even more. It is also obvious that those individuals taking and recording body measurements must be properly trained.

To the interior designer, architect, and industrial designer, however, it should be evident that the same factors that contribute to the complexity and tediousness of the discipline of anthropometry also necessitate a very cautious approach in the application of the data generated. It is essential, therefore, that the designer have some understanding of anthropometrics, its basic vocabulary, the nature of the data available, the forms in which it is usually presented, and the restraints involved in their application.

1.2 SOURCES OF DATA

Generally, the collection of anthropometric data is a costly, time-consuming, and relatively cumbersome undertaking, requiring skilled observers, particularly if the objective is to obtain a truly representative national sampling. Accordingly, most of the research in this area has been related to the military rather than the civilian sectors of the world's population. The reasons are obvious. First, it is within these sectors that a compelling need for anthropometric data exists in order to properly equip and clothe the respective armies, navies, and air forces. Second, there exists a national and almost infinite reservoir of available subjects. Third, the funds to implement the studies are committed and made available by the governments involved.

The basic disadvantage in mass military surveys of this kind is usually the restrictions of sex and age. In addition, the measurements have often been limited to height and weight and in many instances have been gathered by unskilled observers. In 1919, however, a survey was made of some 100,000 American troops upon discharge from the service. Reportedly, it was the first study to include measurements other than height and weight.[2] The study was intended for use as a guide in the design of clothing but was never actually used for that. It did, however, during the period between the First and Second World Wars, serve as a standard description of U.S. males.

Most of the early and more successful applications of anthropometry to design actually took place during the Second World War and were predicated on studies prepared by the United States Air Force, the Royal Air Force, and the British Navy. Apparently, this period was a turning point because since that time, the United States, in addition to many other countries, has conducted extensive military an-

thropometric studies. A 1946 study by Randall, Damon, Benton, and Patt, "Human Body Size in Military Aircraft and Personnel Equipment," has been cited as a major contribution in this area.[3]

Relatively few civilian anthropometric surveys, however, have been taken. Perhaps the most current and complete study of the civilian population of the United States—the National Health Survey—was prepared for the Department of Health, Education, and Welfare (HEW) by Dr. Howard W. Stoudt, Dr. Albert Damon, and Dr. Ross McFarland formerly of the Harvard School of Public Health and Jean Roberts of the U.S. Public Health Service.[4] This study involved a nationwide probability sample of over 7500 nonmilitary and noninstitutionalized people between the ages of 18 and 79 years, of which 6 672 were examined.

Most anthropometric research, nevertheless, is still being done for the military. All branches of the service have active programs, and in many instances will share their data with professionals in the private sector. An excellent example is the three-volume *Anthropometric Source Book* published by the National Aeronautics and Space Administration. This book is probably the most comprehensive source of summarized body size data currently in existence anywhere in the world.[5] Appendix 1 lists military anthropometry laboratories, as well as other national and international sources of anthropometric data. The designer should use the data cautiously and, in instances where the nature of the design problem requires more sophisticated data, consult with a qualified professional in the field of anthropometry.

1.3 TYPE OF DATA

Human body dimensions that impact on the design of interior spaces are of two basic types—structural and functional. *Structural* dimensions, sometimes referred to as "static" dimensions, include measurements of the head, torso, and limbs in standard positions. *Functional* dimensions, also referred to as "dynamic" dimensions, as the term suggests, include measurements taken in working positions or during the movement associated with certain tasks. The former are simpler and more readily obtained, while the latter are normally far more complicated. Figures 1-4 through 1-6 illustrate the basic anthropometric instruments usually employed in the measurement of body parts and their use. There are more sophisticated measuring devices and techniques, such as multiple probe contour devices, photometric camera systems, andrometric camera systems, stereophotogrammetry, but their use is not presently widespread.

A glance at any anatomy textbook is sufficient to suggest the endless number of body dimensions possible. One recent publication contains almost one thousand measurements.[6] The number of possibilities and the exotic medical terminology involved can be somewhat intimidating for the designer. For example, the "crinion-menton" is the term for the distance between the hair line in the middle of the forehead and the midpoint of the lower edge of the chin, while the "menton-supramentale" is the distance from the angle between the chin and the lower lip to the lower edge of the chin. Such data might be extremely useful to a designer of a helmet for a pressurized spacesuit, but would be of little value to an interior designer.

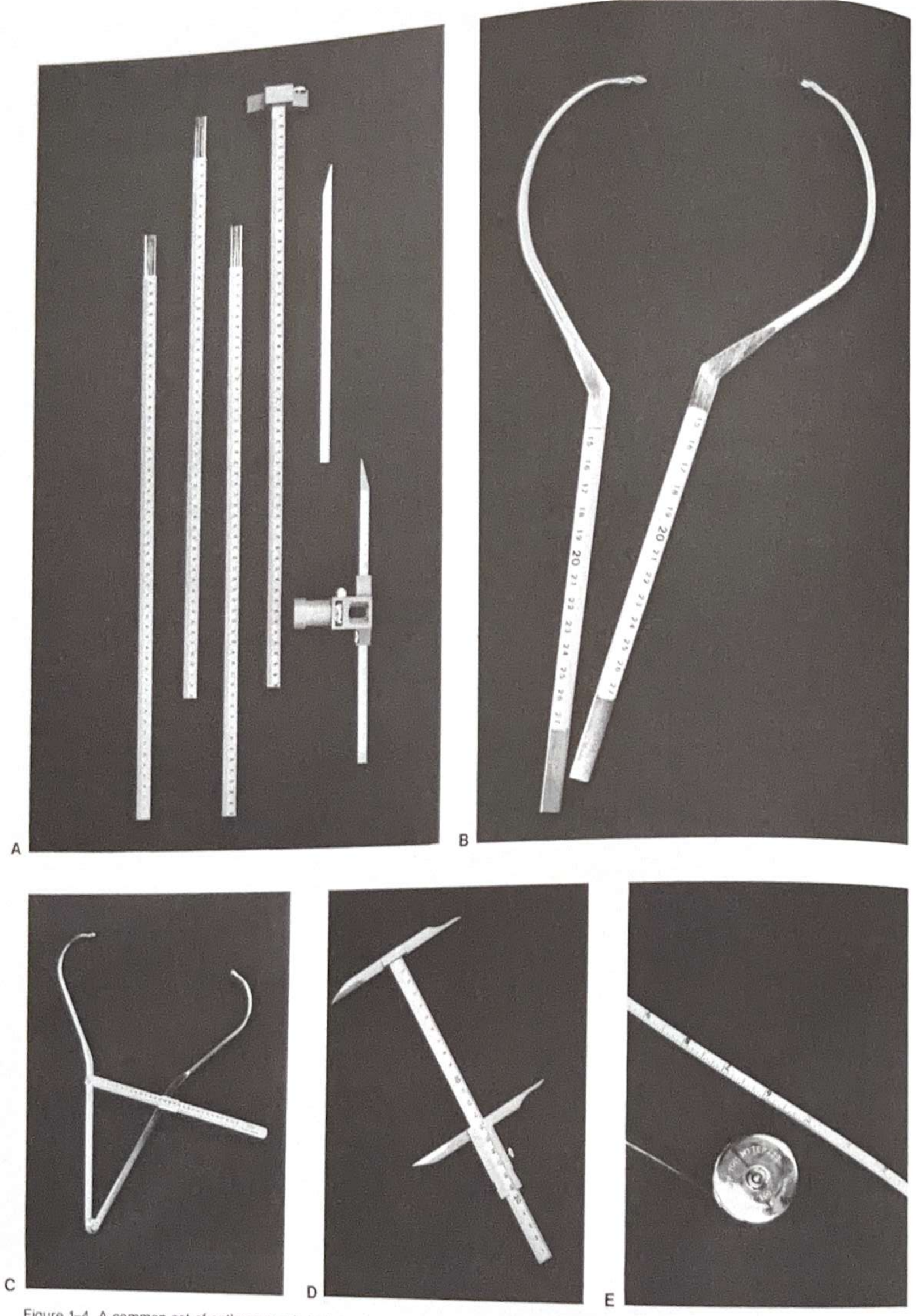


Figure 1–4. A common set of anthropometric instruments (courtesy Pfister Import-Export Inc., 450 Barrel Ave., Carlstadt, N.J. 07072). (*a*) Anthropometer; (*b*) curved branches for anthropometer; (*c*) spreading calipers; (*d*) sliding compass; (*e*) anthropometric tape.

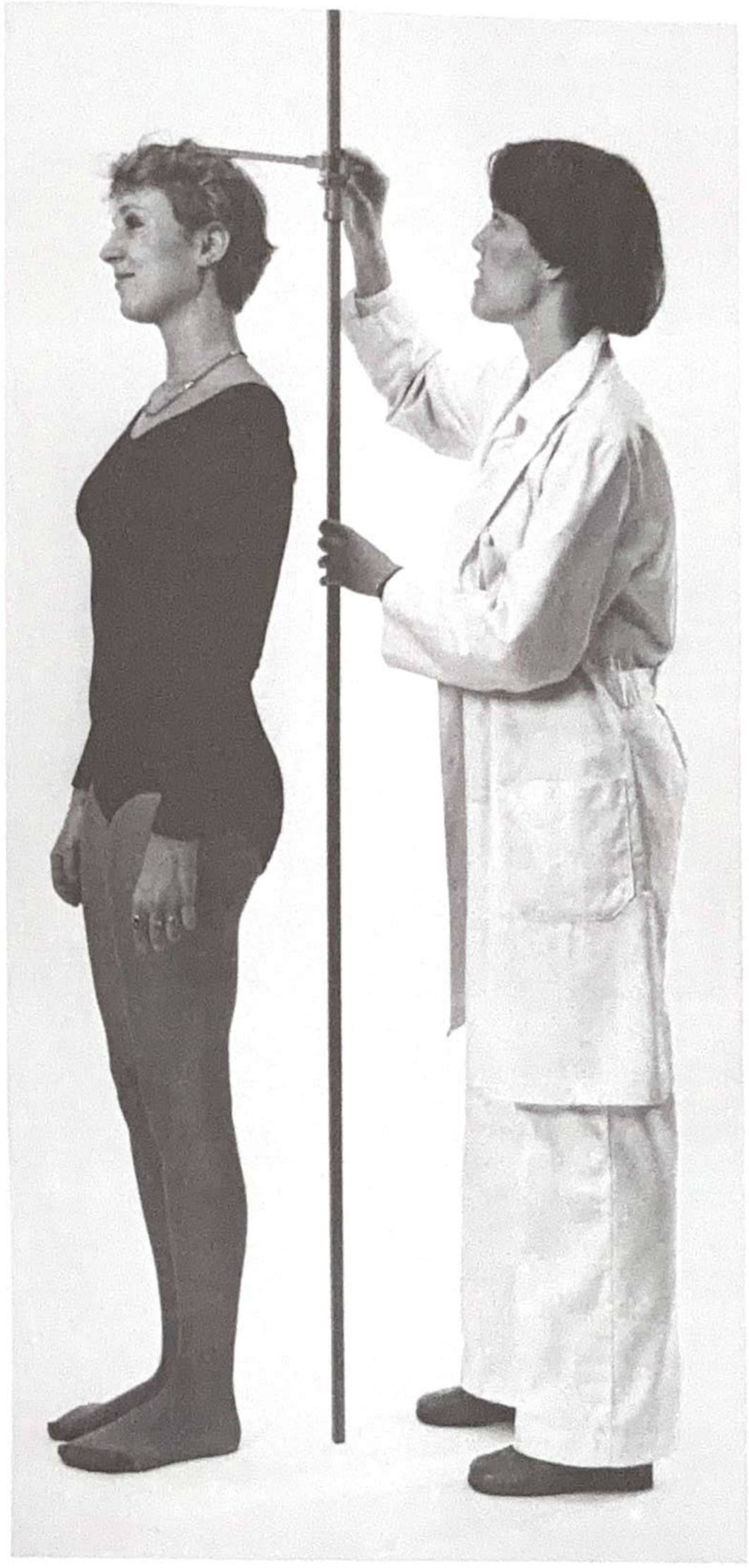


Figure 1–5. Interior design students at the Fashion Institute of Technology illustrating the use of the anthropometer.

Figure 1–6. Interior design students at the Fashion Institute of Technology illustrating the use of the sliding compass for measuring hand breadth.

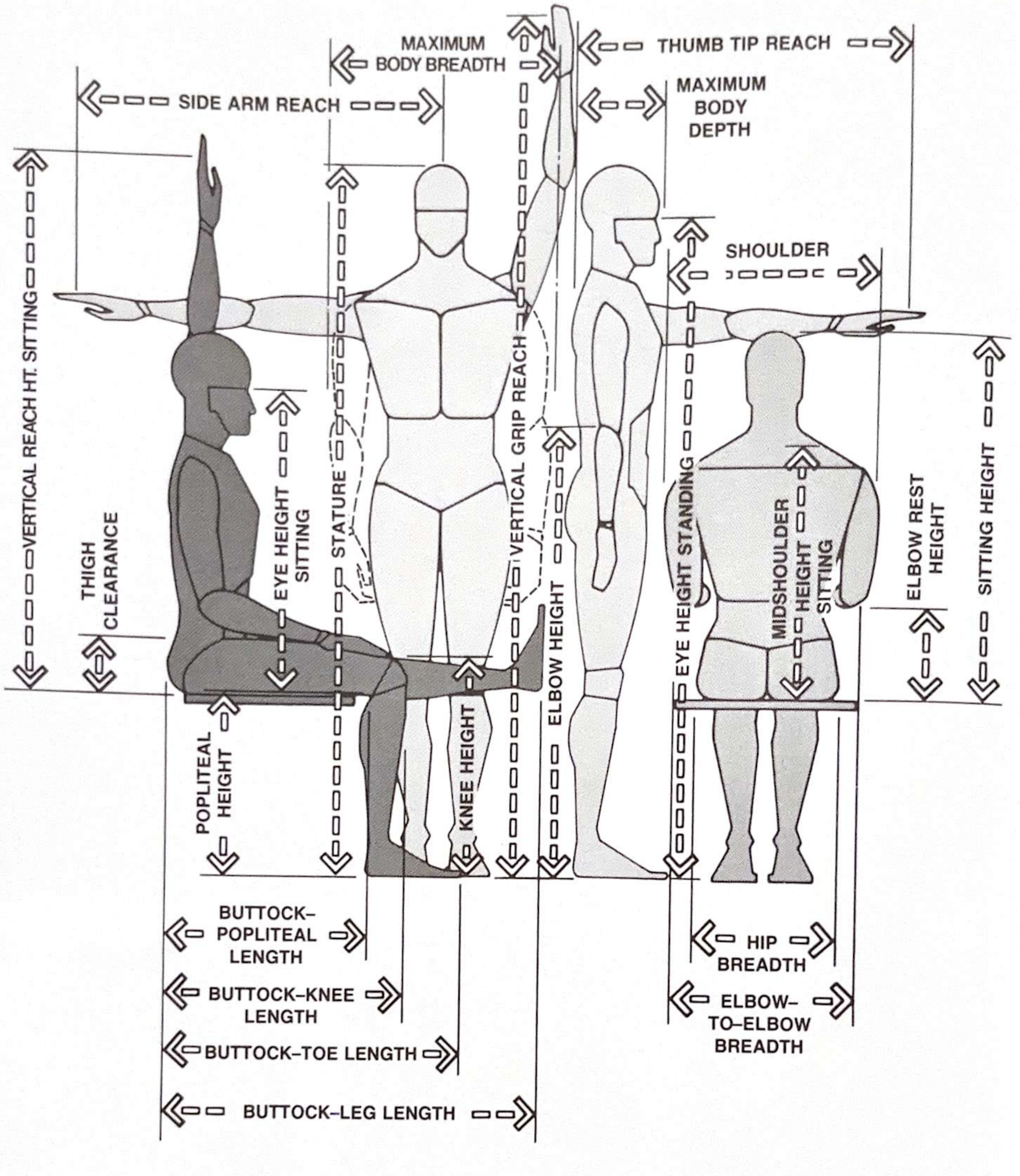


Figure 1–7. Body measurements of most use to the designer of interior spaces.

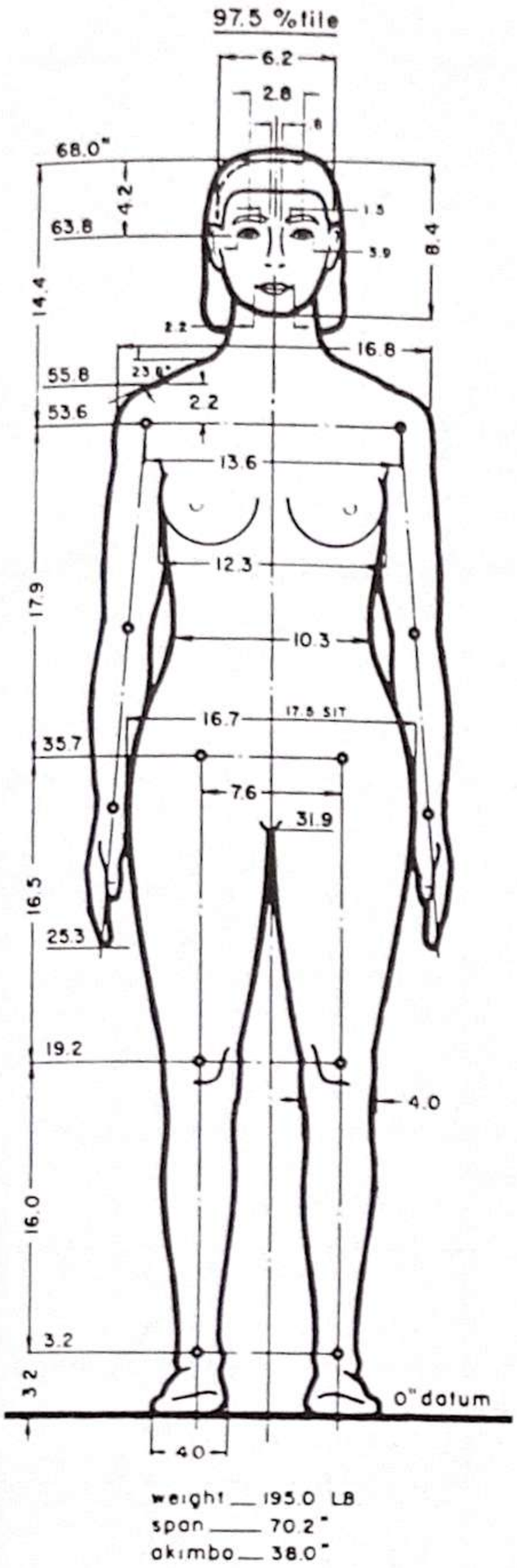


Figure 1–8. Anthropometric data of a standing adult female. Drawing from Henry Dreyfuss, *The Measure of Man*, 1978.

Similarly, "interpupillary diameter," the distance between the centers of the pupils, will be of far more value to the designer of optical equipment than to an architect.

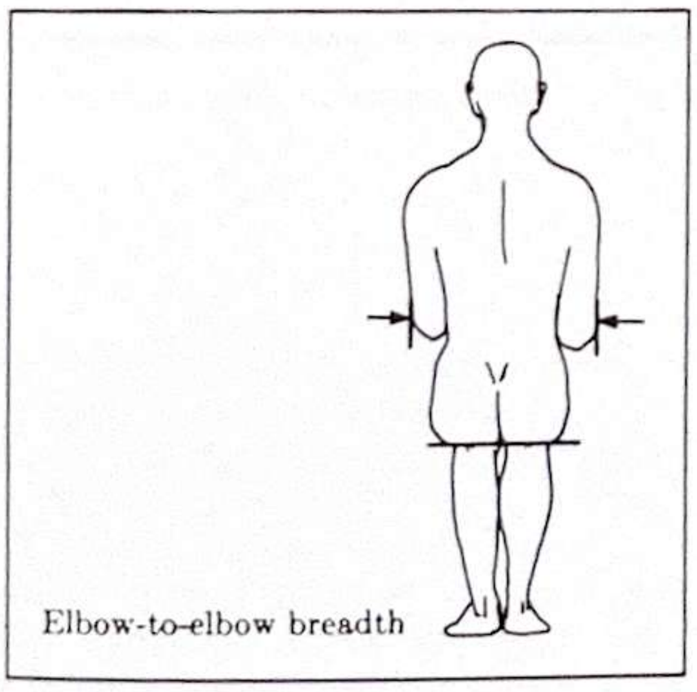
Damon et al. contend that "if one wishes to describe a group for human engineering purposes, the ten most important dimensions to obtain are in order: height; weight; sitting height; buttock-knee and buttock-popliteal lengths; breadths across elbows and hips, seated; knee and popliteal heights; and thigh clearance height."[7] These ten measurements are equally essential to the design of interiors.

Figure 1-7 indicates all those body measurements that are of the most significance to the architect, interior designer, or industrial designer. The necessary data for these measurements are developed in the various tables in Part B of this book. Table 1 in Part B, entitled "Metrological Analysis," defines the terms and discusses the application and design implication of the data.

1.4 PRESENTATION OF DATA

Generally, anthropometric data for use by the designer may be presented in graphic form, as in the well-known Dreyfuss figure (Figure 1-8), or in a tabular form (Figure 1-9). When data are initially recorded, however, their form, of necessity, is statistically disorganized. Figure 1-10 is an example of a form used to record initial data. Subsequently, the data are then reorganized in a more orderly and logical manner. With regard to anthropometric data, it is usually restructured to indicate frequency, as illustrated in Figure 1-11. Since individual body sizes and measurements vary greatly within any population, it is not practical to design for the entire group. Consequently, statistical distribution of body sizes is of great interest to the designer in establishing design standards and making design decisions.

The restructured array of data in the form of a frequency table, as shown on Figure 1-11, begins to suggest the pattern of distribution. The array of data lists, in order of magnitude from smallest to largest, certain height intervals in inches for army aviators and the corresponding number of instances in which such measurements were observed. Certain information can be immediately noted. The smallest height interval is from 158.8 to 160.5 cm, or 62.5 to 63.2 in, while the tallest interval is between 191.3 and 193 cm, or 75.3 and 76.0 in. It



ELBOW-TO-ELBOW BREADTH OF U.S. MALE MILITARY AND CIVILIAN SAMPLES

Population	Percentiles (in.) 1st	5th	50th	95th	99th	S.D.
Air Force personnel [1]	14.5	15.2	17.2	19.8	20.9	1.42
Cadets [2]	14.4	15.1	16.7	18.4	19.1	....
Gunners [2]	13.9	14.6	16.4	18.2	18.9	....
Army personnel:						
Separatees, white [3]	14.4	15.3	17.4	20.3	21.8	1.54
Separatees, Negro [4]	14.4	15.1	16.9	19.3	20.4	1.28
Truck and bus drivers [5]	13.8	14.9	17.5	20.7	22.2	....

[1] Hertzberg et al. (1954).
[2] Randall et al. (1946).
[3] Newman and White (1951).
[4] USA (1946).
[5] McFarland et al. (1958).

Figure 1–9. Elbow-to-elbow breadth data presented in tabular form with accompanying diagram of human figure to explain measurement. Diagram and table from Van Cott and Kinkale, *Human Engineering Guide to Equipment Design*, 1972, p. 507.

RECORDING FORMS USED

IF ✓ NO REPORT	REASON FOR NO REPORT	PROCEDURE	RECORDING	CODE
		9. **Height** Height decreased by	☐ cm. Curved Spine ☐ NO ☐ Deformed Legs ☐	
		10. **Weight**	☐ Lbs.	

IF ✓ NO REPORT	REASON FOR NO REPORT	MEASUREMENT	RECORDING IN Cm.	FOR OFFICE USE	CODE
		11. **Sitting height normal**	— — — . —		
		12. **Sitting height erect**	— — — . —		
		13. **Knee height***	— — — . —		
		14. **Popliteal height**	— — — . —		
		15. **Thigh clearance height**	— — — . —		
		16. **Buttock-knee length**	— — . —	X	
		17. **Buttock-popliteal length**	— — . —	X	
		18. **Seat breadth (across hips)**	— — . —	X	
		19. **Elbow-to-elbow breadth**	— — . —	X	
		20. **Elbow rest height**	— — — . —		

Figure 1–10. An example of a recording form used in an anthropometric study. From National Health Survey.

Interval	Midpoint	Frequency
62.5–63.2	62.85	1
63.3–64.0	63.65	3
64.1–64.8	64.45	3
64.9–65.6	65.25	16
65.7–66.4	66.05	20
66.5–67.2	66.85	47
67.3–68.0	67.65	48
68.1–68.8	68.45	64
68.9–69.6	69.25	73
69.7–70.4	70.05	63
70.5–71.2	70.85	48
71.3–72.0	71.65	43
72.1–72.8	72.45	37
72.9–73.6	73.25	14
73.7–74.4	74.05	10
74.5–75.2	74.85	9
75.3–76.0	75.65	1

Figure 1–11. Example of a frequency table of the standing height in inches of Army aviators. The frequency figures indicate the number of measurements within each interval. From Roebuck, Kroemer, Thomson, *Engineering Anthropometry Methods*, 1975, p. 134.

can also be observed that the number of cases in which these particular extreme high and low measurements occurred were minimal.

The data, however, particularly the nature of the distribution, can be communicated more effectively by means of "column diagrams," or "frequency histograms," as illustrated in Figure 1-12. The heights of the bars vary in order to indicate the frequency or number of cases for each interval, while the width of the bars are equal. It is also possible to use a curve, in lieu of bars, by plotting the frequency against the midpoint for each interval, as shown by the broken line in the figure. This resulting configuration is known as a "frequency polygon."

Despite the variation, the general pattern of distribution of anthropometric data, as with many other types of data, is fairly predictable and approximates the so-called Gaussian distribution. Such distribution, when presented graphically, in terms of frequency of occurrence versus magnitude, usually resembles a bell-shaped symmetrical curve. The significance of the bell-shaped configuration is that the large percentage of the distribution is somewhere in the middle, with a few extremes at either end of the scale, as illustrated in Figure 1-13.

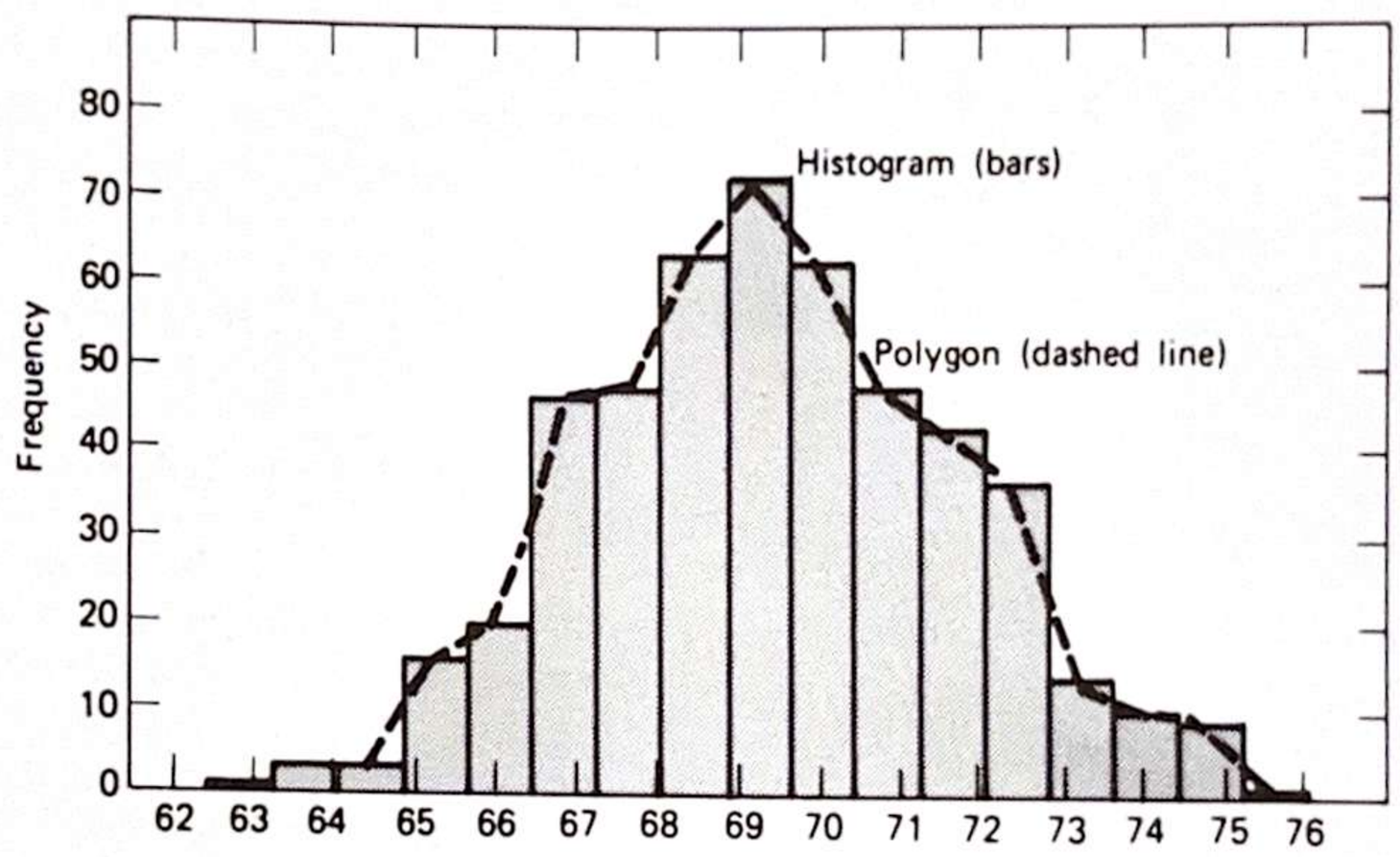


Figure 1–12. Example of a frequency histogram and polygon. From Roebuck, Kroemer, Thomson, *Engineering Anthropometry Methods*, 1975, p. 135.

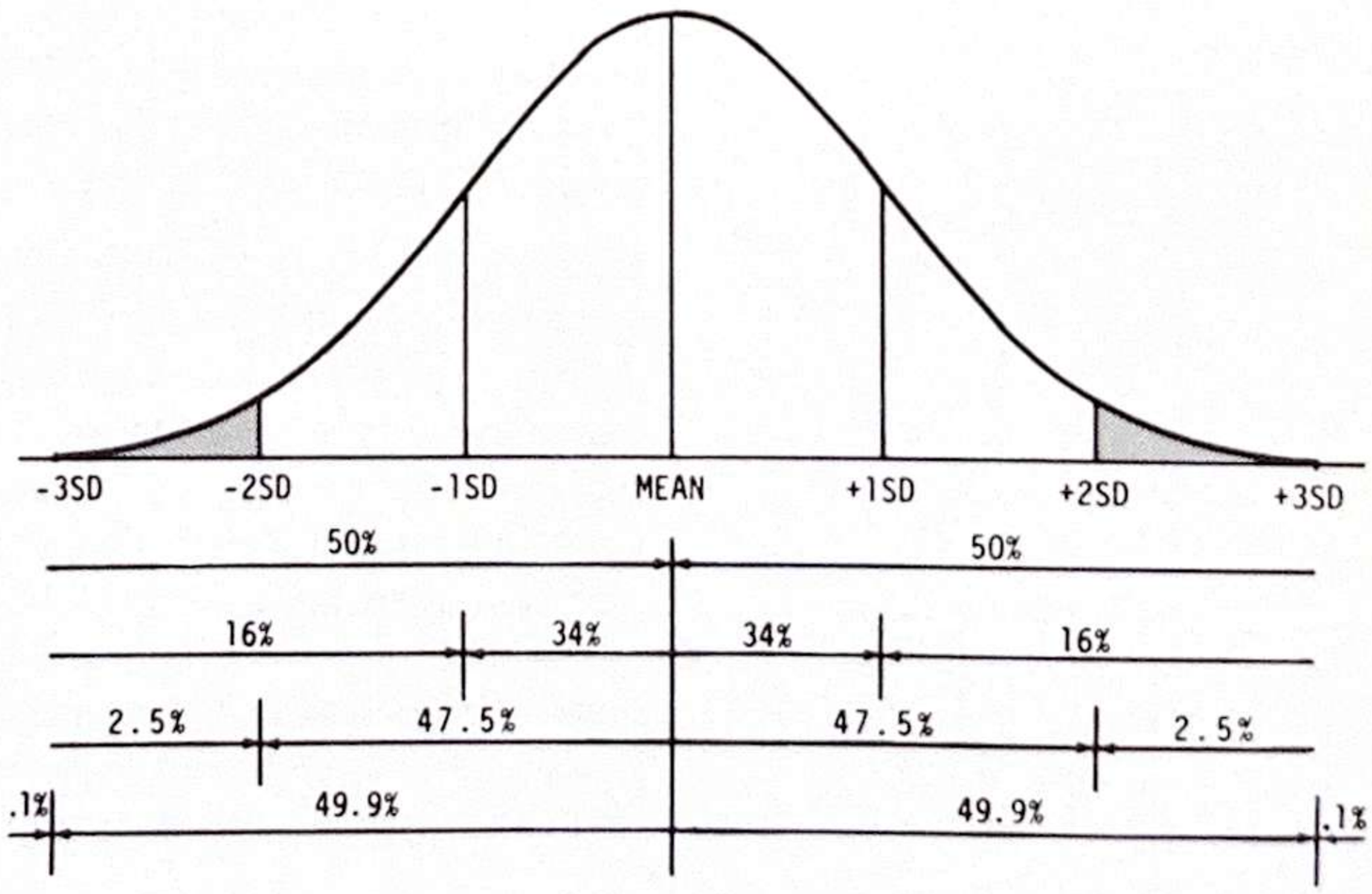


Figure 1–13. Example of areas under a normal curve. Most human dimensions, in a normally distributed group, follow the bell-shaped configuration. A small number of measurements appear at either end of the scale, but most are grouped within the middle portion. Drawing adapted from NASA, *Anthropometric Source Book*, vol. 1.

1.5 PERCENTILES

Due to the significant variations in individual body size, "averages" are obviously of little use to the designer and it is necessary, instead, to deal with range. Statistically, it has been shown that human body measurements in any given population will be distributed so that they will fall somewhere in the middle, while a small number of extreme measurements may fall at either end of the spectrum. Since it is impractical to design for the entire population, it is necessary to select a segment from the middle portion. Accordingly, it is fairly common today to omit the extremes at both ends and to deal with 90 percent of the population group.

Most anthropometric data, therefore, are quite often expressed in terms of percentiles. The population is divided, for study purposes, into 100 percentage categories, ranked from least to greatest, with respect to some specific type of body measurement. The first percentile in stature or height, for example, indicates that 99 percent of the study population would have heights of greater dimension. Similarly, a 95th percentile height would indicate that only 5 percent of the study population would have heights greater and that 95 percent of the study population would have the same or lesser heights. Percentiles "indicate the percentage of persons within the population who have a body dimension of a certain size (or smaller)."[8] The *Anthropometric Source Book* published by the National Aeronautics and Space Administration (NASA) defines percentiles in the following manner:

> The definition of the percentiles is fairly simple. For any set of data—the weights of a group of pilots, for example—the first percentile is a value which is, on the one hand, greater than the weights of each of the lightest 1% of the pilots and is, on the other hand, less than the weights of each of the heaviest 99% of these men. Similarly, the second percentile is greater than each of the lightest 2% and less than each of the heaviest 98%. Whatever the value of K—from 1 to 99—the K-th percentile is a value greater than each of the smallest k% of the weights and less than the largest (100 K)%. The 50th percentile, which we encountered among the averages as the median, is a value dividing a set of data into two groups containing the smallest and largest 50% of the values.[9]

A 50th percentile rating represents fairly closely the average value of a dimension for a certain group, but under no circumstances should be misinterpreted as suggesting that the "average man" has the body dimension indicated. This fallacy of the "average man" will be amplified later in Section 2.2.

When dealing with percentiles, two important factors should be kept in mind. Firstly, anthropometric percentiles on actual individuals refer to only one body dimension. This may be stature or sitting height, for example. Secondly, there is no such thing as a 95th percentile or 90th percentile or 5 percentile person. These are mythical figures. An individual having a 50th percentile stature dimension might have a 40th percentile knee height or a 60th percentile hand length, as suggested in Figure 1-14. The graph in Figure 1-15, representing actual data of three individuals, reinforces the mythical aspect of percentile people with respect to all body dimensions. Examination of the graph and its very pronounced angular and uneven path clearly indicates

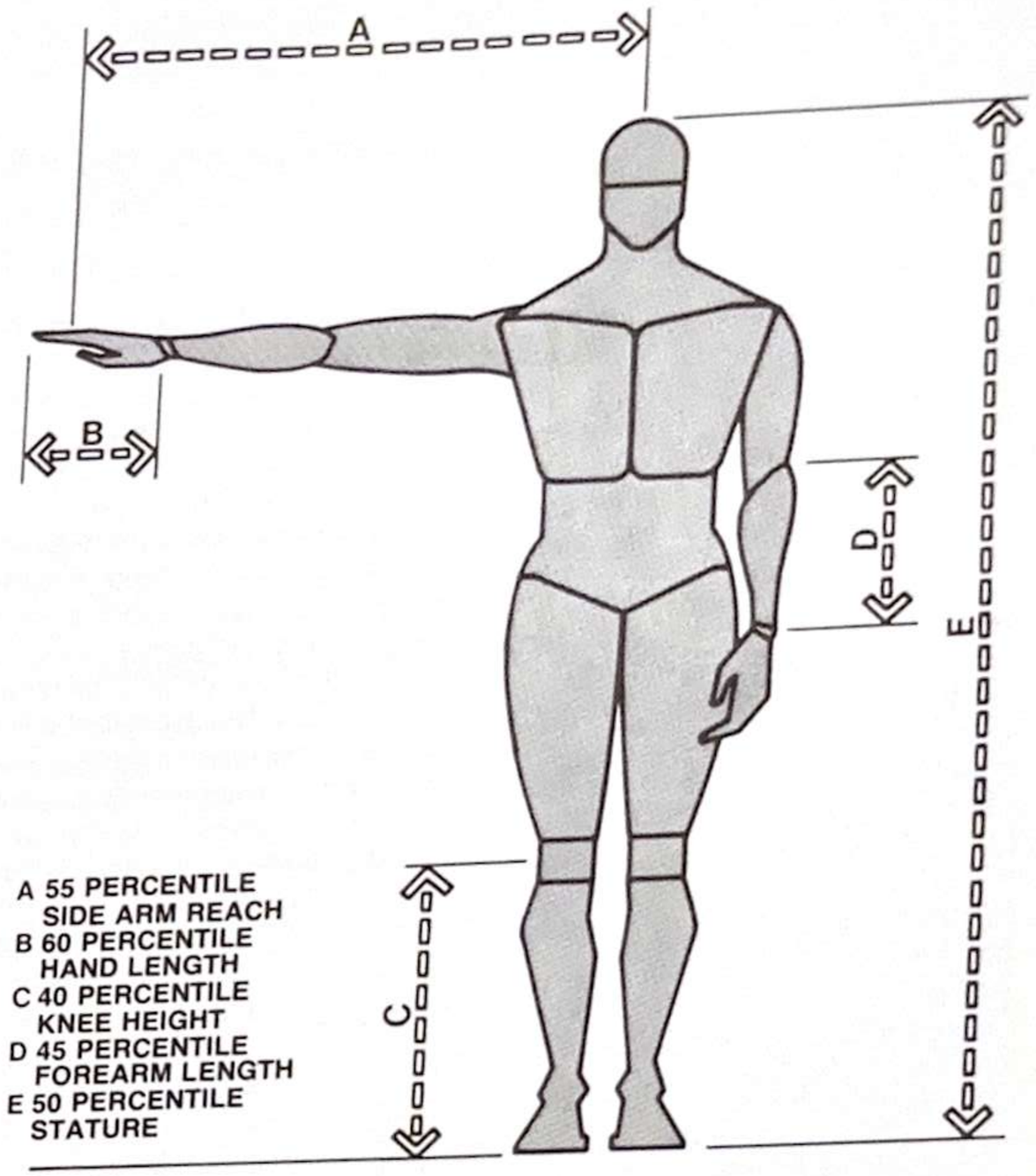


Figure 1–14. Humans are not, in reality, normally distributed in all body dimensions. As the illustration indicates, a person with a 50th percentile stature may well have a 55th percentile side arm reach.

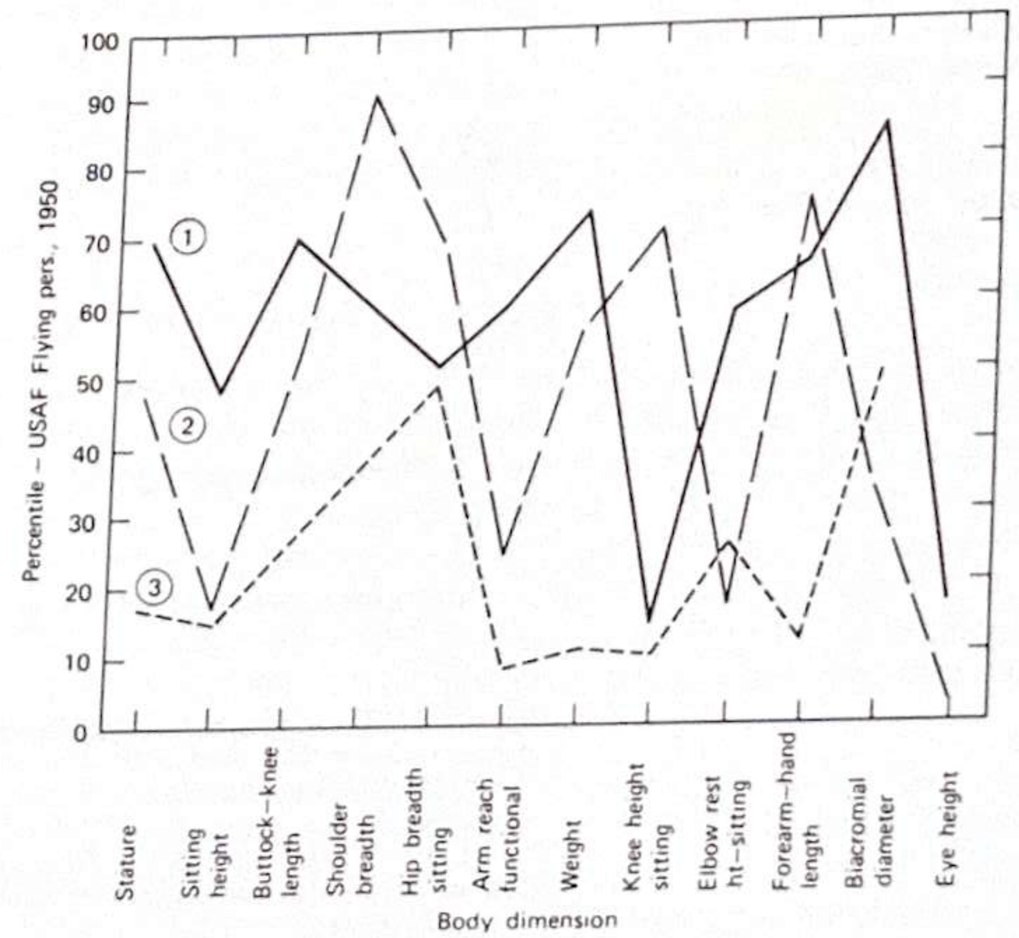
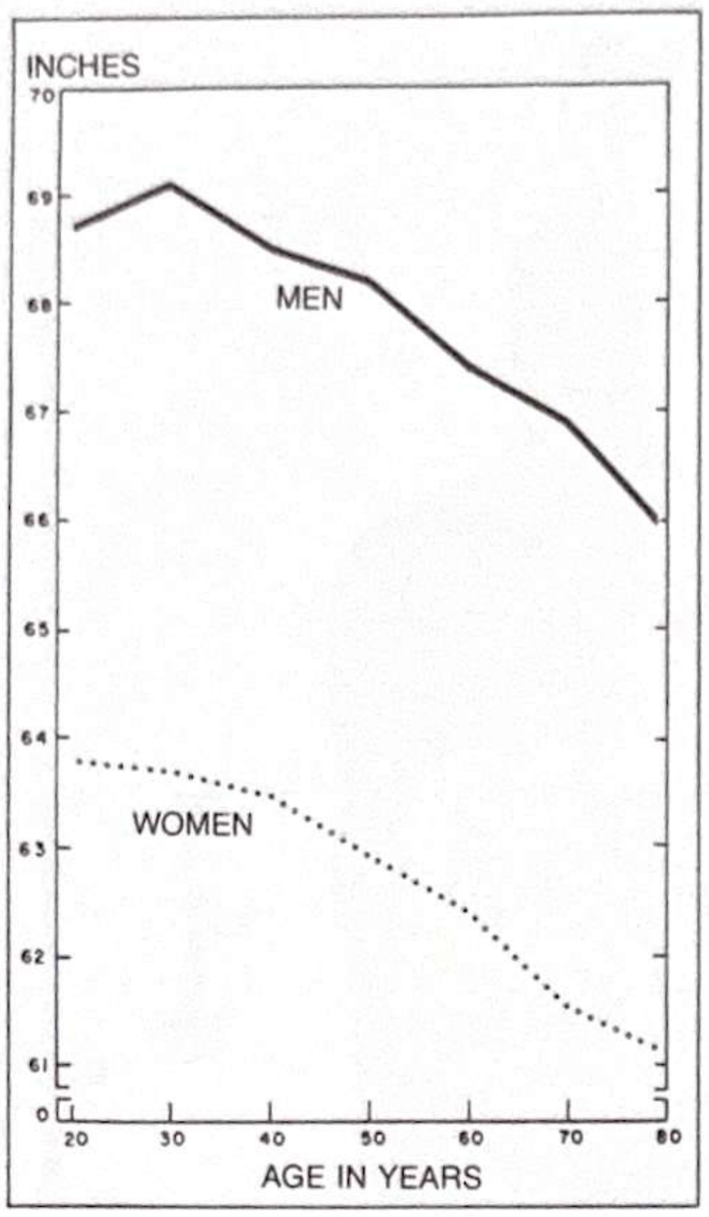
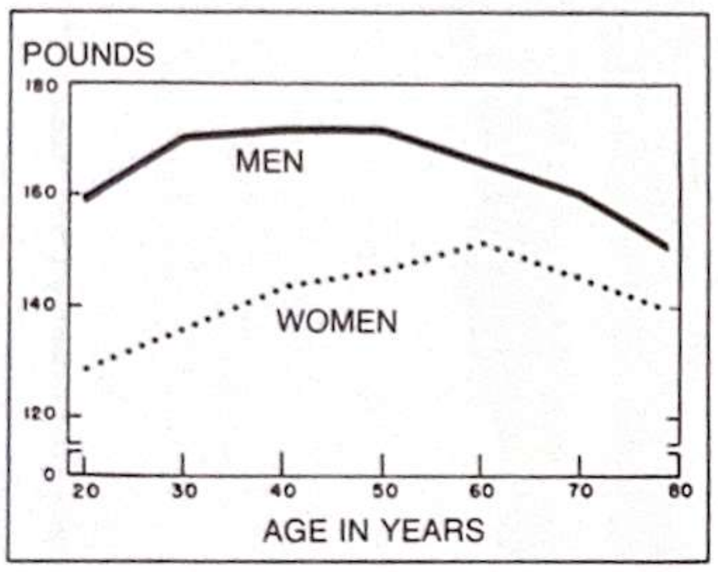


Figure 1–15. A graph indicating the percentiles for the various body dimensions of three actual individuals. Each graph line represents one person. Note that the individual represented by the solid line, for example, shows a 70th percentile buttock-knee length, a 15th percentile knee-height sitting, and a 60th percentile shoulder height. If all the body dimensions were equivalent to the same percentile, that fact would be shown in a straight horizontal line across the graph. Drawing from Roebuck, Kroemer, Thomson, *Engineering Anthropometry Methods*, 1975, p. 172.



A



B

Figure 1–16. (*a*) The graph indicates that men as a group are generally taller than women as a group and that the height of both men and women decreases with age. From National Health Survey. (*b*) The graph indicates that men as a group are heavier than women as a group and that the body weight of both men and women decreases with age. From National Health Survey.

that each of the three individuals has a differing percentile ranking for each of the body dimensions shown.

1.6 VARIABILITY AND RELIABILITY

As discussed earlier in this section, a number of factors can cause significant variations in human body size. Individuals from one part of the country may be taller and heavier than those from another part. A socioeconomic study has indicated a significant difference in stature between people having different occupations. A comparison in stature between truck drivers and research workers, for example, indicated that the latter, as a group, were taller than the former. The military, as a group, differs anthropometrically from the civilian population.[10] Men within the same group are usually taller and heavier than the women within that group, and elderly people differ in body size from the middle-aged (Figure 1-16). Moreover, measurements of general body sizes within a country may change over a period of time. American soldiers in the Second World War were proven to be taller and heavier than soldiers of the First World War (Figure 1-17). It has been demonstrated that ethnicity is also an extremely significant factor in body size. This has been an area of such growing concern and interest to ergonomists the world over that in 1972 the first international symposium on "natural and cultural variables in human factors engineering" was held in The Netherlands under the auspices of the North Atlantic Treaty Organization. Body size was one of five topics discussed. Papers delivered at that symposium revealed some very substantial anthropometric differences among the various populations of the world.

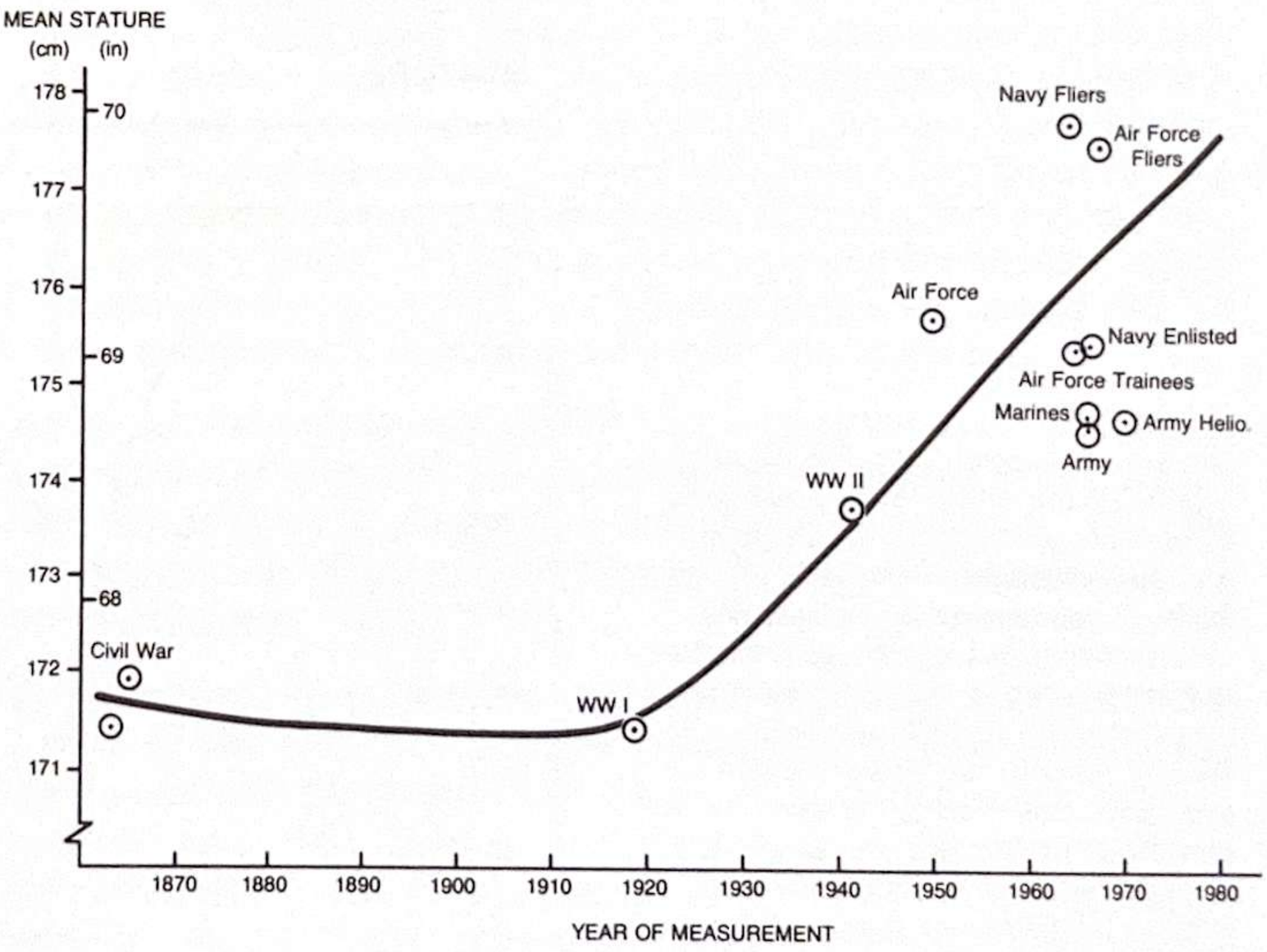


Figure 1–17. The graph compares the mean stature for young U.S. males with the year of measurement. The trend, referred to as "secular change," indicates a growth in the stature of U.S. males from generation to generation. A publication of the National Center for Health Statistics (Hammill et al., 1976), however, concludes that the secular growth trend appears to have stopped in American children born after 1955–1956. Graph adapted from NASA, *Anthropometric Source Book,* vol. 1.

2 ANTHROPOMETRIC DATA/ APPLICATION

2.1 APPROPRIATENESS

It is essential, due to the many variables involved, that the data selected be appropriate to the user of the space or furniture to be designed. It becomes necessary, therefore, for the intended user population to be properly defined in terms of such factors as age, sex, occupation, and ethnicity. If the user is an individual, or constitutes a very small group, it may, in certain situations, be feasible to develop your own primary anthropometric data by actually having individual body measurements taken. Surely, if one is prepared to take the time to be fitted for a dress or a suit, one should be willing to spend the time to be fitted for an interior environment or components of that environment, particularly since, in most cases, the latter will reflect a far greater financial investment. The measurements, in the event individual data are generated, should, however, be taken with proper instruments by a trained observer. In situations where specific body dimensions or other data for a particular user population are unavailable, and both time and funds prevent undertaking sophisticated studies, an engineering anthropometrist can be consulted to discuss the statistical methods of obtaining the necessary information.

2.2 "AVERAGE MAN" FALLACY

As suggested previously, a very serious error in the application of data is to assume that the 50th percentile dimensions represent the measurements of an "average man" and to create a design to accommodate 50th percentile data. The fallacy in such an assumption is that by prior definition 50 percent of the group may suffer. There simply is no "average man." Depending on the nature of the design problem, the design should usually be conceived to accommodate the 5th or the 95th percentile, so that the greatest portion of the population is served.

Dr. H. T. E. Hertzberg, one of the country's most distinguished research physical anthropologists, in discussing the so-called average man, indicated, "there is really no such thing as an 'average' man or woman. There are men who are average in weight, or in stature, or in

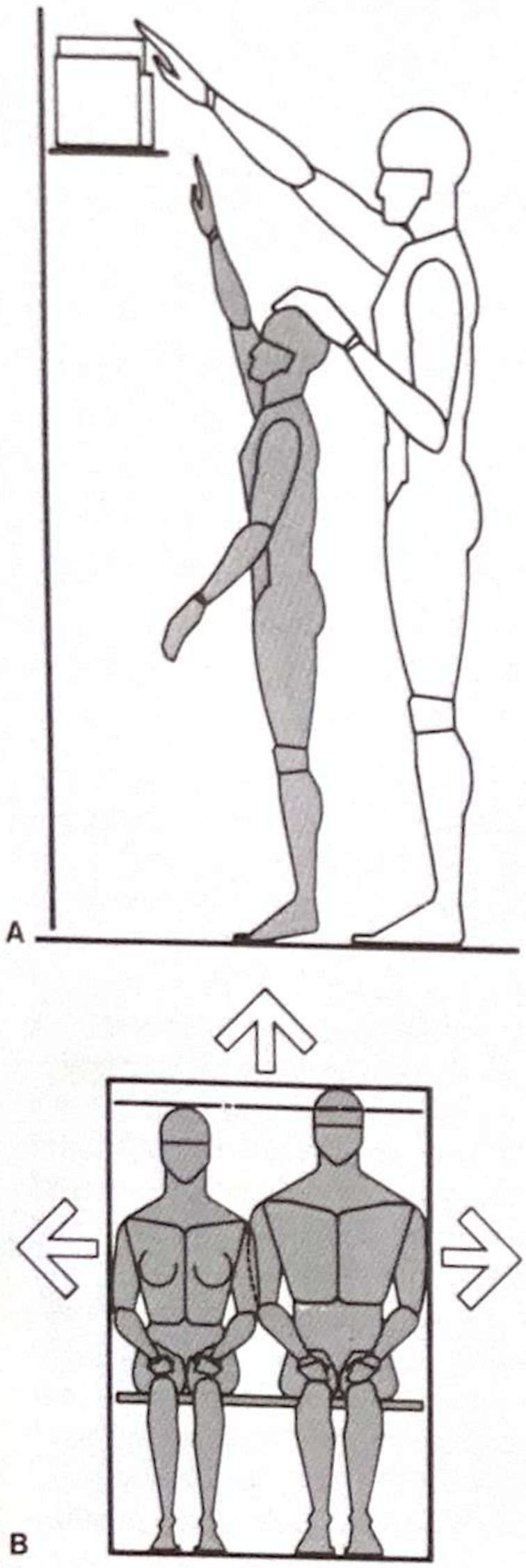


Figure 2–1. (*a*) People of smaller body dimensions and, correspondingly, the lower-range percentile data should be used to establish dimensions where reach is the determining factor. (*b*) Larger-size people and, correspondingly, the high percentile range data should be used in establishing clearance dimensions.

sitting height, but the men who are average in two dimensions constitute only about 7 percent of the population; those in three, only about 3 percent; those in four, less than 2 percent. There are no men average in as few as 10 dimensions. Therefore, the concept of the 'average' man is fundamentally incorrect, because no such creature exists. Work places to be efficient should be designed according to the measured range of body size."[1]

2.3 REACH, CLEARANCE, AND ADJUSTABILITY

The selection of appropriate anthropometric data is based on the nature of the particular design problem under consideration. If the design requires the user to reach from a seated or standing position, the 5th percentile data should be utilized. Such data for arm reach indicates that 5 percent of the population would have an arm reach of short (or shorter) dimension, while 95 percent of the population, the overwhelming majority, would have longer arm reaches. If the design in a reach situation can accommodate the user with the shortest arm reach, obviously it will function for the users with longer reaches as well; it is equally obvious that the opposite is not true, as shown in Figure 2.1*a*.

In designs where clearance is the primary consideration, the larger or 95th percentile data should be used. The logic is simple. If the design will allow adequate clearance for the users with the largest body size, it would also allow clearance for those users with smaller body size. Here, too, it can be seen from Figure 2-1*b* that the opposite is not true.

In other situations it may be desirable to provide the design with a built-in adjustment capability. Certain chair types, adjustable shelves, etc., are examples of such. The range of adjustment should be based on the anthropometrics of the user, the nature of the task, and the physical or mechanical limitations involved. The range should allow the design to accommodate at least 90 percent of the user population involved, or more.

It should be noted that all the foregoing examples were used primarily to illustrate the basic logic underlying the selection of the body dimensions involved and the particular percentiles to be accommodated. Wherever possible, however, it is naturally more desirable to accommodate the greatest percentage of the user population. In this regard, there is no substitute for common sense. If a shelf can just as easily be placed an inch or two lower, without significantly impacting on other design or cost factors, thereby accommodating 98 or 99 percent of the user population, obviously that is the correct design decision.

2.4 THE HIDDEN DIMENSIONS

Applied anthropometry can serve as an extremely helpful tool in the design process, if used intelligently and within the larger perspective of all the other human factors that impact on that process. In fitting the body to the environment, the factors involved in the tailoring of that fit cannot be limited to measurements and distances in the absolute sense of the meaning of those terms. Distance and, by exten-

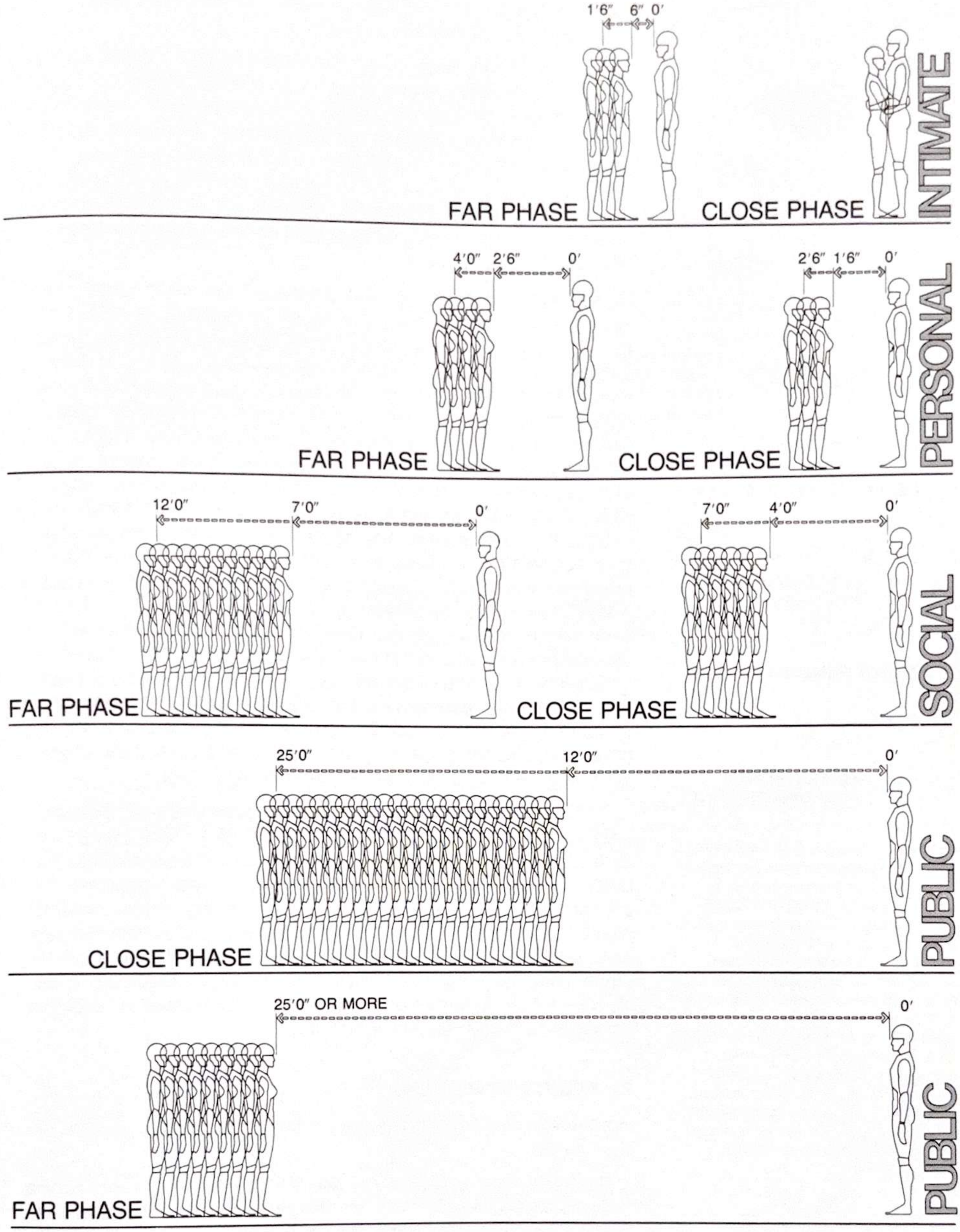


Figure 2–2. Graphic illustration of the distance zones suggested by Hall, *The Hidden Dimension*, 1966.

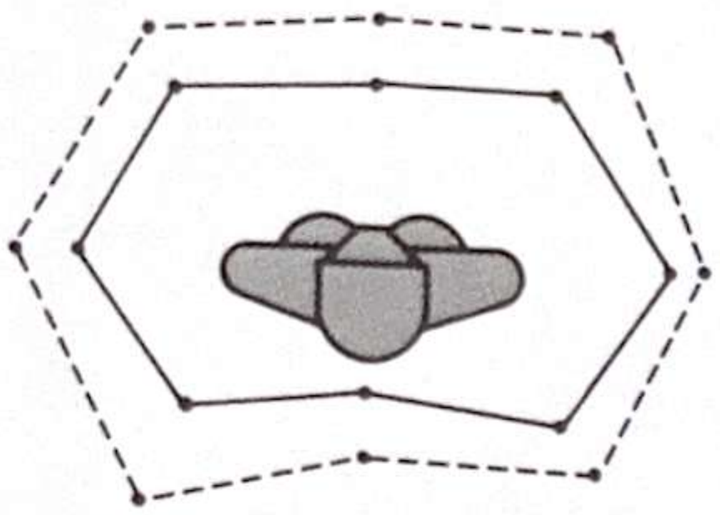


Figure 2–3. Horowitz et al. "body buffer zone." The diagrams depict the mean of the approach of the subjects over a three-day period. Although the schizophrenic group had a significantly greater buffer zone area, both groups approached the inanimate object more closely than the animate object. No significant difference between approaches to male or female was found in either group. One of the hypotheses emerging from the finding was that "an area of personal space appears to surround every individual, which seems to be reproducible and may be regarded as an immediate 'body-buffer zone.'" Adapted from *Archives of General Psychiatry.*

sion, clearance and space generally have many other more sophisticated and subtle connotations.

There are, as Hall suggests, "hidden dimensions." To assume that people's boundaries begin and end with the skin is to fail to "grasp the significance of the many elements that contribute to man's sense of space." Hall, by way of example, contends that people function within four "distance" zones, each of which has a "near" and "far" phase. The zone selected for use at any one time is predicated on the nature of the activity or social transaction in progress.[2] Figure 2-2 illustrates the zones referred to by Hall as well as the activities usually associated with each.

Some years ago, Horowitz et al. contended that each human being has an internal projection of the space immediately around him or her. They termed the space the "body buffer zone" and suggested that its size, shape, and penetrability were related to the immediate interpersonal events and the individual's psychological and cultural history. Individuals, they held, tend to keep a characteristic distance between themselves and other people and inanimate objects. This contention was demonstrated in an experiment they conducted at a U.S. naval hospital. Under the pretext that their equilibrium was to be studied, subjects were instructed to either "walk over to Smith (or a hatrack that was intentionally located in the area) while we check your equilibrium." In actuality, however, measurements of the distance left between the subjects and the person or hatrack, after completing their approach across the room, were taken. The subjects were taken from two groups. One consisted of 19 patients with an established diagnosis of schizophrenia. The other group were nonschizophrenic people of similar backgrounds. The results revealed that both groups approached the hatrack significantly closer than they did the person. In addition, the tests indicated that when approaching another person, there was definitely an area beyond which they would not go,[3] as indicated in Figure 2-3.

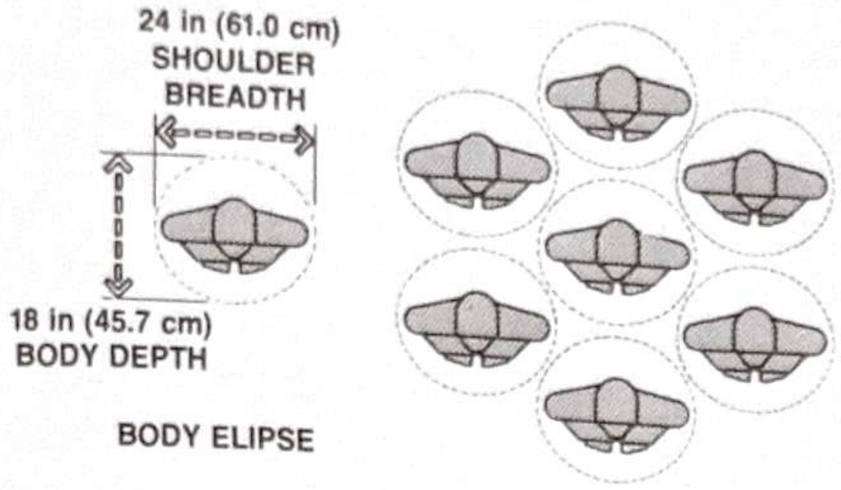
Dr. John J. Fruin, in studying pedestrian movements and "queuing," talks of "touch," "no-touch," "personal comfort," and "circulation" zones, as illustrated in Figures 2-4 through 2-7.[4] The term "flight distance" has been used to describe the distance that organisms usually place between themselves and other organisms. Sommer studied "personal distance" and observed interaction between subjects seated around a table in terms of their particular locations around that table. Figure 2-8 shows the seating arrangement. It was observed that the greatest frequency of conversation occurred across the corners AB, AH, EF, and ED.[5]

2.5 PEOPLE IN MOTION

In an article dealing with design and human locomotion, Archie Kaplan writes:

> Movement is the natural state of man and the basis of his being. Human life represents no static state; from the blink of an eye to top speed running, in sleep or wakefulness, man is in motion. . . .[6]

With this in mind, it should be recognized that in addition to the psychological factors, the dynamics of space also affect people's inter-



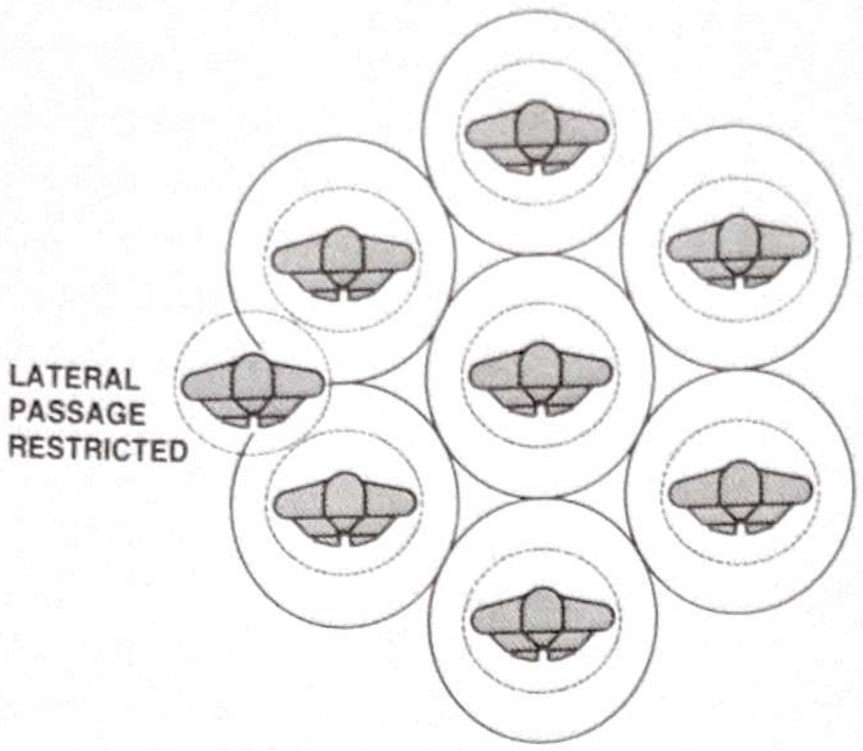
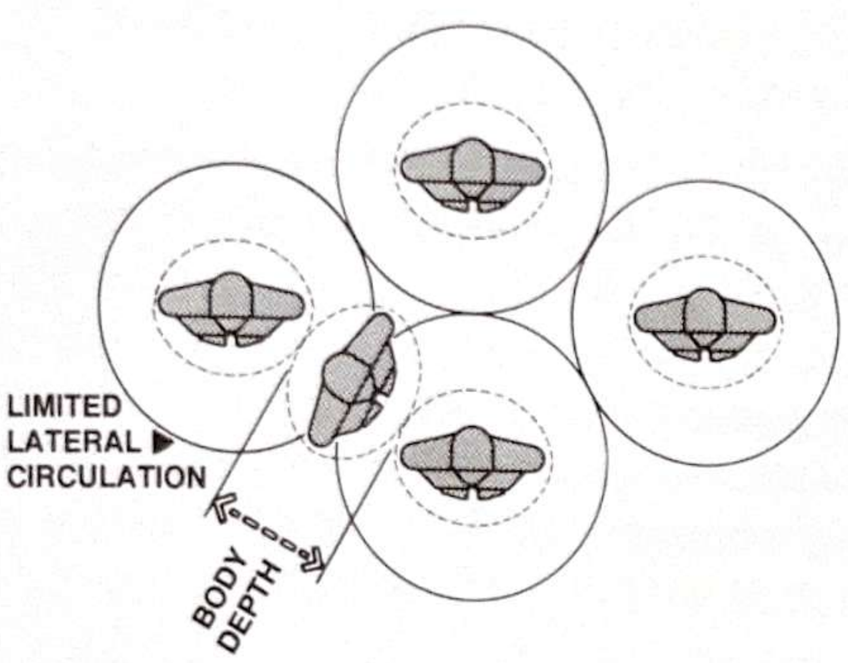


Figure 2–4 (left). Illustration of Fruin's "touch zone" based on a "body elipse" buffer zone with a minor axis related to body depth and a major axis related to shoulder breadth, allowing a queuing area of 3 sq ft, or 0.29 sq m, per person. Below this boundary the frequency of body contact between pedestrians is increased. Figures 2-4 to 2-7 adapted from Fruin, *Pedestrian Planning and Design,* 1971. Figure 2–5 (right). Illustration of Fruin's "no touch zone," based on an expanded interperson spacing of 36 in, or 91.4 cm, and a 7 sq ft, or 0.65 sq m, area per person. Fruin contends that body contact can be avoided between 3 and 7 sq ft, or 0.29 to 0.65 sq m, per person.



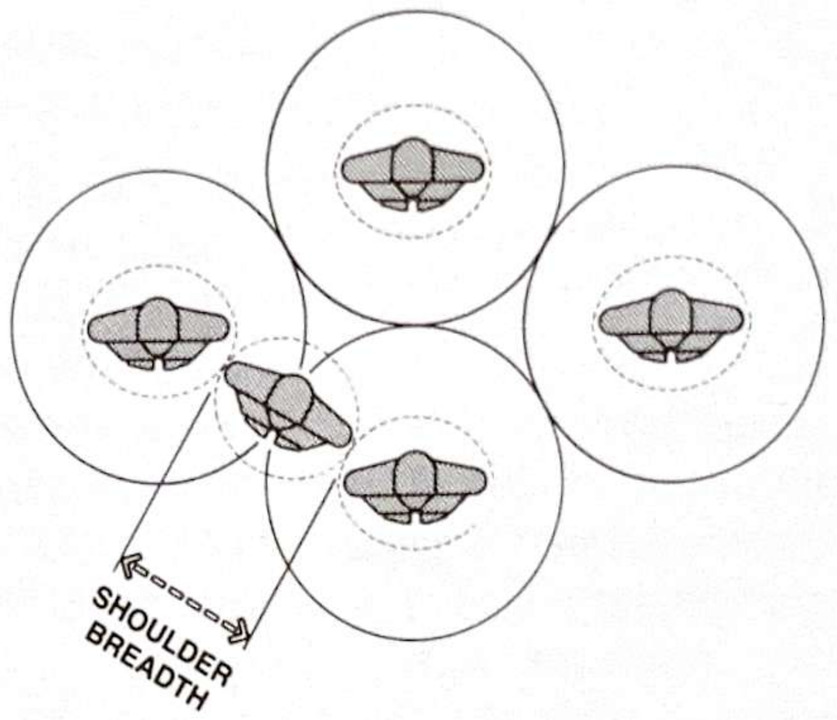


Figure 2–6 (left). Illustration of Fruin's "personal comfort zone," expanding the body buffer zone to a 42-in, or 106.7-cm, diameter and a 10-sq ft, or 0.93-sq m, area. A full body depth separates standees, allowing for limited lateral circulation by moving sideways. Figure 2–7 (right). Illustration of Fruin's "circulation zone," expanding the body buffer zone to a 48-in or 121.9-cm, diameter and 13-sq ft, or 1.21-sq m, area. Fruin contends that 10 to 13 sq ft, or 0.93 to 1.21 sq m, per person would allow circulation without disturbing others.

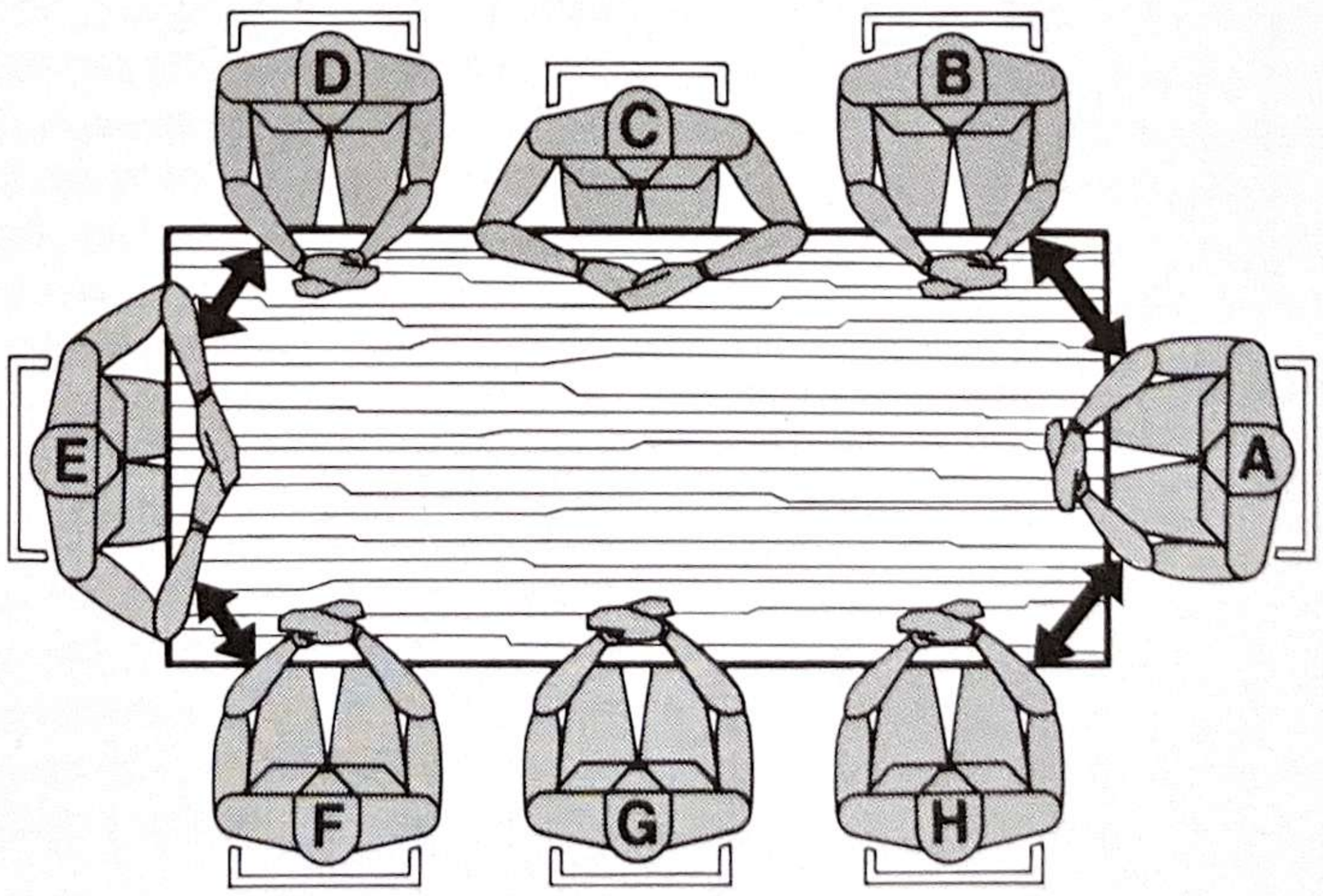


Figure 2–8. Sommer's experiment at the Saskatchewan Hospital involved a seating arrangement as shown at right. It was observed that greater interaction between people occurred across the corners AB, AH, EF, and ED. Adapted from *Sociometry.*

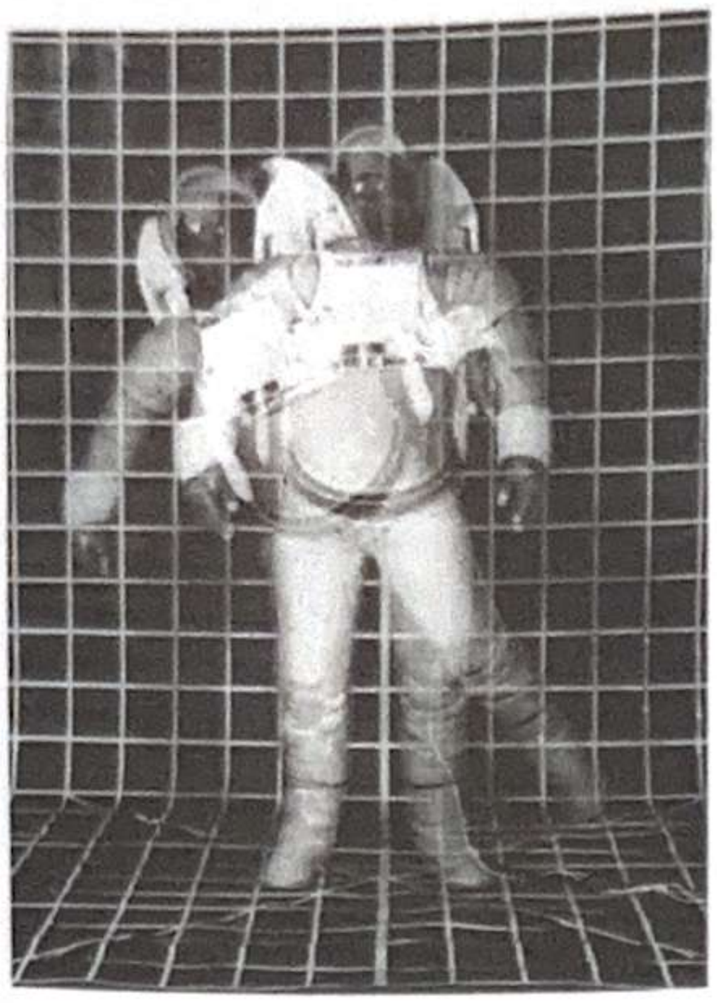


Figure 2–9. *Spatial envelope* defined by body movement in performance of a simple task. Photograph courtesy National Aeronautics and Space Administration.

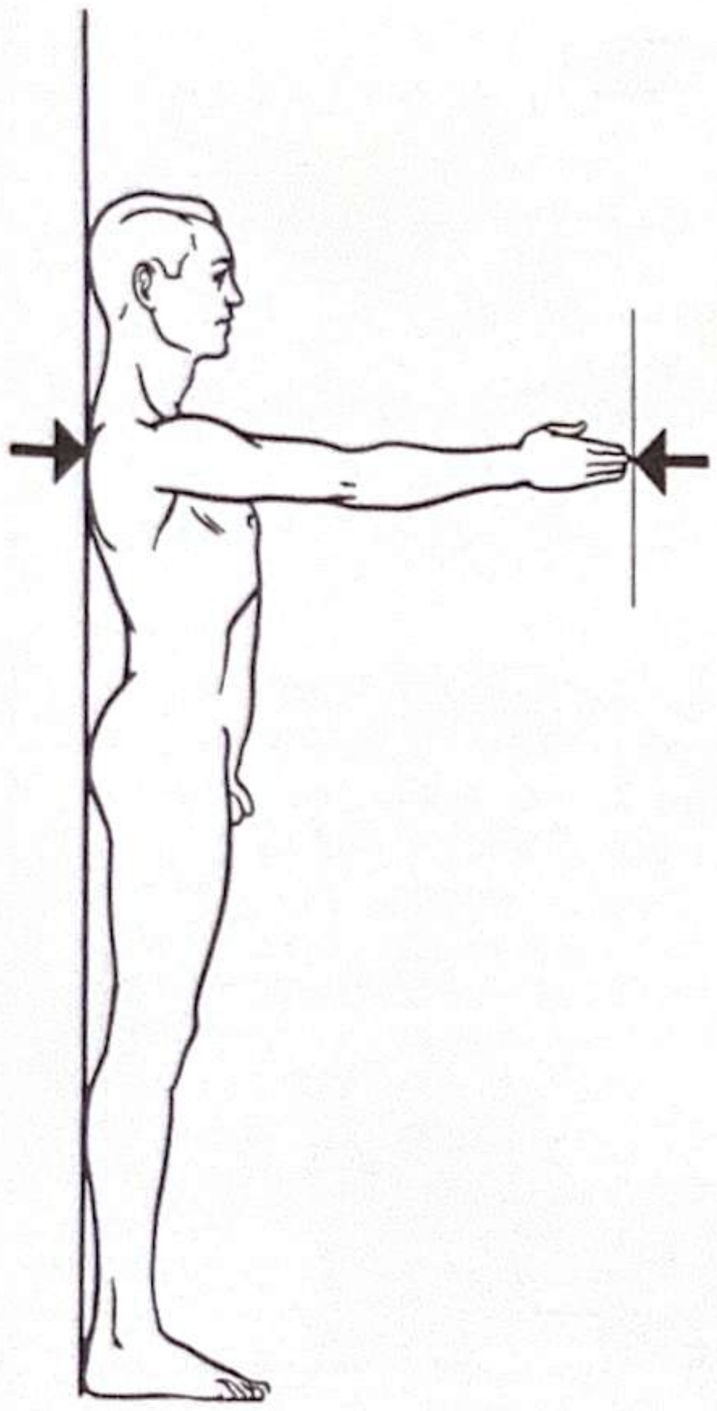


Figure 2–10. Classic anthropometric diagram representing arm reach. From Damon, Stoudt, McFarland, *The Human Body in Equipment Design,* 1966, p. 96.

face with the environment. People, as Kaplan suggests, are constantly in motion. Even when not engaged in a particular activity or task, the human body is never really completely still or at rest, and even when considered to be rigid, the body will, in fact, sway to some extent in all directions. The body is always pliable and can stretch. Limbs can rotate and twist, and electrical energy from body muscles can be harnessed to operate machines. One dramatic example of the relative pliability and elasticity of the human body is the change it undergoes during weightlessness. National Aeronautics and Space Administration data indicate that astronauts "grow" about 3 percent in height during the first few days in a zero-gravity environment. This increase typically amounts to about 5 cm, or 2 in. This increase is caused primarily by a lengthening of the spinal column due to the contraction and expansion of the intervertebral discs. Upon reexposure to one gravity, the process is reversed and the body returns to normal.[7]

Changes in height, however, are not limited to zero gravity conditions. Such changes are also observed on earth after a person has been in a reclining horizontal posture for a period of time, such as when sleeping, and then assumes a standing position. The human body is, by its nature, a dynamic organism.

By contrast, however, much of the anthropometric data available are based on static measurements taken of samples of larger populations in various positions (i.e., standing, sitting, with limbs extended, etc.). The static nature of most of the data is usually related more to the anticipated body positions at the completion of a task rather than the flow of body movements involved at arriving at those final positions. Figure 2-9 illustrates the "spatial envelope" defined by body movement in the performance of a simple task.

In the application of hard-lined anthropometric data, therefore, the designer must somehow reconcile the static nature of the data with the reality of the dynamic aspects of body movements. At the very least, he must be aware of the inherent limitations of the data. By way of example, Figure 2-10 illustrates the classic anthropometric diagram associated with arm reach measurement. It is such hard data on which the maximum distance of a shelf, or perhaps of a control, might be located to accommodate a majority of users. What other factors could impact on the dynamics and/or the geometrics of the activity? Surely the capability of the human body to stretch as well as the idiosyncrasies of the individual user's body posture will affect body movement to some degree. In addition, what about the user's actual body positions and motions immediately preceding the flow of movements associated with the execution of a specific task? The position of the body as well as the momentum generated by the body movements preceding that task are certainly bound to affect the user's reach.

Anthropometric space requirements for walking clearances constitute yet another excellent example of the importance of body movement and its implications in the design process. Human stride and gait affect the clearances to be allowed between people and physical obstructions. Tables, unfortunately, do not reflect these factors. However, very little published research in this particular area is available.

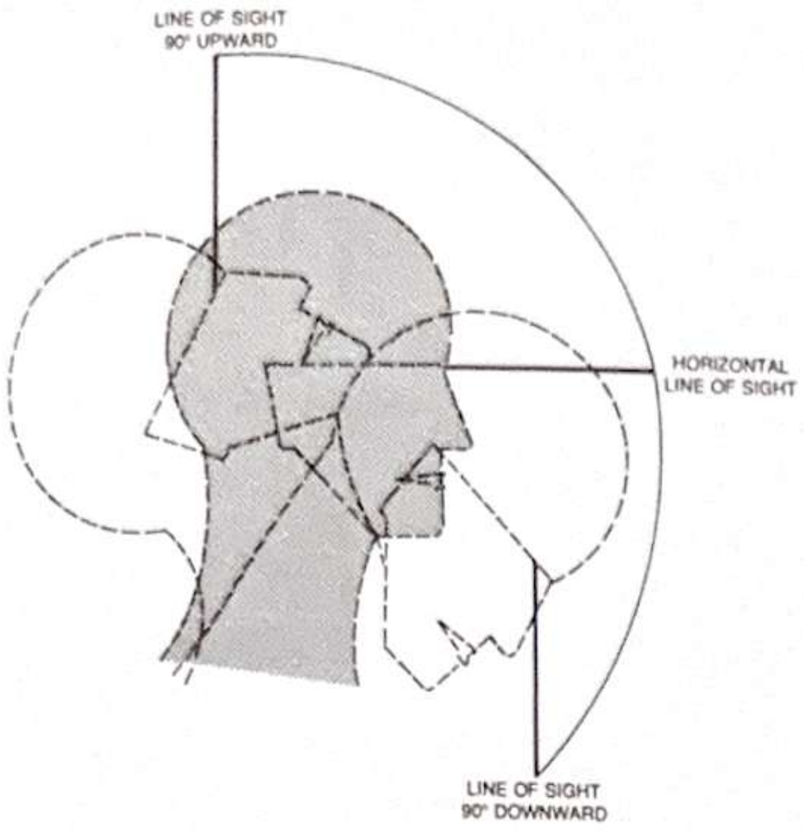


Figure 2–11. Range of head movements in the vertical plane increases area of visibility. From *Human Factors Engineering*, 1977.

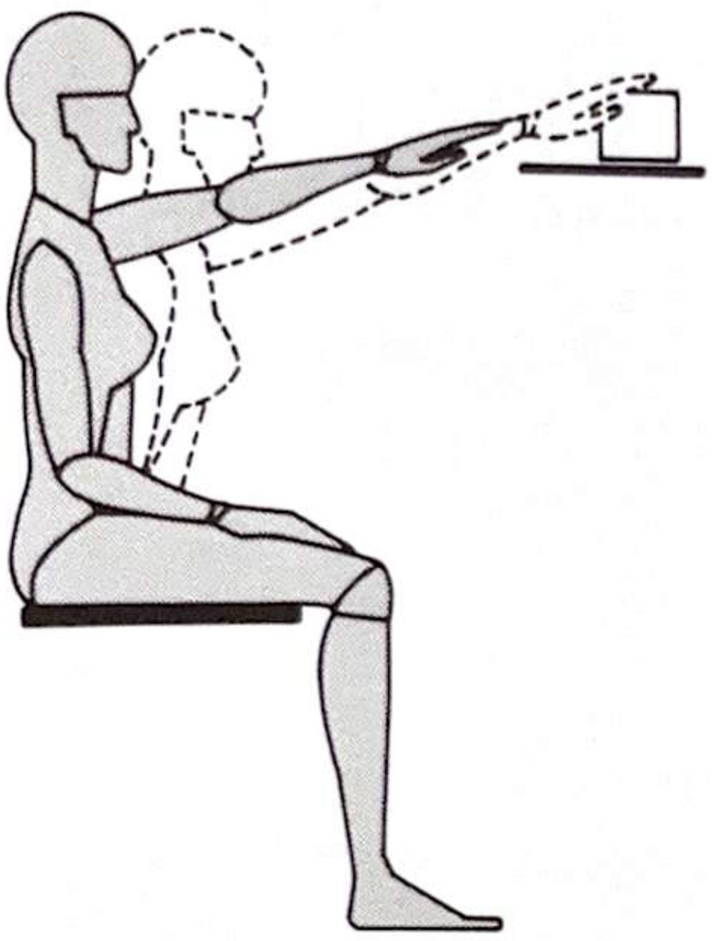


Figure 2–12. The ability to lean forward, even slightly, increases functional reach.

Sitting, all too often, is viewed as a task that is essentially static in nature. Nothing could be further from the truth. The act of sitting, in actuality, involves almost continuous repositioning in order to respond to the demands of the various activities to be performed in that position. Moreover, one cannot deal exclusively with the body in the seated position. The movements involved in getting into and out of the seat must be considered. Also, the entire sitting process must be perceived within a continuum of motion.

On balance, then, given all the other variables involved, many of which have yet to be defined or measured, the designer should not always interpret the anthropometric data too literally. Any attempt to simulate graphically and in two dimensions the dynamic patterns of body movements, which by their very nature involve time, space, and three dimensions, is bound to lose something in the translation.

2.6 RANGE OF JOINT MOTION

It is obvious that the extent to which the body's joints can move or rotate will impact greatly on the individual's interface with the physical environment. Movement of the head, for example, as illustrated in Figure 2-11, will greatly increase the area of visibility. The ability to lean forward, as illustrated in Figure 2-12, will increase functional reach, as will the ability to kneel or to stand on one's toes. It is helpful, therefore, if not essential, that the designer have some knowledge of the range of joint motion.

The angle formed by two body segments or by one such segment and a vertical or horizontal plane usually defines the range of joint motion at any given time. The total range is measured by the angle formed between the two most extreme positions possible, given the normal constraints of bone and muscle structure. The methodologies, devices, and techniques necessary for accurately measuring the range of motion of body joints are numerous and vary in complexity from a goniometer, a simple protractor-like device, to highly sophisticated photographic techniques. Joint motion can be more clearly understood when considered in terms of the body linkage system shown in Figure 2-13. The links are theoretically viewed as straight line distances between centers of joint rotation.

Movable joints are divided into three general types. The first involves a single plane freedom of motion in one direction only from a starting position. Termed hinge joints, the elbow and the knee are typical examples. The second involves motion in two planes originating from a zero starting position. This type of motion is typified by the wrist. The third type of joint, the so-called ball and socket, allows three dimensional, or rotary, motion as in the shoulder or hip.

The types of joint movement of particular concern to the designer are flexion, extension, abduction, adduction, medial rotation, lateral rotation, pronation, and supination. This classic terminology is defined and illustrated in Table 9 in Part B of this book. Several factors can affect the range of joint motion. Sex is a significant factor. A study in this regard indicates that women, in general, exceed men in range of joint motion measurements at all joints except the knee.[8] The widest range of joint motion in both sexes, as would be expected, is found

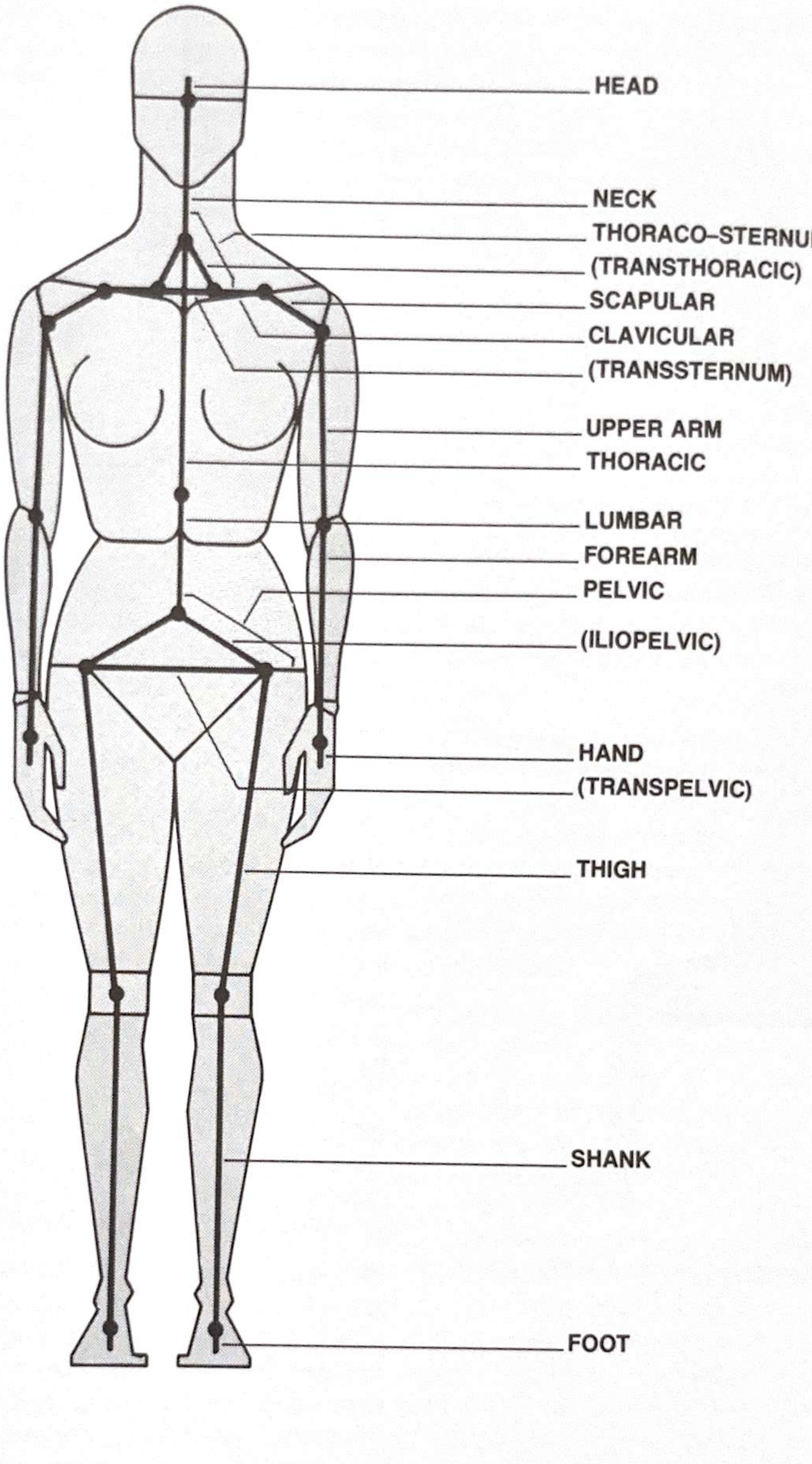


Figure 2–13. Body linkage system. Adapted from linkage system diagram, *Anthropometric Source Book,* vol. 1.

among the most slender, while the least range of motion is found among the fattest. Age, by itself, surprisingly, does not dramatically decrease or otherwise inhibit joint motion. It has been observed that between the first and seventh decades the mobility of joints decreases by approximately 10 percent, with very little of that change occurring after puberty. It should be noted, however, that arthritis, which usually increases in incidence after middle age, will result in a general decrease in average joint mobility of any population.

2.7 RESTRAINTS

It is important here to caution the student, the interior designer, or the architect against viewing the anthropometric data presented as information so precise and so "scientifically correct" as to be infallible. It is stressed that anthropometry, at least at its present stage of development, is not so exact a science as one might wish. The data should be viewed, however, as one of many sources of information or tools available to the designer of interior space. The danger is for the designer to substitute tabular data for common sense, function, or design sensitivity, which are all essential parts of the creative design process. While the authors of this book have provided as much anthropometric information as could be accumulated considering the state of the art, more information is constantly being produced, and undoubtedly, some may not be included here. This is due to the incipient nature of the science of anthropometry and the lack of a significant number of professionals involved in research in the area. In fact, there is a vast amount of data yet unavailable, particularly with respect to children and physically disabled and elderly people. In addition, more information about functional dimensions is needed.

Finally, to place the use of the data presented in ultimate perspective, one should consider the three-dimensional dynamics of "man in motion," the psychological aspects of space and the user, and the proxemic factors involved. Obviously, physical body size is only one of a vast number of human factors that impact on establishing the dimensions of interior spaces.

3 ELDERLY AND PHYSICALLY DISABLED PEOPLE

3.1 ELDERLY PEOPLE

It was noted in the Introduction that most available anthropometric data are related to military populations and, of consequence, are generally restricted in terms of age and sex. The National Health Survey of the U.S. Public Health Service is probably the first large-scale study prepared with respect to civilian populations and is based on a national sampling of Americans between the ages of 18 and 79. If information regarding the civilian population generally appears to be limited, however, anthropometric data for specific segments of the population, such as aged people, is sparser still.

When one considers that there are now close to 20 million Americans over the age of 65, with the number increasing yearly, it becomes apparent that the need for anthropometric data for this segment of the population is critical. Moreover, the data are essential if we are to respond sensitively in designing the interior spaces in which elderly people are to function.

Some data are available and some conclusions have been drawn. The most significant findings are as follows:

1. Older people of both sexes tend to be shorter than younger people. To a certain degree, however, the difference may be accounted for because the older individuals are obviously representative of an earlier generation, while recent studies indicate that body sizes generally are increasing. It has also been suggested that the decreases might be due to the selective survival of short, light people—an extremely interesting speculation.
2. Reach measurements of older people are shorter than those of younger people. There is also considerable variability in the degree to which the reach of elderly people is impaired due to the incidence of arthritis and other joint movement limitations. This is particularly true of vertical grip reach.

The basic problem with most of the available anthropometric data is the small size of the group studied. For example, data on "the functional anthropometry of old men" (Chart 3-1) prepared by Damon and Stoudt[1] and "the functional anthropometry of elderly women" (Chart 3-2 and Figure 3-1) prepared by D. F. Roberts[2] were based on 133 subjects and 78 subjects, respectively. Perhaps the best available data, which are in a percentile form required by the designer, are given in the National Health Survey, which includes data up to age 79. These data are included in Part B.

Measurement	Number	Mean	SD	Percentiles						
				1st	5th	10th	50th	90th	95th	99th
Weight (lb)	130	152.49	23.19	112	119	124	151	184	192	204
Stature	119	66.28	2.09	61.6	63.3	63.7	66.1	69.3	69.9	70.3
Sitting height, erect	119	34.77	1.21	32.5	33.0	33.2	34.7	36.5	37.0	37.2
Sitting height, normal	131	33.42	1.45	29.7	31.0	31.6	33.4	35.2	35.9	36.5
Trunk height, sitting	131	22.57	1.24	19.8	20.5	20.9	22.7	24.3	24.5	24.9
Knee height, sitting	132	21.19	0.85	19.4	19.9	20.1	21.2	22.3	22.6	23.4
Popliteal height, sitting	131	17.31	0.83	15.4	15.7	16.3	17.2	18.4	18.6	19.2
Span	120	68.50	2.76	63.3	64.2	64.8	68.5	71.5	72.7	75.7
Span akimbo	121	35.69	1.52	32.4	33.4	33.8	35.7	37.3	37.9	39.4
Forward arm reach	118	34.21	1.51	31.2	31.7	32.3	34.2	36.1	37.0	38.4
Shoulder–elbow length	131	14.53	0.66	13.4	13.5	13.7	14.5	15.3	15.6	16.4
Elbow–middle finger length	130	18.27	0.71	16.9	17.2	17.4	18.3	19.3	19.5	20.4
Buttock–popliteal length	131	18.57	1.00	16.5	16.9	17.4	18.5	19.8	20.3	21.1
Buttock–knee length	132	23.26	0.96	21.0	21.8	22.1	23.2	24.6	25.0	25.4
Head length	133	7.74	0.25	7.1	7.3	7.4	7.7	8.0	8.1	8.3
Face length	127	4.96	0.27	4.4	4.6	4.6	5.0	5.3	5.5	5.6
Nose length	133	2.37	0.14	2.0	2.1	2.2	2.4	2.5	2.6	2.7
Ear length	132	2.94	0.19	2.5	2.6	2.7	2.9	3.2	3.3	3.4
Hand length	130	7.41	0.31	6.7	7.0	7.0	7.4	7.8	8.0	8.2
Foot length	132	10.24	0.39	9.2	9.7	9.8	10.2	10.8	10.9	11.3
Biacromial breadth	133	14.90	0.64	13.3	13.7	14.1	14.9	15.7	15.9	16.3
Bideltoid breadth	129	17.07	0.90	15.3	15.6	15.8	17.0	18.2	18.5	19.1
Chest breadth	133	11.64	0.81	9.9	10.2	10.6	11.7	12.7	13.0	13.4
Elbow-to-elbow breadth, sitting	132	17.81	1.32	15.0	15.5	16.2	17.8	19.3	20.1	21.0
Bi-iliac breadth	132	12.28	0.67	10.9	11.2	11.4	12.3	13.2	13.5	13.9
Hip breadth, sitting	131	14.87	0.94	13.2	13.5	13.7	14.8	16.1	16.7	17.2
Knee-to-knee breadth, sitting	129	8.07	0.52	7.3	7.5	7.6	8.0	8.5	8.7	10.1
Head breadth	133	6.07	0.20	5.6	5.8	5.8	6.1	6.3	6.4	6.5
Face breadth	132	5.55	0.23	5.1	5.2	5.3	5.6	5.8	5.9	6.1
Nose breadth	131	1.57	0.15	1.3	1.4	1.4	1.6	1.8	1.9	2.0
Ear breadth	122	1.47	0.12	1.2	1.3	1.4	1.5	1.6	1.7	1.8
Hand breadth	129	3.32	0.15	3.0	3.1	3.1	3.3	3.5	3.6	3.7
Foot breadth	119	3.93	0.19	3.5	3.6	3.7	3.9	4.2	4.3	4.3
Chest depth	133	9.58	0.78	7.9	8.2	8.5	9.6	10.6	10.8	11.2
Abdominal depth	126	10.83	1.32	8.4	8.6	9.1	10.8	12.4	13.2	14.0
Chest circumference, rest	133	37.87	2.98	32.0	33.3	33.7	37.9	41.3	42.0	46.0
Chest circumference, insp.	130	38.42	2.92	32.6	33.5	34.6	38.4	42.1	42.9	46.9
Chest circumference, exp.	130	37.28	3.00	31.5	32.0	33.3	37.4	40.9	42.1	44.9
Waist circumference	108	35.46	3.68	28.5	30.2	30.7	35.2	40.2	42.1	44.1
Upper arm circumference	133	11.28	1.11	8.9	9.5	9.8	11.4	12.8	13.0	14.0
Calf circumference, right	110	13.50	1.07	11.6	12.0	12.2	13.4	14.8	15.2	16.2
Calf circumference, left	109	13.48	1.01	11.7	11.9	12.1	13.4	14.8	15.4	15.8
Head circumference	133	22.34	0.72	21.0	21.3	21.5	22.4	23.2	23.3	23.8
Triceps skinfold (mm)	133	11.36	4.22	4.2	5.9	6.7	10.6	17.1	19.0	24.2
Subscapular skinfold (mm)	133	16.18	6.76	5.9	7.0	8.5	15.5	24.8	26.7	43.2
Grip strength, right (lb)	118	63.49	17.33	27.8	41.2	45.6	62.4	87.3	90.8	102.1
Grip strength, left (lb)	119	58.77	18.10	38.6	41.0	43.2	61.3	79.4	84.4	97.9

Chart 3–1. Functional anthropometry of elderly men. From Damon and Stoudt, "The Functional Anthropometry of Old Men," *Human Factors,* 1963, p. 488.

		M*	SD*	n*
	age	71–65 yr	7–51	78
	weight	132–68 lb	29–74	76
A	stature with shoes	61–16 in	2–50	77
	stature without shoes	60–06 in	2–45	78
B	eye height, standing	55–54 in	2–66	78
C	acromial height, standing	49–48 in	2–14	78
D	elbow height, standing	36–73 in	1–89	78
	heel height	1–13 in	0–44	77
Sitting on a 17–in chair				
		in		
a	elbow height above seat	7–57	1–21	78
b	vertex height above seat	31–27	1–43	78
c	eye height above seat	26–82	1–47	78
d	occiput height above seat	28–09	1–44	78
e	height of shoulder blades above seat	15–68	1–09	78
f	height to acromion above seat	20–67	1–23	78
g	popliteal height from floor	15–15	0–85	78
h	height to top of knee from floor	18–83	0–87	78
i	height of top of thighs above seat	4–96	0–90	78
j	distance from front of knee to sacral plane	22–04	1–36	78
k	distance from popliteal angle to sacral plane	18–46	1–14	78
l	distance from heel to sacral plane	36–76	1–78	78
m	width of thighs	14–74	1–55	78
n	bideltoid width	16–26	1–17	78
o	horizontal distance from back of thorax to gripped pencil, arm horizontal	28–56	1–67	78
p	horizontal distance from back of thorax to gripped pencil, arm straight, hand 11 in above seat	25–35	1–84	78
Standing				
		in		
q	distance from abdomen to gripped pencil, arm horizontal	18–54	2–40	77
r	distance from abdomen to gripped pencil, hand on 34–in table	13–96	2–34	77
s	maximum comfortable upward reach	71–67	3–43	78
t	maximum comfortable upward reach with 14–in obstruction	67–04	3–89	77
u	fist carrying height at side	27–58	1–87	78
v	fist carrying height with 14–in obstruction	32–43	2–07	77
w	radius of chalk circle, right hand, arm straight	19–29	1–55	77
	grip diameter—index finger	1–34	0–15	76
	grip diameter—middle finger	1–56	0–17	77
	grip strength	13–95 kg	4–29	76

*M = mean; SD = standard deviation; n = no. in sample.

Chart 3–2. Functional anthropometry of elderly women. From Roberts, "Functional Anthropometry of Elderly Women," *Ergonomics* 3 (1960), pp. 321-327.

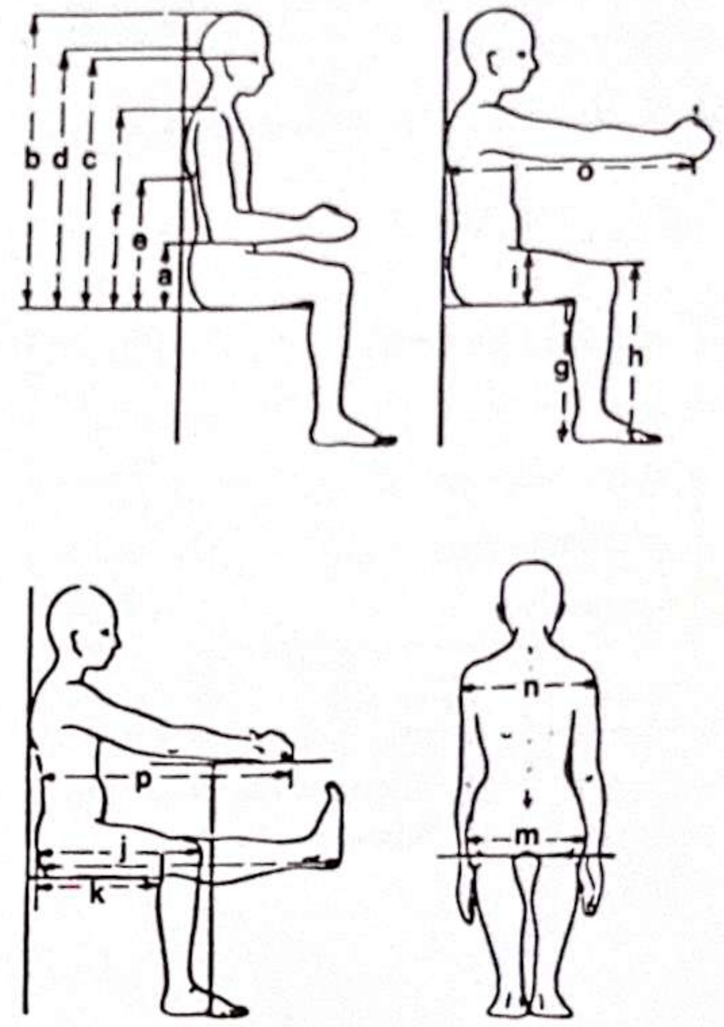


Figure 3–1. Figures illustrating body measurements indicated in Chart 3.2. From Roberts, "Functional Anthropometry of Elderly Women," *Ergonomics* 3 (1960), pp. 321-327.

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CATEGORY	NUMBER OF INDIVIDUALS
VISUAL:	
25% vision loss	4,105,000
50% vision loss	184,000
75% vision loss	618,000
100% vision loss	483,000
	5,390,000
ORTHOPEDIC AIDS:	
Wheelchairs	409,000
Crutches	443,000
Canes	2.156,000
Walkers	404,000
Braces	1,102,000
Artificial Limbs	172,000
Special Shoes	2,337,000
	7,023,000
AUDITORY:	
Deaf	1,800,000
Hard of Hearing	18,300,000
	20,100,000
CARDIO-VASCULAR:	7,600,000
RESPIRATORY:	14,500,000
MENTAL RETARDATION:	5,120,000
ARTHRITIS:	18,300,000
AGING: Over age 65	7,000,000
CHILDHOOD: Ages 5-12	32,550,000
PREGNANCY:	3,730,000
	TOTAL = 121,313,000
Total U.S. population	= 215,000,000

Chart 3–3. Distribution of disabilities by category. From Selim, *Barrier Free Design*, 1977.

3.2 PHYSICALLY DISABLED PEOPLE

The problem of physically disabled people coping with the man-made environment is a massive one. The U.S. Department of Health, Education, and Welfare estimated in 1970 that some 69 million people in the United States alone are physically limited.[3] Chart 3-3 shows a distribution of disabilities by category compiled by the Michigan Center for a Barrier-Free Environment from the sources indicated. It underscores the magnitude of the problem on a national basis. On a cosmopolitan basis, figures place the worldwide physically disabled population at 400 million, of which over 75 percent are left to their own devices.

To solve all the problems of all the physically disabled people with respect to their interface with physical barriers is obviously an interdisciplinary undertaking that transcends the scope of this book. However, the anthropometrics involved can be introduced here; they will be explored further in Part C.

3.3 CHAIRBOUND PEOPLE

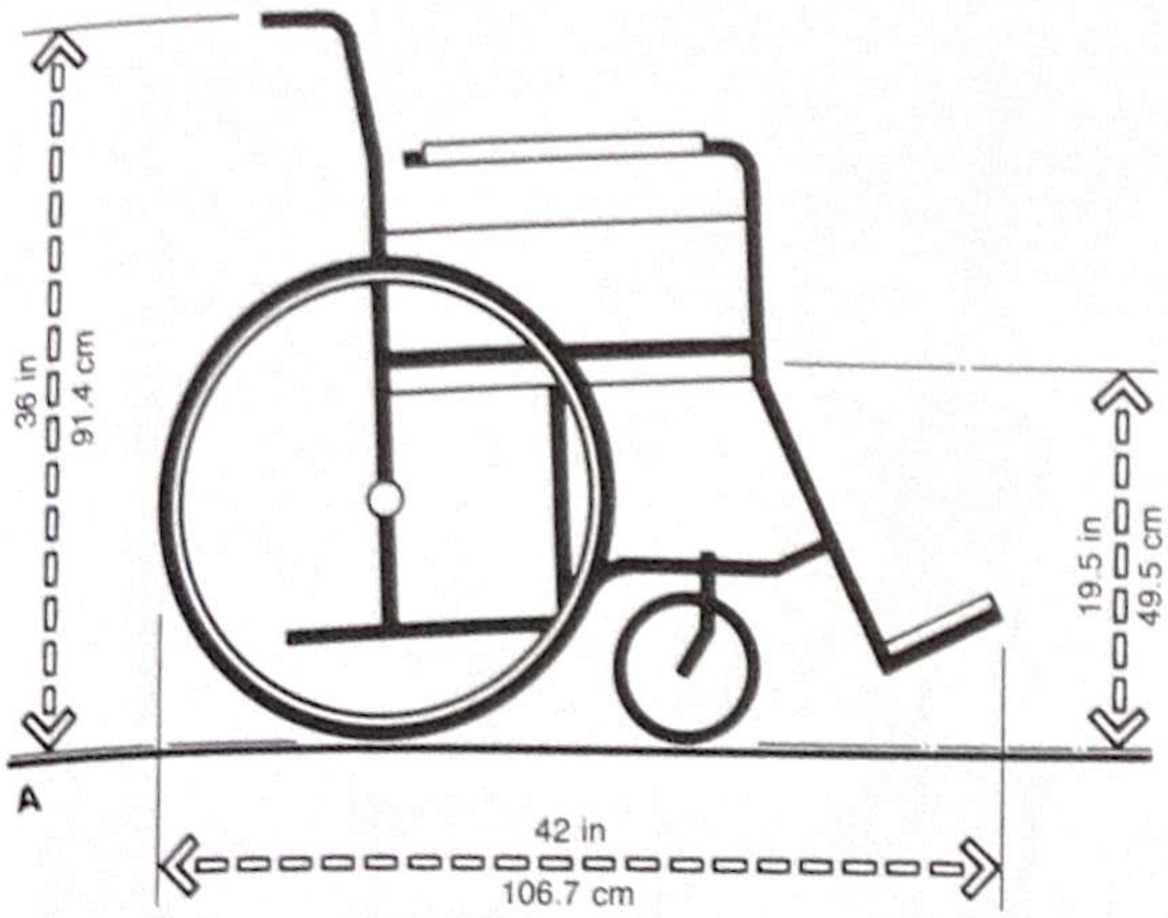
There are no large-scale data on the anthropometrics of chairbound people. Such a study would be quite difficult in view of the many variables involved: the types of disabilities, the limbs or segments of the bodies involved, the extent of paralysis, the degree of muscle dysfunction, the cumulative effect on overall limb mobility due to chair confinement, etc. All would have to be considered. For study purposes, therefore, the assumption has been made that where limb mobility has not been impaired, the range of movement would approximate that of able-bodied people.

It is, however, important that in determining appropriate reach, clearance, and other dimensions, the individual and the wheelchair be viewed together. This requires some knowledge of the anatomy of the wheelchair itself. Figure 3-2 provides some basic and useful data on this.

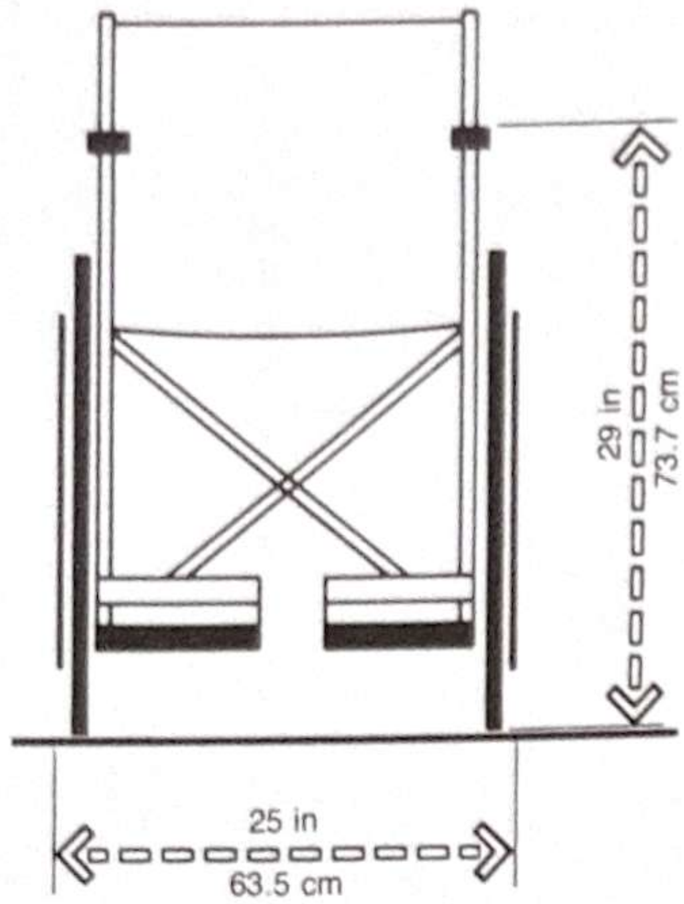
With regard to the anthropometrics involved, there are many diagrams in circulation illustrating body measurements of men and women in wheelchairs. Caution should be exercised in interpreting, and subsequently applying, the data indicated. In many instances, the reach dimensions are qualified to indicate a so-called average dimension. This notion of average was discussed in Section 2.2 and proved to be fallacious. If reach is a critical factor in the particular design, it is essential to base the design on those body dimensions representative of the lower range of the population, not the average. Consequently, the 5th percentile arm reach data should be used. If the design were based on the so-called average reach, half of the chairbound users simply could not function.

Figure 3-3, Chart 3-4, and Figure 3-4 illustrate the anthropometrics of chairbound people. What should be noted, however, is that most wheelchairs are not built to keep the body in an erect position. Accordingly, body parts are not strictly vertical or horizontal. In describing the geometrics involved, Dr. Herman L. Kamenetz states:

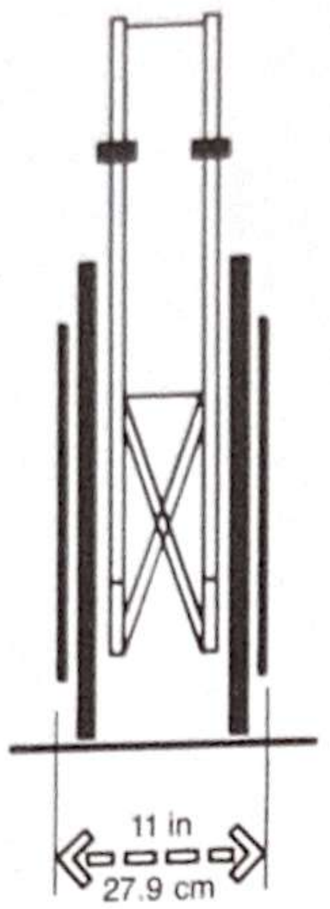
> From this imagined posture only the ankles keep their position of 90 degrees. The legs are lifted by about 15 degrees so that the knees assume



SIDE ELEVATION



FRONT ELEVATION



FRONT ELEVATION

TURNING RADIUS BASED ON MOVING WHEELS IN OPPOSITE DIRECTIONS AND PIVOTING ABOUT CENTER

TURNING RADIUS BASED ON LOCKING ONE WHEEL AND TURNING THE OTHER WITH THE PIVOT POINT ON THE LOCKED WHEEL

ALTERNATE WHEELCHAIR TURNING RADII

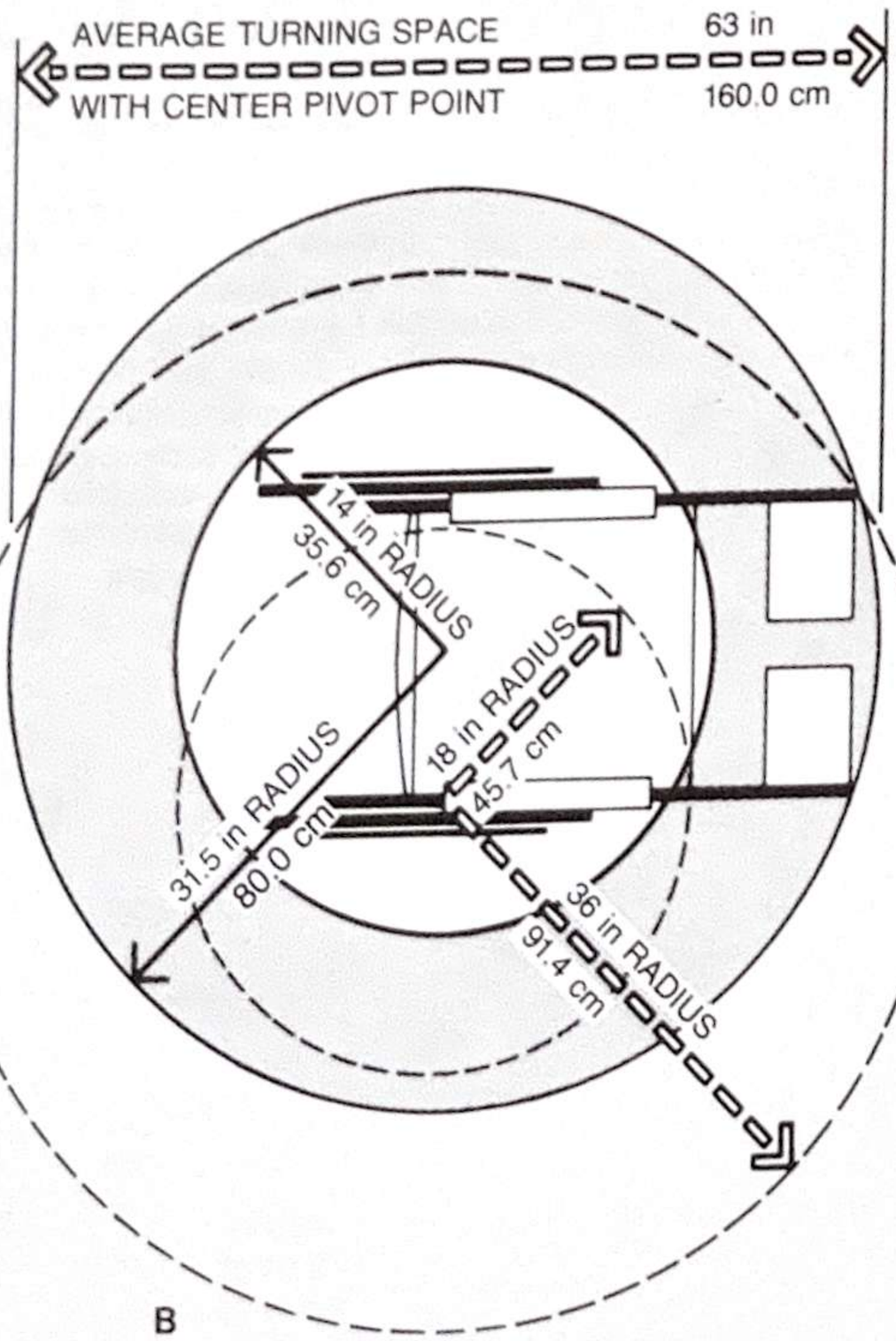


Figure 3–2. (*a*) Wheelchair dimensions. The source of the dimensions shown is the American National Standards Institute (ANSI Pub. A117–1961, Revalidated 1971). The measurements indicated, however, vary with model and manufacturer, and each chair should be measured individually. The length of the chair is of particular importance since it determines the turning radius. It is essential also, when calculating clearances, to allow for the protrusion of the feet beyond the edge of the footrests. ANSI contends that the collapsible model wheelchair of tubular metal construction with plastic upholstery for back and seat is the one most commonly used and falls within the dimensions indicated. (*b*) Alternate wheelchair turning radii.

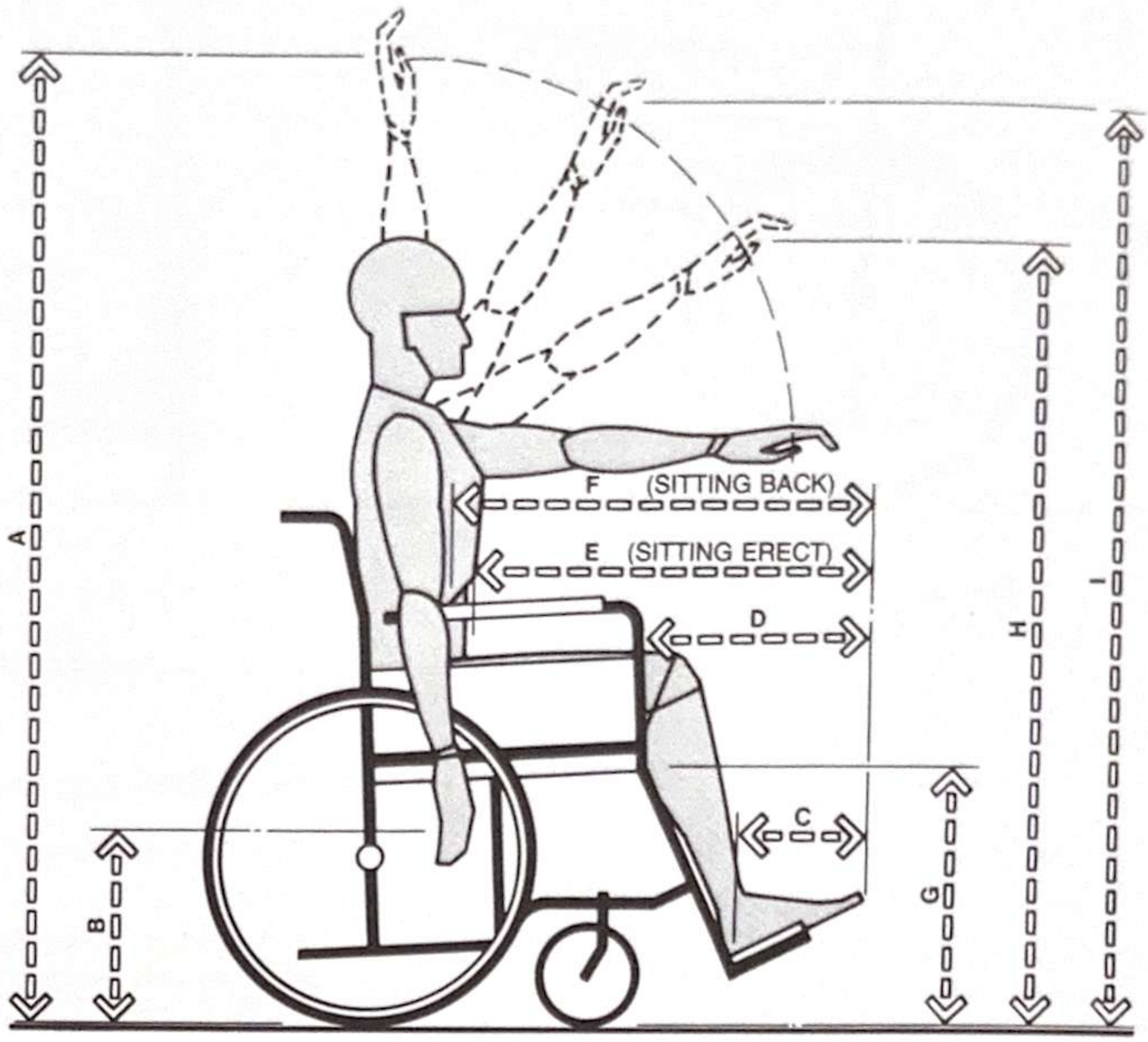


Figure 3–3. Anthropometrics of chairbound people. The side view, showing user and chair, indicates some of the more critical anthropometric measurements for both men and women. All reach dimensions are based on 2.5 percentile data to accommodate those users with smaller body sizes. It is recommended that since the female body size is smaller than the male, the female dimensions be used for the design of all reach situations. Dimensions involving clearance problems are based on 97.5 percentile data. Since the male body size is larger, the dimensions for men should be used to satisfy clearance requirements. The figure and data were adapted from Goldsmith's *Designing for the Disabled,* 1963, and were based on measurements obtained from British and American studies.

	MALE		FEMALE	
	in	cm	in	cm
A	62.25	158.1	56.75	144.1
B	16.25	41.3	17.5	44.5
C	8.75	22.2	7.0	17.8
D	18.5	47.0	16.5	41.9
E	25.75	65.4	23.0	58.4
F	28.75	73.0	26.0	66.0
G	19.0	48.3	19.0	48.3
H	51.5	130.8	47.0	119.4
I	58.25	148.0	53.24	135.2

Chart 3–4. Data accompanying Figure 3–3.

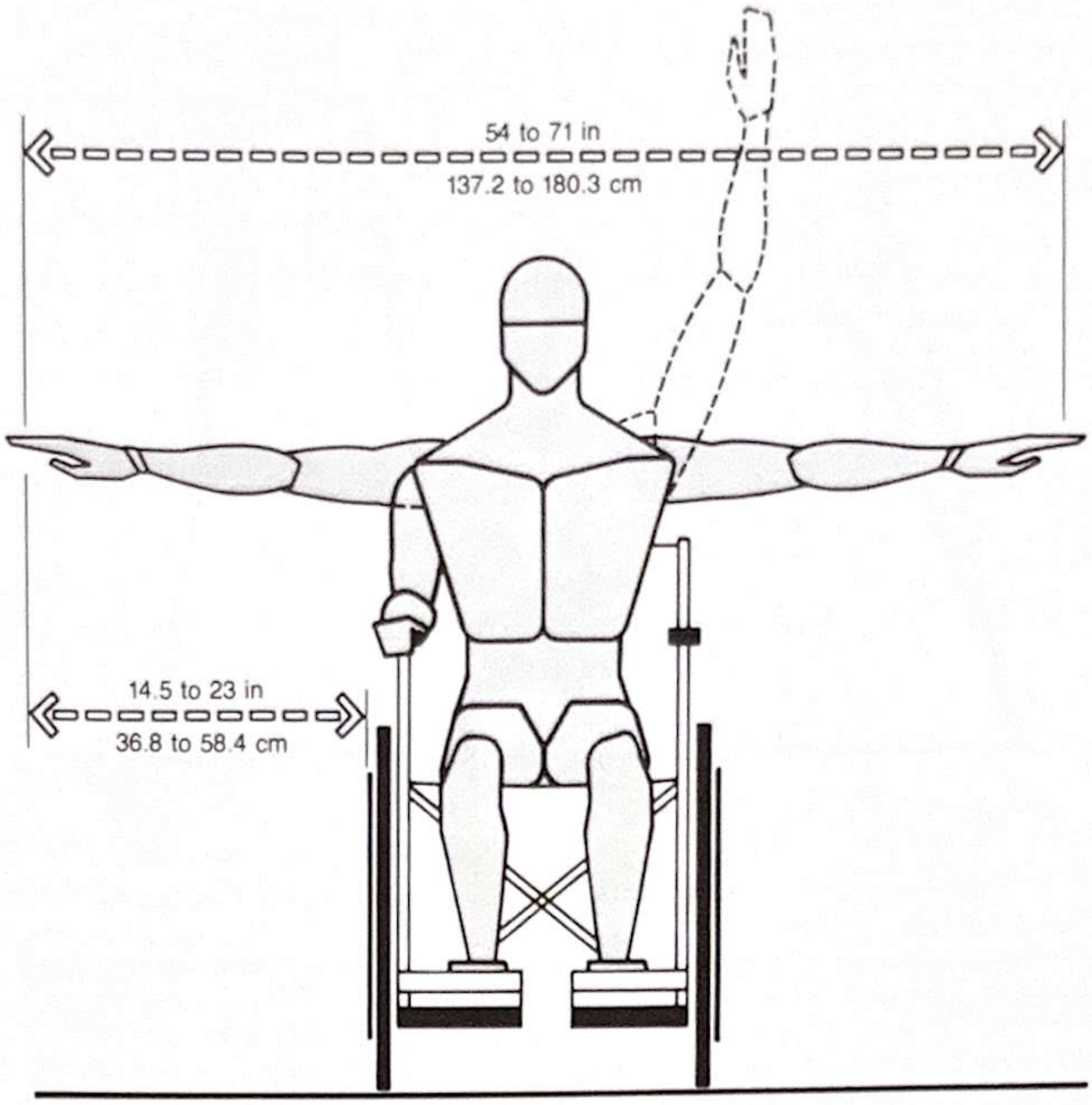


Figure 3–4. Anthropometrics of chairbound people. The front view, showing user and chair, also indicates some of the more critical anthropometric measurements. The source of the bilateral horizontal reach dimensions with both arms extended to each side, shoulder high, was the American National Standards Institute (ANSI Pub. A117-1961, Revalidated 1971). It should be noted that no data were available with regard to sex or precise percentile grouping.

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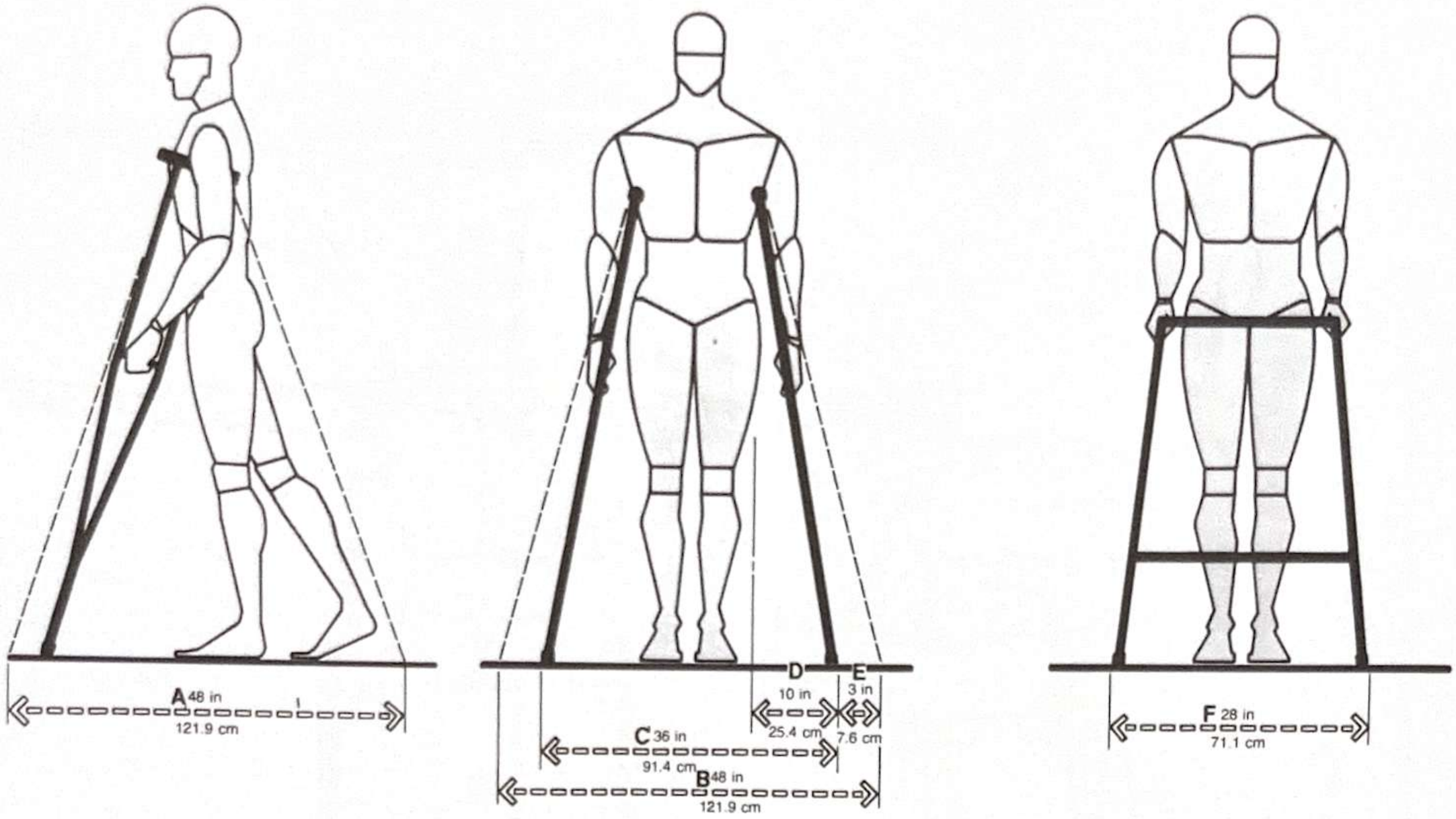

Figure 3–5. Crutches. The mode, gait, and speed of the user is impeded significantly by the use of crutches. Changes of grade and circulation up or down stairs are extremely difficult and in some situations almost impossible. The limited use of the user's lower extremities as well as manipulation and placement of crutches significantly limit the leverage that he or she can develop, particularly as may be required in opening or closing doors and getting in and out of seats. The critical dimensions that impact on clearance include crutch swing (A), walking crutch swing (B), standing crutch span (C), body crutch span (D), and body crutch swing (E). For users with severe arthritis and cerebral palsy, the clearances indicated may have to be increased.

Figure 3–6. Walker. The clearance required by a user employing the aid of a walker is more easily defined by the inherent nature of the device and method of operation. The front view of the user indicates a minimum of 28 in (F), or 71.1 cm.

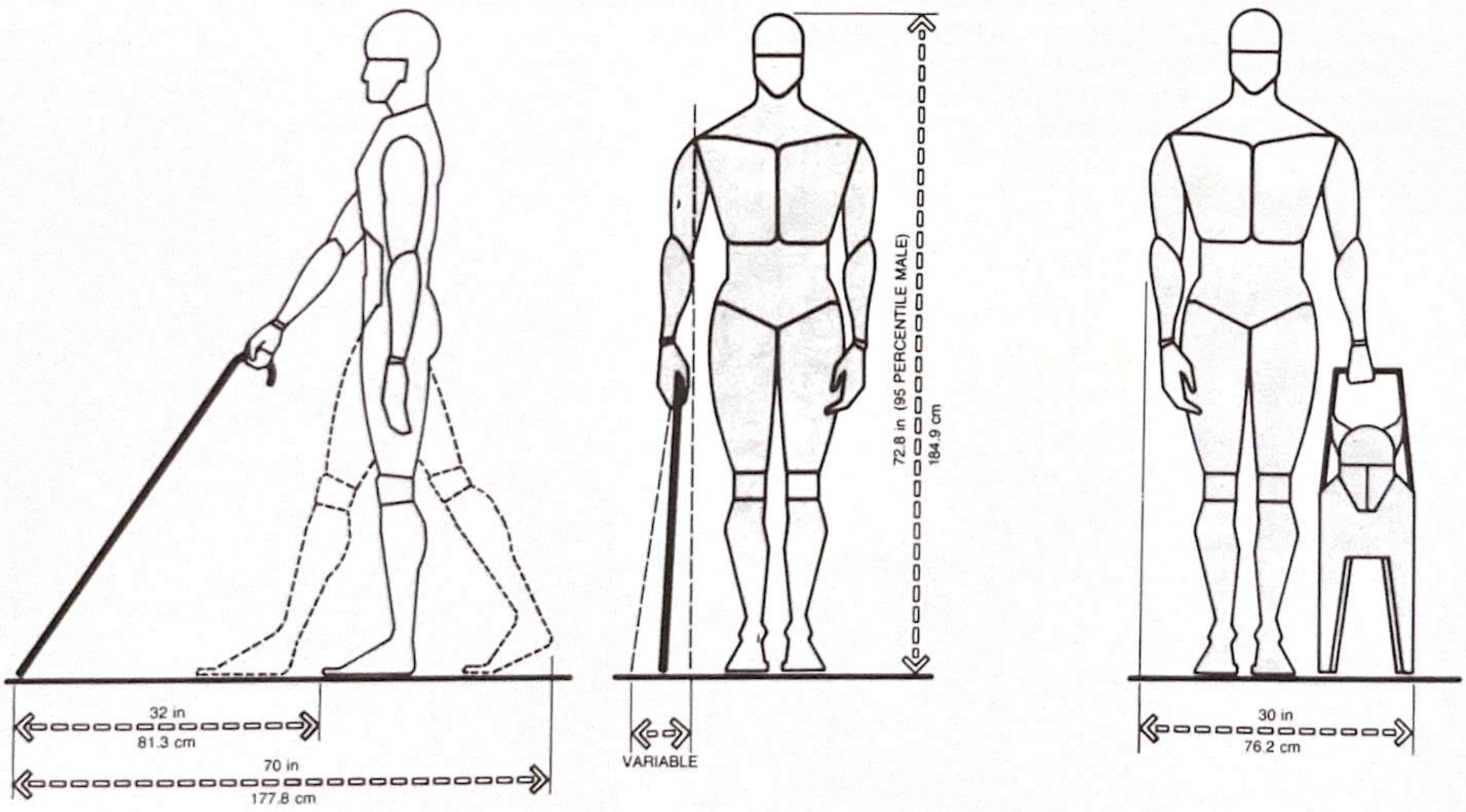

Figure 3–7. Canes. Canes may be utilized by someone who is blind, who has an injured limb, or who might be suffering from a host of afflictions such as varying degrees of aging, arthritis, cerebral palsy, diabetes, multiple sclerosis, and other maladies. The blind user, however, because of the nature of the disability, would require the maximum space for clearance. The side and front views of the user indicate the clearance allowances required.

Figure 3–8. Seeing-eye dog. Given the many variables involved, the precise combined clearance data for user and dog are difficult to establish. A clearance of 30 in, or 76.2 cm, however, would constitute the very minimum allowance.

an angle of about 105 degrees, and the back reclines by about 10 degrees, which results in an angle at the hip joints of about 100 degrees. Finally, the body being kept in this relationship of its parts to one another, the entire chair is as though it were tilted backward by about 5 degrees, so that the seat is 5 degrees from the horizontal, the legs 20 degrees, and the back 15 degrees from the vertical.[4]

If the user's impairment permits him or her to assume an erect position, the incline of the chair back notwithstanding, standard anthropometric data for arm reach would be adequate, given the nature of the task and degree of fit involved.

If, however, arm reach is based on the back being in an inclined position, 15° from the vertical, the standard anthropometric arm reach data would have to be modified accordingly. It should be noted that measurement of standard arm reach is taken with the back erect and with the subject seated on a horizontal plane.

3.4 AMBULANT DISABLED PEOPLE

For ambulant disabled people, it is necessary to consider those users functioning with crutches (Figure 3.5), walkers (Figure 3.6), canes (Figure 3.7), and seeing-eye dogs (Figure 3.8). All these aids become, in essence, a functional part of the individual's body. Accordingly, both aid and user should in almost every instance be viewed as a single entity. For design purposes it is useful to know something not only of the anthropometry involved, but of the total spatial considerations.

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4 ANTHROPOMETRICS OF SEATING

The design of seating can be traced at least to antiquity. The stool, for example, had already been developed into a valued article of furniture by the Egyptians as far back as 2050 B.C. and the chair as far back as 1600 B.C.[1] Despite its ubiquity and long history, however, seating is still one of the most poorly designed elements of interior space. Industrial designer Neils Diffrient has said that "Chair design is the acid test for designers."[2] One of the major difficulties in the design of seating is that sitting is, quite frequently, viewed as a static activity while, in actuality, it is a rather dynamic one. Accordingly, the application of static two-dimensional data, alone, to solve a dynamic three-dimensional problem, involving biomechanical considerations, is not a valid design approach. Paradoxically, a chair that is anthropometrically correct may not necessarily be comfortable as well. If the design, however, is simply not responsive at all to human dimensions and body size, there is no question that the seating will, in fact, be uncomfortable.

Another difficulty is that very little data are available with respect to the biomechanics of chair design and practically no research has been published with respect to "comfort." All that can be provided in this section, as well as in Part C, are some broad guidelines, basic concepts, and recommendations.

4.1 THE DYNAMICS OF SITTING

The dynamics of sitting can be more clearly illustrated by studying the mechanics of the support system and the general bone structure involved. According to Tichauer, "The axis of support of the seated torso is a line in a coronal plane passing through the projection of the lowest point of the ischial tuberosities on the surface of the seat."[3] Figures 4-1 and 4-2 show the tuberosities. Branton makes two observations in this regard. The first is that, when sitting, about 75 percent of the total body weight is supported on only 4 square inches (sq in), or 26 sq cm, of these tuberosities.[4] This constitutes an exceptionally heavy load, distributed over a relatively small area, and as a result, very high compressive stresses are exerted on the areas of the buttocks beneath. Tichauer indicated that these stresses have been estimated at 85 to 100 pounds per square inch (psi).[5] Other data have

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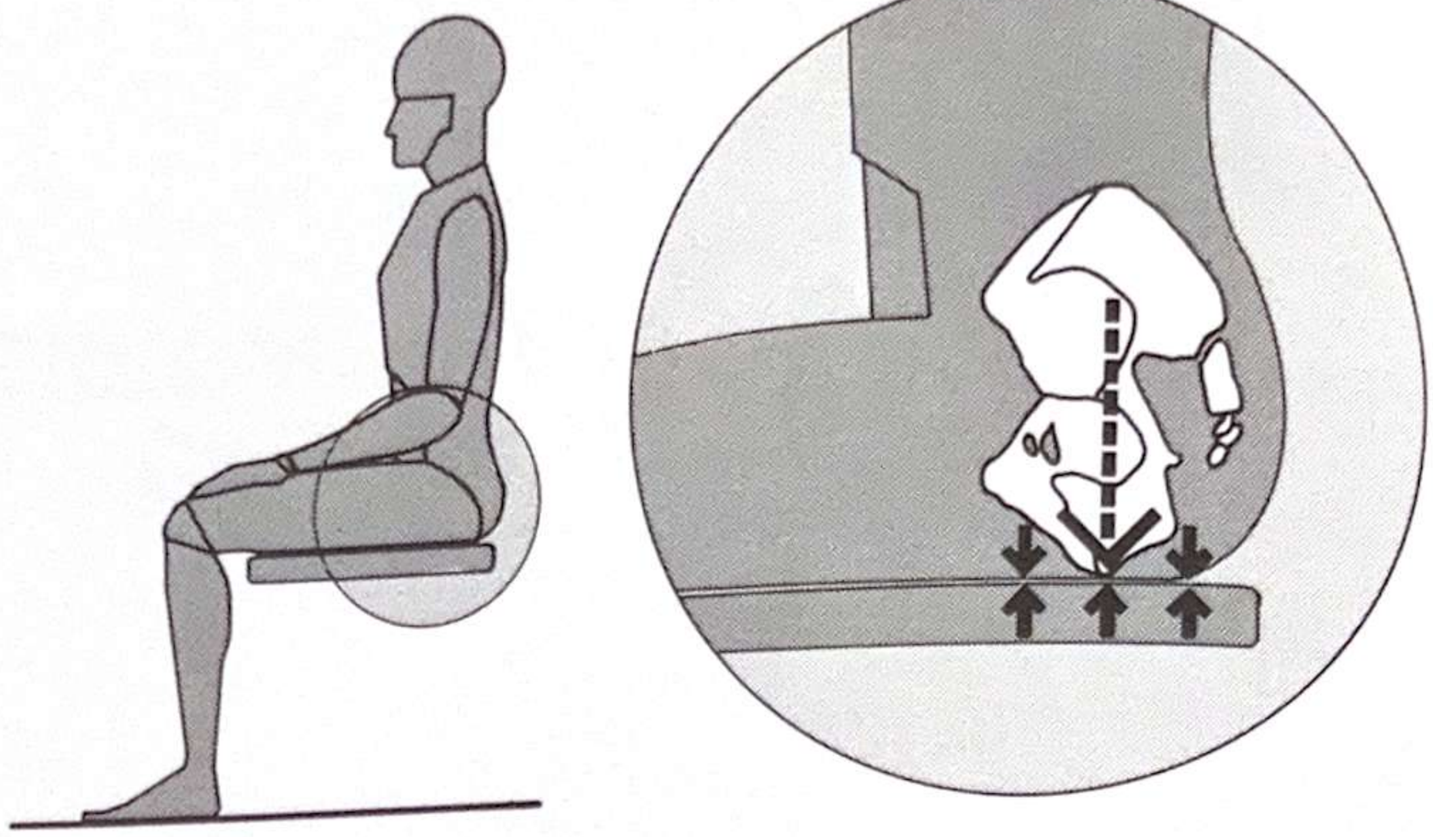

Figure 4–1. A sectional view of the seated figure showing the ischial tuberosities.

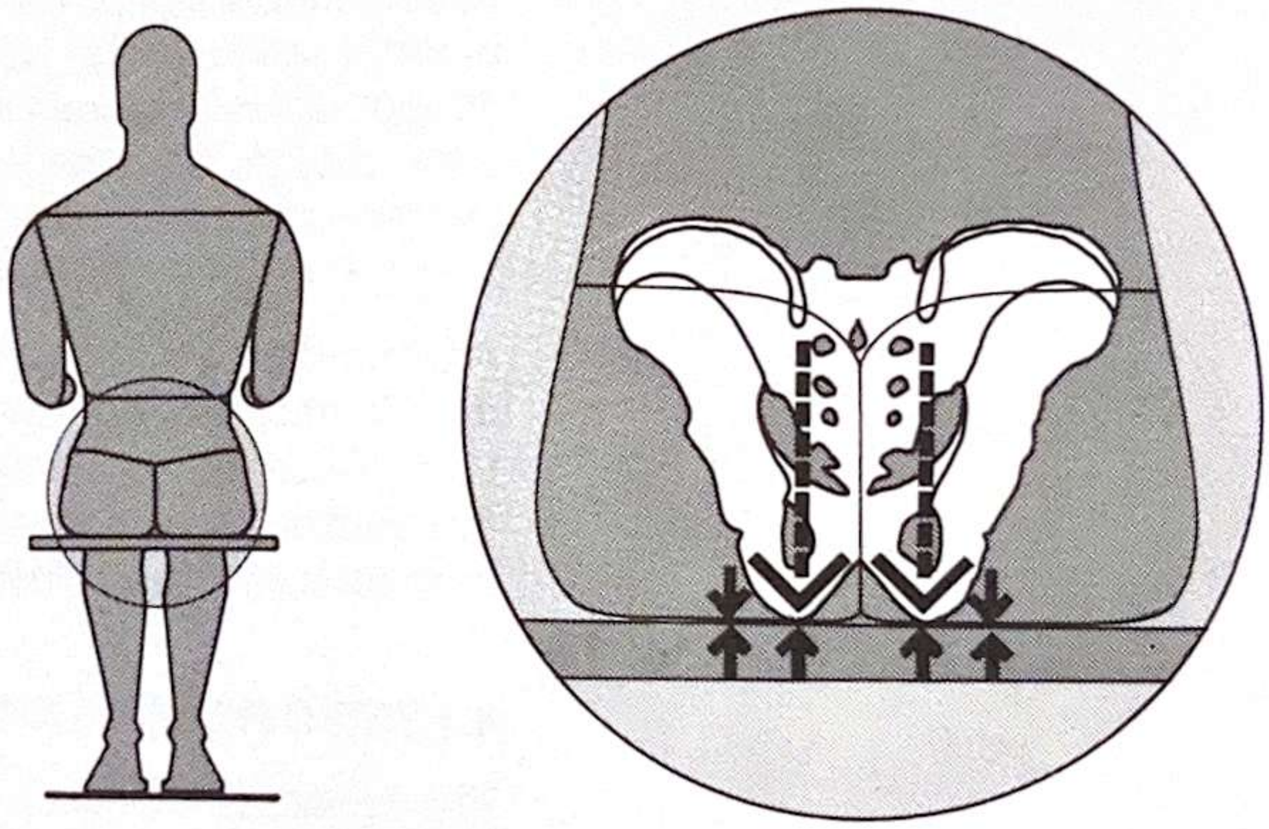

Figure 4–2. An enlarged posterior sectional view of the ischial tuberosities.

shown the compression pressures on the areas of the skin between the buttocks and a hard seat pan as high as 40 to 60 psi and the pressure a few inches away as only about 4 psi.[6] These pressures cause fatigue and discomfort and result in a change in the sitter's posture in an attempt to alleviate the condition. Prolonged sitting, without change in posture, under the compressive pressures cited may cause ischemia, or an interference in the blood circulation, resulting in aches, pains, and possible numbness.

It becomes obvious that the design of seating should provide for the distribution of the body weight supported by the ischial tuberosities over a larger area. Proper padding on the seat pan can accomplish this. It is apparent, too, that the design of the seating should also permit the sitter to change posture when necessary to alleviate discomfort. In this regard, proper anthropometric data are essential in determining the proper measurements and clearances required.

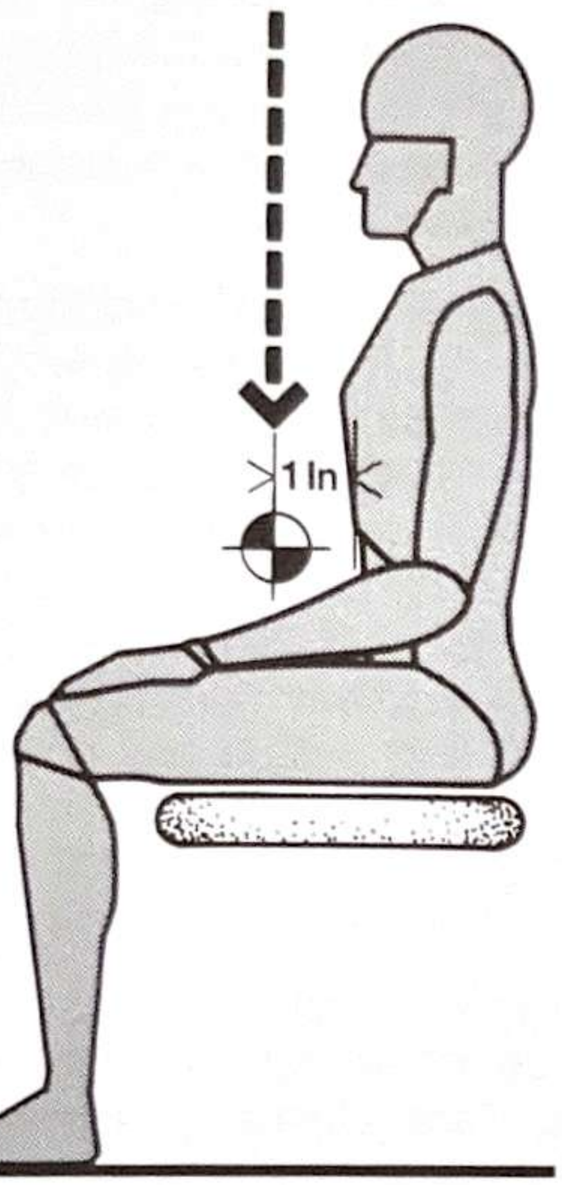

Figure 4–3. Center of gravity of the upright seated figure.

Branton's second observation is that, structurally, the tuberosities form a two-point support system which is inherently unstable.[7] The seat pan alone, therefore, is not sufficient for stabilization. Theoretically, the legs, feet, and back, in contact with surfaces other than the seat pan, should produce the necessary equilibrium. This would presuppose that the center of gravity was directly over the tuberosities. The center of gravity of the upright seated body, however, is actually located outside the body, about 1 in, or 2.5 cm, in front of the navel, as indicated in Figure 4-3. The combination of the two-point support system, in addition to the position of the center of gravity, has led Branton to suggest a scheme "in which a system of masses is inherently unstable on the seat."[8] He further suggests that if the system is to remain as stable as it normally appears to be, some internally active (muscular) forces must be assumed to be at work.

Given the many body postures assumed during any sitting period, in addition to the muscular activity involved, even when the body seems to be at rest, sitting is not the static type of activity it frequently is conceived to be. According to Branton, "the sitting body, therefore, is not merely an inert bag of bones dumped for a time in the seat, but a live organism in a dynamic state of continuous activity."[9]

It has also been contended that the many postures assumed while sitting are attempts to use the body as a lever system in an effort to counterbalance the weights of the head and trunk. Stretching the legs forward and locking the knee joints, for example, enlarges the base of the body's mass and reduces the effort of other muscles to stabilize the trunk. Other postures, such as holding up the chin with the hand while the elbow rests on the armrest or the lap, or supporting the head by leaning it against the headrest, are still other examples of the body's attempt at stabillization, providing relief to the muscle system and, in turn, alleviating discomfort. More significantly, these changes in posture occur without deliberation. Branton attempts to explain this phenomenon by suggesting the existence of an "internal 'posture program,' which enables the body to strike a running compromise between its twin needs for stability and variety."[10]

Of particular significance to the designer is the importance of the lo-

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cation of back-, head-, and armrests as well as their size and configuration, since it is these elements of the chair or seat that function as stabilizers. If the seat does not provide for proper body stabilization, the user must stabilize himself by assuming the various postures mentioned earlier. This requires the expenditure of additional energy due to the muscular effort involved and increases discomfort.

4.2 ANTHROPOMETRIC CONSIDERATIONS

In view of the elusive nature of sitter comfort and the fact that sitting is more of a dynamic activity than a static one, the relative importance of an anthropometrically oriented approach to seating design has occasionally been challenged. Although, as mentioned earlier, there is no guarantee that an anthropometrically correct chair will be comfortable, there seems to be general agreement that the design must, nevertheless, be based on properly selected anthropometric data. If it is not, there is little doubt that the seating design will cause the user discomfort. The essential anthropometric dimensions for seating design are shown in Figure 4-4 and Chart 4.1.

It should also be noted, however, that the data cannot be applied in a vacuum. In establishing chair dimensions, the anthropometric aspects must be related to the biomechanical demands involved. It was demonstrated previously, for example, that body stabilization involved not only the seat pan, but the legs, feet, and back in contact with other surfaces. In addition, some muscular force was also required. If, through improper anthropometric design, the chair did not allow the majority of users to, in fact, have foot or back contact with other surfaces, body instability would be increased and additional muscular force would have to be introduced in order to maintain proper equilibrium. The greater the degree of muscular force or control required, the greater the fatigue and discomfort.

It is necessary, therefore, that the designer become familiar with the anthropometric considerations involved in the design of seating and their relationship to the biomechanical and ergonomic imperatives implied. To deal with one without knowledge of the others is to solve only a part of the design problem. In this regard the generally accepted basic dimensions required in the design of seating include seat height, seat depth, seat width, backrest height, and armrest height and spacing.

4.3 SEAT HEIGHT

One of the basic considerations in the design of seating is the height of the top of the seat surface above the floor. If the seating surface is too high, the underside of the thigh becomes compressed, as illustrated in Figure 4-5. This can cause considerable discomfort as well as a restriction in blood circulation. If the height of the seat does not permit the soles of the feet proper contact with the floor surface, body stability is weakened. If the height of the seat is too low (Figure 4-6), the legs may become extended and positioned forward. The feet then are deprived of any stability. By and large, however, a tall person would be far more comfortable using a chair with a low seat height than a short person using a chair with a seat height that is too high.

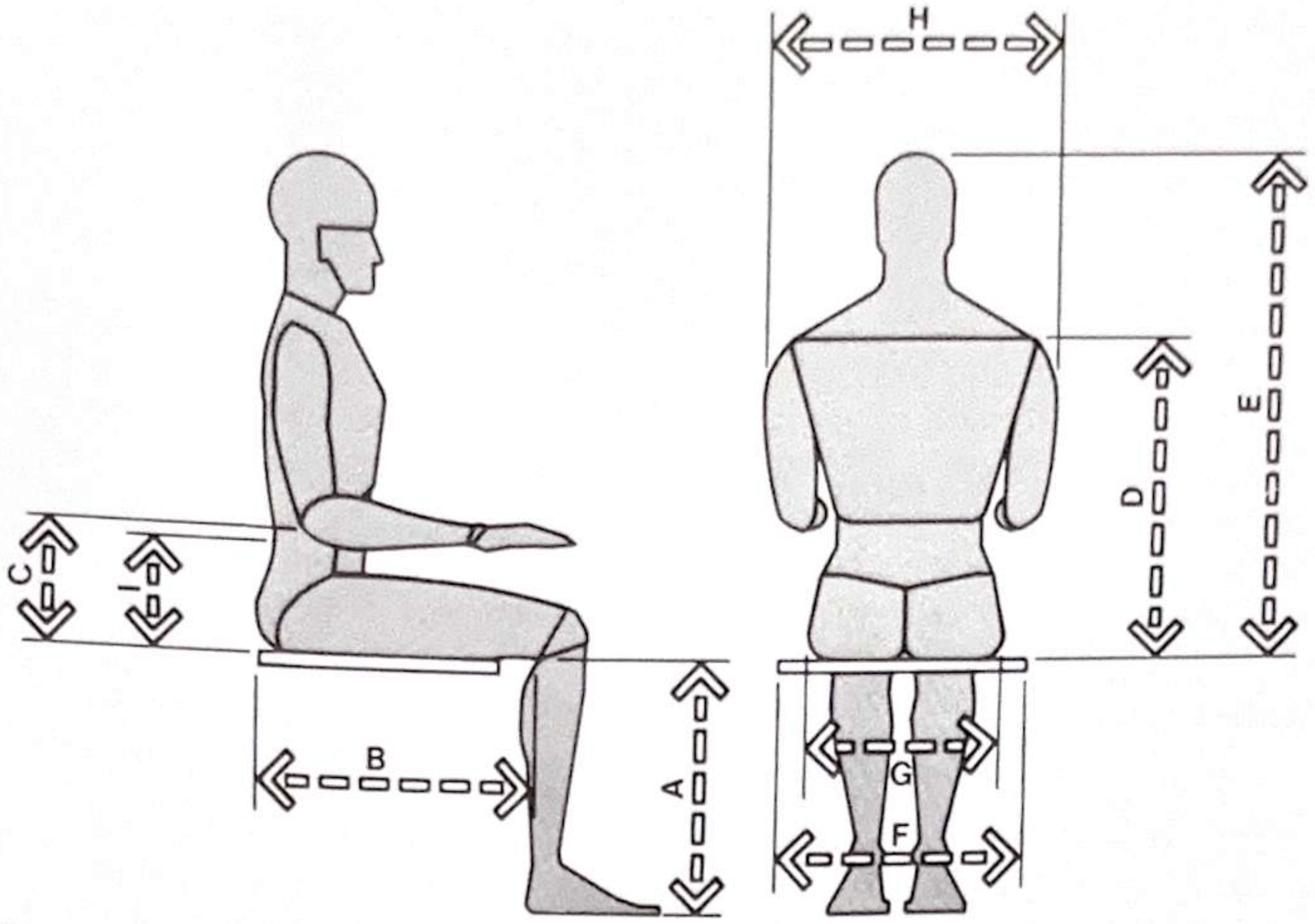

Figure 4–4. Key anthropometric dimensions required for chair design.

	MEN				WOMEN			
	Percentile				Percentile			
	5		95		5		95	
MEASUREMENT	in	cm	in	cm	in	cm	in	cm
A Popliteal Height	15.5	39.4	19.3	49.0	14.0	35.6	17.5	44.5
B Buttock-Popliteal Length	17.3	43.9	21.6	54.9	17.0	43.2	21.0	53.3
C Elbow Rest Height	7.4	18.8	11.6	29.5	7.1	18.0	11.0	27.9
D Shoulder Height	21.0	53.3	25.0	63.5	18.0	45.7	25.0	63.5
E Sitting Height Normal	31.6	80.3	36.6	93.0	29.6	75.2	34.7	88.1
F Elbow-to-Elbow Breadth	13.7	34.8	19.9	50.5	12.3	31.2	19.3	49.0
G Hip Breadth	12.2	31.0	15.9	40.4	12.3	31.2	17.1	43.4
H Shoulder Breadth	17.0	43.2	19.0	48.3	13.0	33.0	19.0	48.3
I Lumbar Height	See Note.							

Note: No published anthropometric studies concerning lumbar height can be located. A British study [H-D. Darcus and A.G.M. Weddel, *British Medical Bulletin* 5 (1947), pp. 31–37], however, gives a 90 percent range of 8 to 12 in, or 20.3 to 30.5 cm, for British men. Diffrient (*Humanscale 1/2/3*) indicates that the center of forward curvature of the lumbar region for adults is located about 9 to 10 in, or 22.9 to 25.4 cm, above the compressed seat cushion.

Chart 4–1. Selected body dimensions, taken from Tables 2 and 3 of Part B, useful in the design of seating. Little detailed published data are available with regard to lumbar heights. Estimates, however, vary from a range of 8 to 12 in, or 20.3 to 30.5 cm, and 9 to 10 in, or 22.9 to 25.4 cm.

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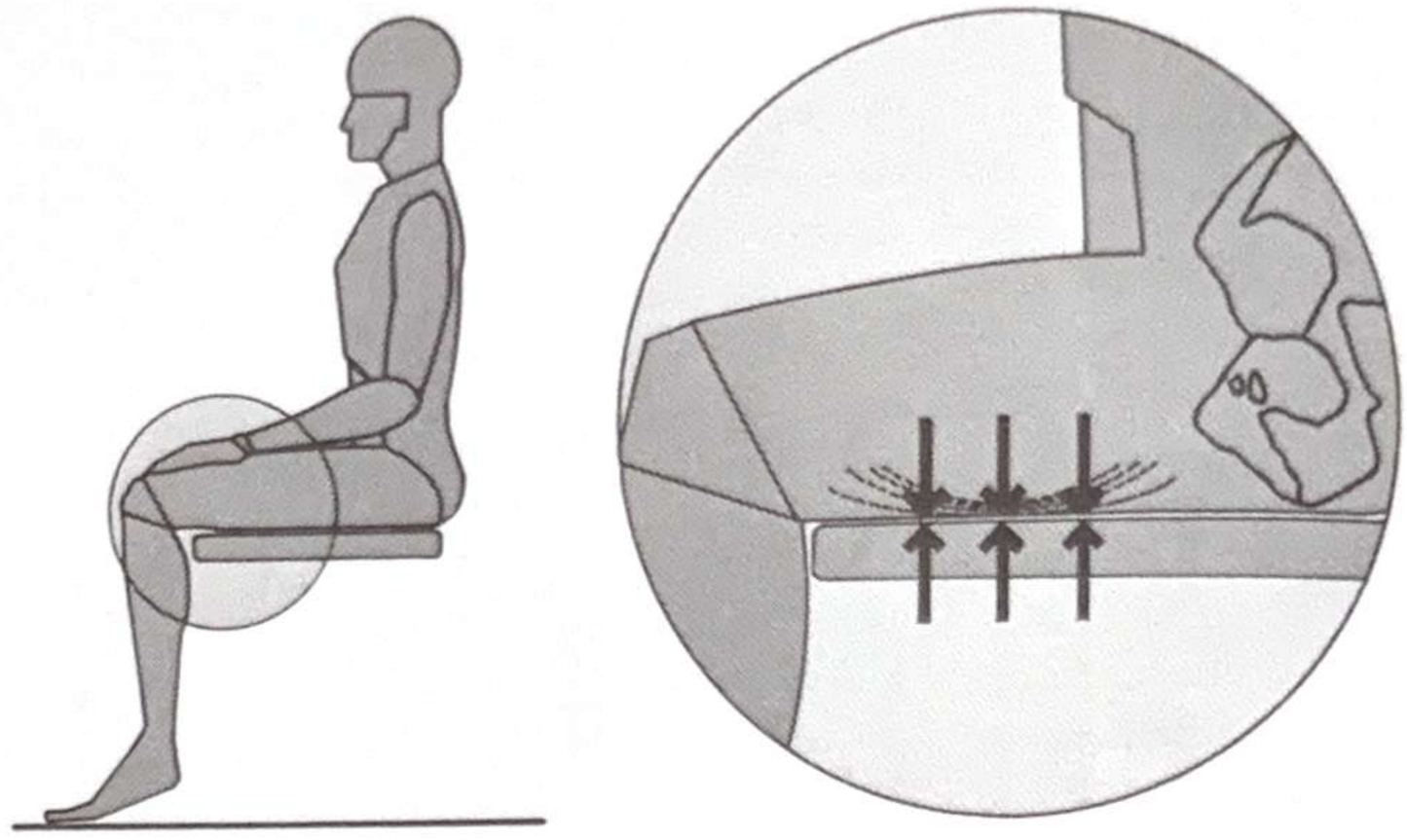

Figure 4–5. A seat surface placed too high causes the thigh to become compressed and blood circulation to be constricted. In addition, the soles of the feet are not permitted proper contact with the floor surface, thus weakening body stability.

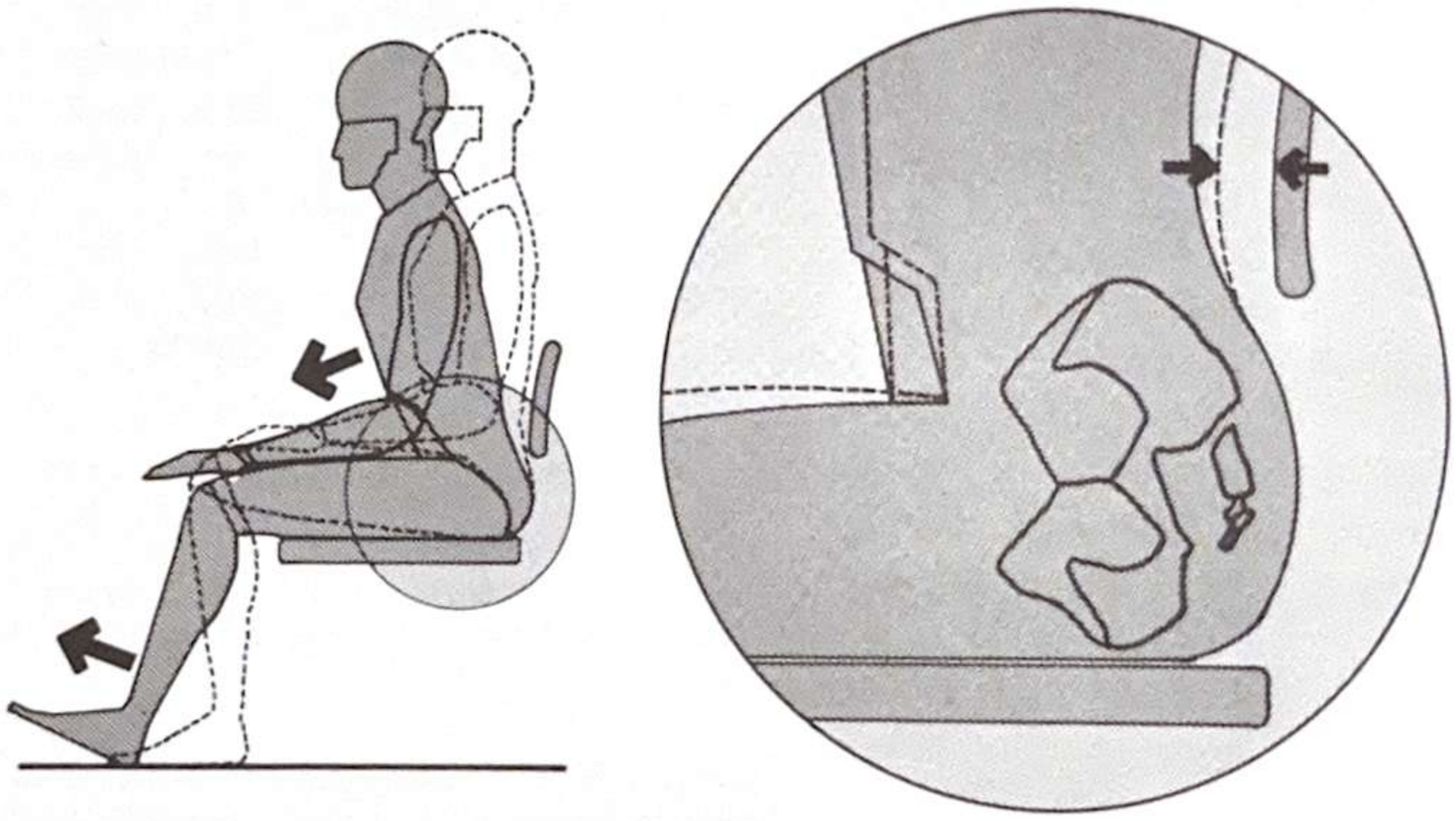

Figure 4–6. A seat surface located too low may cause the legs to become extended and positioned forward, depriving them of any stability. In addition the movement of the body forward will also cause the back to slide away from the backrest and deprive the sitter of proper lumbar support.

Anthropometrically, the popliteal height (the distance taken vertically from the floor to the underside of the portion of the thigh just behind the knee) should be the measurement in the tables used as reference in establishing the proper seat height. The lower range of the table, such as the 5th percentile data, would be appropriate since these will serve the segment of the population with the smallest body dimension. The rationale, as discussed earlier, is that a seat height that will accommodate a person with a smaller popliteal height measurement will also accommodate one with a larger measurement. Chart 4-1 indicates a 5th percentile popliteal height of 15.5 in, or 39.4 cm, for men and 14.0, or 35.6 cm, for women. The measurements, however, were recorded with the examinee stripped to the waist, pockets emptied, without shoes, and wearing a knee-length examining gown—hardly the kind of attire most people normally wear while sitting. It is necessary, therefore, to compensate for these conditions by increasing the measurements accordingly.

Since the items of clothing as well as the shoes are a function of climate, time of day, location, socioeconomic class, age, culture, and fashion, it is obvious that the factor to be added is, at best, an educated guess or reasonable approximation. Given the dangers involved in making the seat height too high, it would make sense to be conservative in estimating this factor and to err on the smaller side. It is suggested, therefore, that 1.5 in, or 3.8 cm, be added to both measurements; the figures then become 17 and 15.5, or 43.2 and 39.4 cm, respectively. These figures, however, could just as easily be increased if boots or very high heels were assumed to be the footwear. Similarly, the figures would be smaller if the user were lounging at home in slippers and a bathrobe. Given the great variation possible in popliteal height due exclusively to attire, not to mention body size, a very strong argument can be presented for adjustability in all chair types. It should be noted that in determining seat height the type, resiliency, and sag of padding or upholstery should be considered. Moreover, when the chair is used in conjunction with a table, desk, or other work surface, or footrest, seat height dimensions can vary. These conditions, as well as others involving the anthropometrics of seating, will be examined graphically in Part C.

4.4 SEAT DEPTH

Another basic consideration in chair design is the depth of the seat. If the depth is too great, the front surface or edge of the seat will press into the area just behind the knees, cutting off circulation to the legs and feet as shown in Figure 4-7. The compression of the tissues will also cause irritation and discomfort. A greater danger, still, is the possibility of blood clotting, or thrombophlebitis, if the user does not change body position. To alleviate the discomfort in the legs, the user may move his buttocks forward, in which case his back becomes unsupported, body stability is weaker, and greater muscular force is required to maintain equilibrium. The result is fatigue, discomfort, and back pain. Too shallow a seat depth (Figure 4-8) may result in an awkward situation where the user has the sensation of falling off the front of the chair. In addition, a shallow seat depth will also result in a lack of support of the lower thighs.

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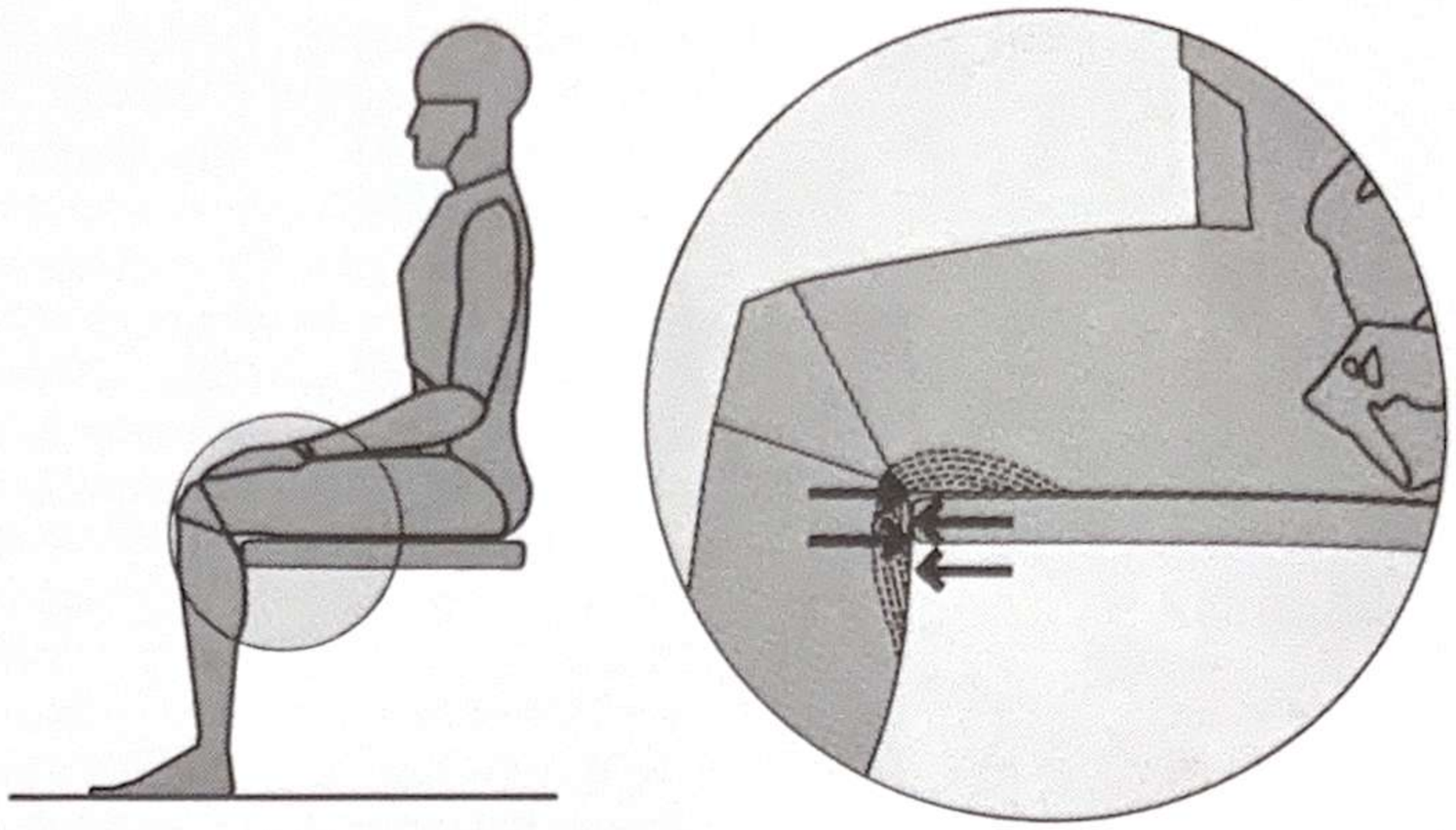

Figure 4–7. If the depth of the seat is too great, the seat front will press into the area just behind the knee, causing discomfort and problems with blood circulation.

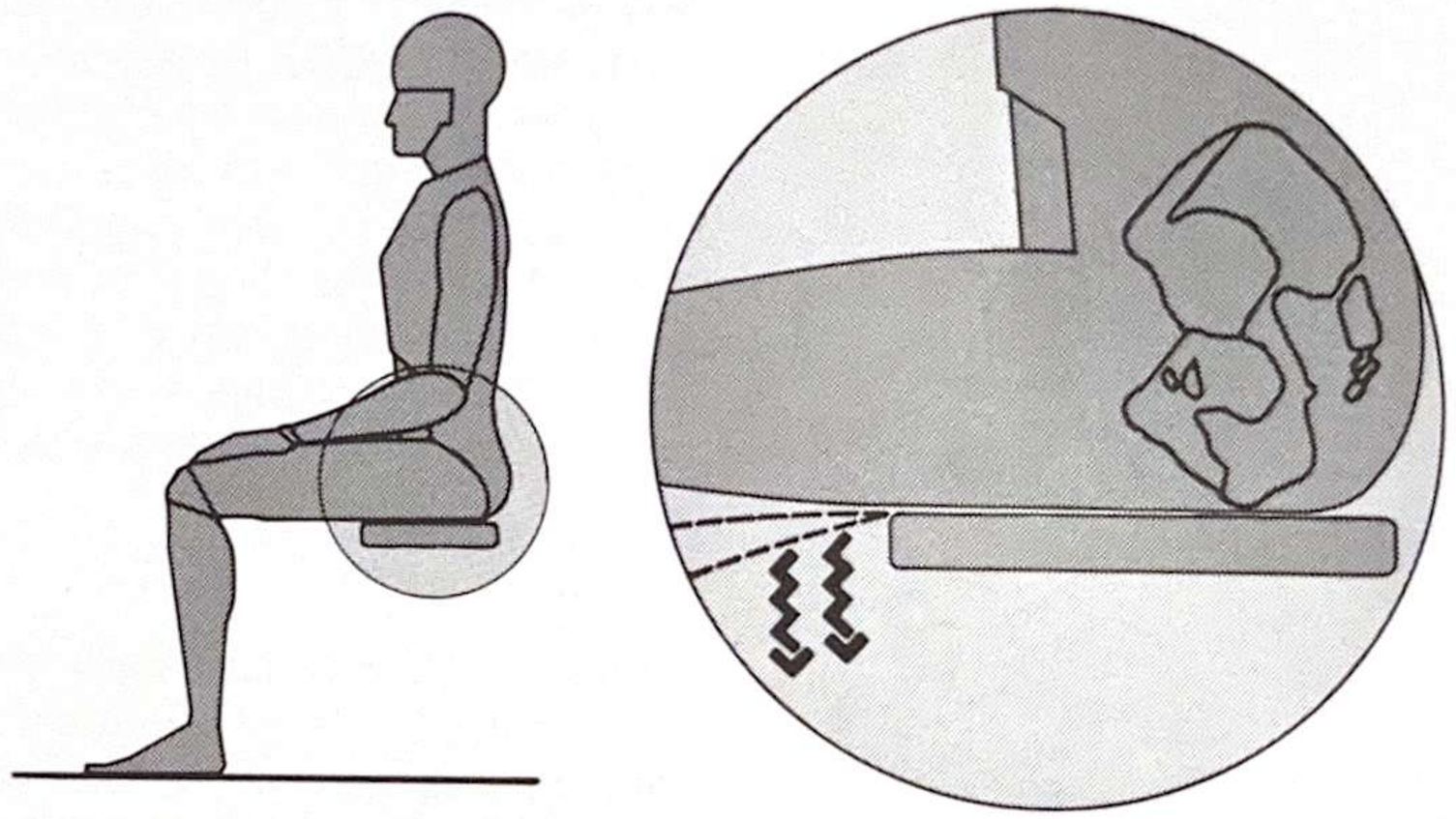

Figure 4–8. A shallow seat depth will deprive the sitter of proper support under the thighs. It may also give the sitter the sensation of tipping off the chair.

Anthropometrically, the buttock-popliteal length (the horizontal distance from the rearmost surface of the buttock to the back of the lower leg) is the measurement in the tables to be used to establish the proper seat depth.

Chart 4-1 indicates a 5th percentile buttock-popliteal length of 17.3 in, or 43.9 cm, for men and 17.0 in, or 43.2 cm, for women, while the smallest measurement indicated in Table 2K in Part B is the 1st percentile female data, with a measurement of 16.1 in, or 40.9 cm. Accordingly, a depth of seat measurement that exceeds about 16 in, or 40.6 cm simply would not accommodate the very small user, while a seat depth of 17 in, or 43.2 cm, for an easy chair, however, would accommodate about 95 percent of all users.

4.5 BACKREST

Although the size, configuration, and location of the backrest is one of the most important considerations necessary to ensure a proper fit between user and chair, it is also the most difficult component to dimension in reference to published anthropometric data. Despite the availability of those body measurements required in dimensioning

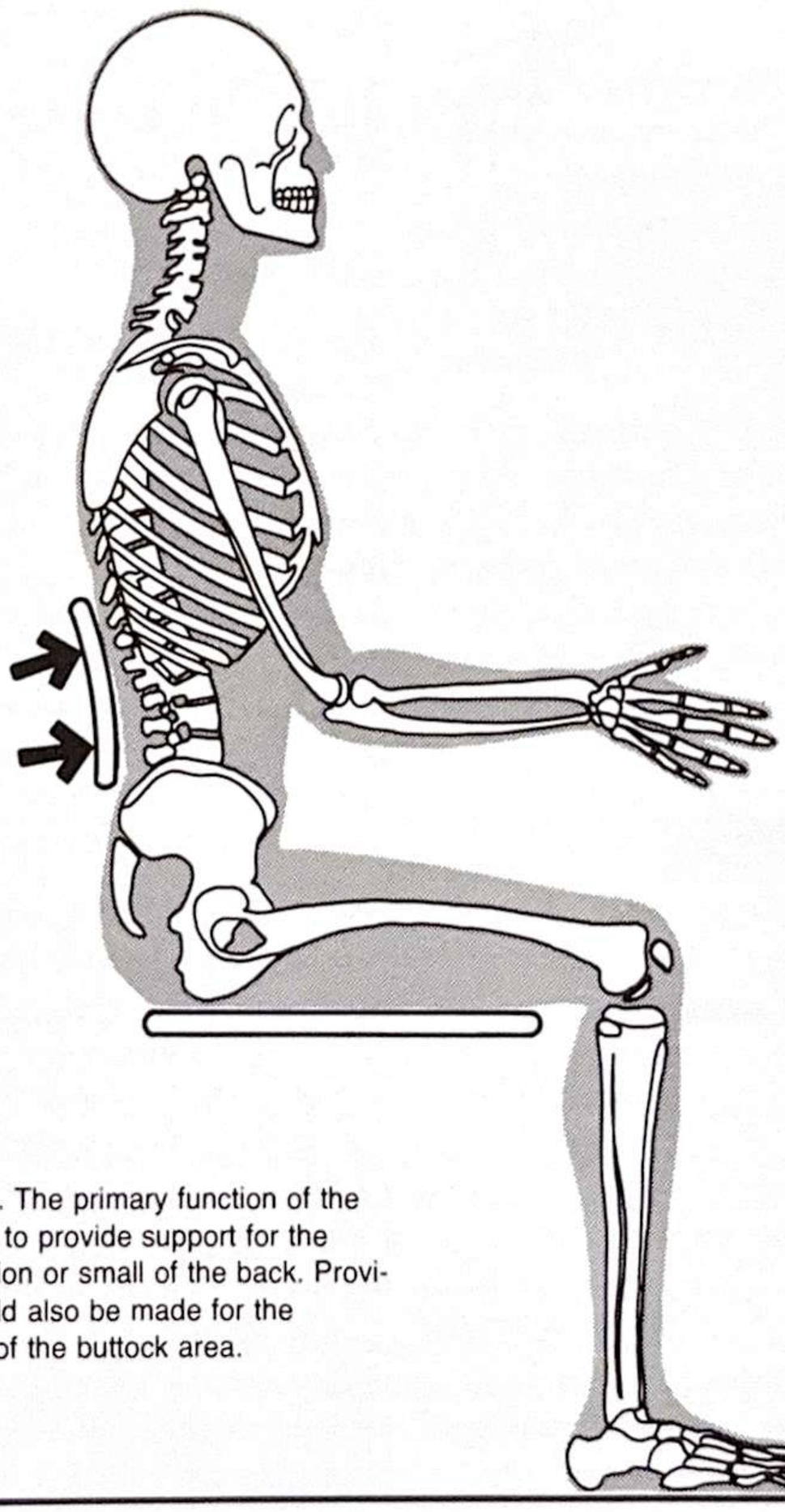

Figure 4–9. The primary function of the backrest is to provide support for the lumbar region or small of the back. Provisions should also be made for the protrusion of the buttock area.

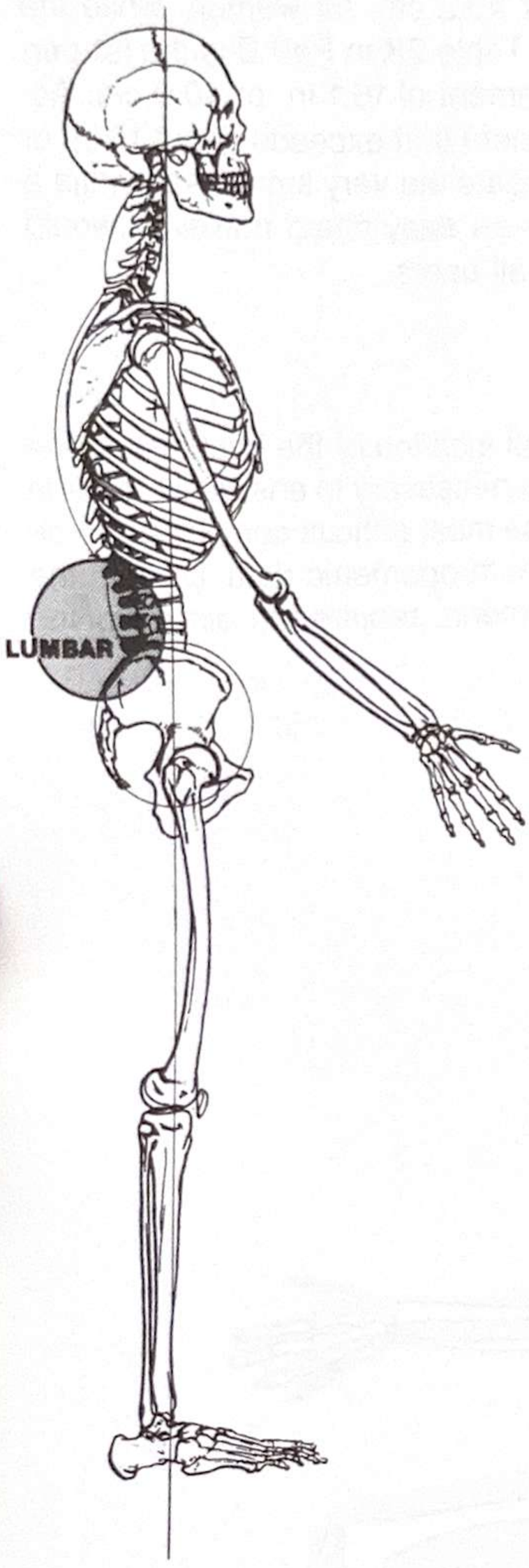

Figure 4–10. The lumbar region.

basic chair parts, such as seat height, seat depth, seat width, and armrest heights, there is a paucity of data relating specifically to the lumbar region and spinal curvature. Accordingly, it will be necessary to limit discussion of the backrest to guidelines and some generalizations.

There appears to be general agreement that the primary function of the backrest is to provide support for the lumbar region, or small of the back (Figure 4-9). This is the concave lower portion which extends approximately from the waist to about the middle of the back. The configuration of the backrest, therefore, should to some extent accommodate the spinal profile, particularly in the lumbar area, as shown in Figure 4-10. Caution should be exercised, however, not to provide so close a fit as to prevent the user from shifting body position.

The overall height of the backrest may vary depending on the type and intended use of the chair involved. It may be just sufficient to provide lumbar support and little more, as in the case of the typical secretarial chair; or it may extend all the way to the back of the head or nape of the neck, as in easy chairs or reclining chairs, or possibly somewhere in between, as in general purpose seating. Provisions should also be made for necessary clearance to allow space for the protrusion of the buttock area. This clearance may take the form of an open area or recess between the seat surface and the lumbar support. Soft padding in this area will also accommodate the protrusion in the buttock region.

4.6 ARMRESTS

Armrests serve several functions. They support the weight of the arms and assist the user in lowering himself into the seat or in pushing or raising himself out of the seat. If the chair is used in conjunction with some work task, for instance, one involving the manipulation of sensitive console dials or controls the armrest can also function to steady the arm during the performance of the particular activities. Anthropometrically, several factors must be taken into consideration in sizing and locating the armrests. For the height of the armrest, the elbow rest height would appear to be the proper anthropometric reference measurement to apply. This measurement is the dimension from the tip of the elbow to the seat surface. The decision to be made is the particular percentile data to be selected.

But consider the problem of one user with a large body breadth dimension as opposed to another extremely slender person with a relatively small body breadth dimension, who both have identical elbow rest height measurements. It has been observed in such cases that the user with the narrow body breadth would require higher armrests, because as the arms swing outward to connect with the armrest, the vertical distance from the elbow to the seat increases. Since no basic relationship exists between transverse measurements and those in the vertical plane, it has been suggested that the armrest should accommodate the higher range elbow rest height. Those users with shorter elbow rest heights can use the armrests by abducting the arms or raising the shoulders. However, if the armrest is too high, the user may have to force or lever the trunk out of the chair and round

the shoulders, resulting in fatigue and discomfort due to the muscular activity generated. Chart 4-1 shows the highest measurement for elbow rest height to be the 95th percentile male data, or 11.6 in, or 29.5 cm. Such an armrest height would, in fact, be uncomfortable for most people. The 70th percentile data would appear to be an optimal high range limitation and the 5th percentile the low limit. Most sources, therefore, recommend an armrest height between 7 and 10 in, or 17.8 and 25.4 cm.

4.7 CUSHIONING

The purpose of cushioning is essentially to distribute the pressure, due to the weight of the body at the point of interface, over a larger surface area. The danger, however, is for the designer to assume that the more opulent, deeper, and softer the cushioning, the greater the degree of comfort. This simply is not the case. All too often it is the very seating that appears overstuffed that, in fact, can provide the most discomfort, fatigue, and pain. Where the bone structures are closest to the skin are the areas of greatest potential discomfort due to the compressive stresses imposed on the body tissue. The ischial tuberosities in the buttock area mentioned previously are an excellent example of a sensitive area, in which the importance and need for proper cushioning is shown.

If cushioning is not properly designed, it is possible that relief from compressive stress may be obtained at the expense of body stability. Branton suggests that a state could be reached whereby the cushioning could deprive the body structure of support altogether. The body would "flounder about" in the soft mass of cushioning with only the feet resting on the floor, thereby increasing the burden of body stabilization on internal muscular activity.[11]

Still another source of discomfort may develop if the body weight causes the front end of the seat cushion to elevate, placing pressure on the bottom of the thigh and the nerves in that area. Similarly, if the body sinks too deeply into the cushioning, the sides and possibly the rear portions of the seat cushion may also elevate, producing additional pressures on the various parts of the body involved. In addition, the deeper the body sinks into the chair, the more effort is required to get out of the chair.

It is obvious that hard, flat seats are uncomfortable for extended use. It has also been suggested that excessively deep, soft cushioning can result in extreme discomfort. Although more research is required to objectively study the entire notion of sitter comfort, certain guidelines for proper cushioning have been suggested. Diffrient recommends that, for comfort, an average padded seat would have about 1.5 in, or 3.8 cm, of medium foam padding over .5 in, or 1.3 cm, of firm closed-cell padding, or a total of about 2 in, or 5.1 cm, with a maximum allowable seat compression of about 1.5 in. The seat compression allowance is based on a 172-lb, or 78-kg, male. For every 30 lb, or 13.6 kg, less, .25 in, or 6.4 mm, should be deducted. For every additional 30 lb, .25 in should be added.[12] Croney recommends a depression of about ½ in, or 13 mm.[13] Damon et al. suggest that 1 to 2 in, or 2.5 to 5.1 cm, of compression would suffice.[14]

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B HUMAN DIMENSION/ ANTHROPOMETRIC TABLES

As discussed in Part A, there is a paucity of anthropometric data appropriate in both content and form, specifically for use by the designers and builders of interior space. Much of the data available were not originally gathered with either the designer or the builder necessarily in mind. Accordingly, a large portion of the information in circulation is limited in use, since it usually reflects a specific population, age group, and sex not at all representative of the customary design market. In most instances, with the exception of the National Health Survey, the population is military, the age between 18 and 45 years, and the sex male—hardly a typical cross section of the broad market served by the architectural and interior design professions. To find all the data useful to the designer within a single reference source is almost impossible.

After some research, an inventory of nearly one hundred anthropometric studies involving almost one thousand different body measurements was compiled. It was then necessary to scan this inventory and filter out for presentation that information of most value to the architect and interior designer. In certain instances, it was necessary to modify the original form of the data so that they might be used more efficiently by designers. Moreover, in all cases where metric units were not indicated, necessary conversions were made. Where appropriate, diagrams and figures were drawn to further illustrate and explain the data. The result is the nine tables shown on the following pages.

Every effort has been made to review all the data for errors and inconsistencies. The quantity of statistics, the many different sources, the lack of control over methodologies employed, the metrication involved, the reproduction process, and the secondary nature of some of the material, however, make it impossible for the accuracy or consistency of all the data to be unconditionally guaranteed. In instances where the user requires more precise information with respect to various aspects of the data, the measuring techniques employed, or a more accurate description of the population involved, it is suggested he or she refer to the original sources. For this reason, the sources from which all the data for each table were extracted are cited at the beginning of each table or set of tables.

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The user is also cautioned against the selection and application of data without first familiarizing himself with some of the fundamentals and basic theory discussed in the earlier section of the book. Data can be misleading and if used improperly can result in serious design errors. Finally, the user is cautioned that statistical data of itself is no substitute for common sense and prudent design analysis.

The data indicated in the tables that follow have been based on measurements taken of nude subjects or subjects wearing thin hospital gowns, who are either barefooted or wearing paper slippers. It is essential, therefore, that appropriate allowances be made for garments, shoes, and hats. These allowances may vary, depending on season, particular environment, sex, and even current fashion. In most cases these allowances will add to the body dimensions, but extremely heavy and bulky outerware, for example, may decrease reach measurements and the range of joint motion.

Although the tolerances and interface problems faced by the architect or interior designer will normally not be so complex or sophisticated as some of the military applications, the effect of clothing on human dimension and interior space is still an important factor. Sound judgment and common sense must be exercised by the designer in determining what body measurements will be affected and by how much. Reach and clearance are the essential factors to be considered. The following are allowances suggested for some of the more standard items of clothing and the more significant body dimensions affected. Each design situation, however, should be viewed individually. In some cases it may be necessary for the designer to develop additional allowance factors, appropriate to the specific design requirements and the critical body dimensions involved.

CLOTHING TYPE	ALLOWANCE		MOST IMPORTANT BODY DIMENSIONS AFFECTED
Men's suit	.50 in	1.3 cm	Body depth
	.75-1.0 in	1.9-2.5 cm	Body breadth
Women's suit or dress	.25-.50 in	0.6-1.3 cm	Body depth
	.50-.75 in	1.3-1.9 cm	Body breadth
Winter outerware including basic suit or dress	2.0 in	5.1 cm	Body depth
	3.0-4.0 in	7.6-10.2 cm	Body breadth
	1.75-2.0 in	4.4-5.1 cm	Thigh clearance
Men's heels	1.0-1.5 in	2.5-3.8 cm	Stature, eye height, knee height sitting , popliteal height
Women's heels	1.0-3.0 in	2.5-7.6 cm	Stature, eye height, knee height sitting , popliteal height
Men's shoes	1.25-1.5 in	3.2-3.8 cm	Foot length
Women's shoes	.5-.75 in	1.3-1.9 cm	Foot length
Gloves	.25-.50 in	0.6-1.3 cm	Hand length, hand breadth

1 METROLOGICAL ANALYSIS

DESCRIPTION

The anthropometric data reflected in the other tables (2 through 8) involve certain specific structural and functional measurements. The proper use of this information requires some knowledge of the nature of these measurements. Table 1 includes the generally accepted anthropometric terms for the various measurements, their definitions, information regarding their particular applicability and use, general factors to be considered, and indications as to whether 5th or 95th percentile data should be selected.

The user is cautioned not to view all the definitions as necessarily representing precise technical descriptions of the specific measuring techniques used, since those techniques may differ slightly with each survey. The definitions are, however, reasonably accurate and representative, particularly in terms of the nature of their intended usage by architects or interior designers. If unique design situations make a more precise definition critical, refer to the original survey upon which the data are based.

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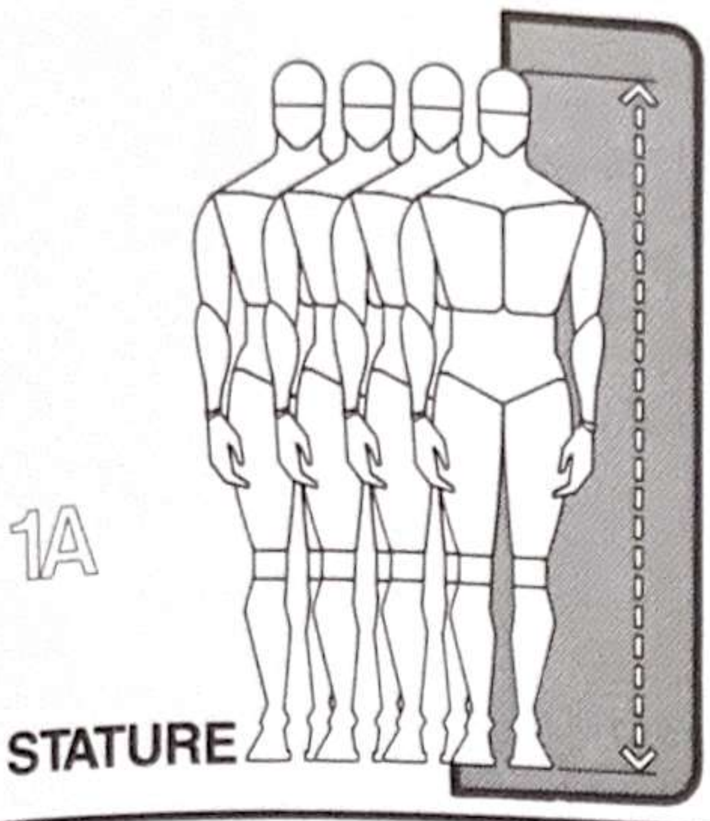
SOURCE

No single authority was consulted for all the definitions provided. Various sources of reference, however, were consulted, including Albert Damon, Howard W. Stoudt, Ross McFarland, *The Human Body in Equipment Design* (Cambridge, Mass.: Harvard University Press, 1971); Wesley Woodson and Donald W. Conover, *Human Engineering Guide for Equipment Designers,* 2d ed. (Berkeley and Los Angeles: University of California Press, 1964); and *Anthropometric Source Book, vol. 2: A Handbook of Anthropometric Data,* NASA Reference Publication 1024, July 1978. In some instances, the exact wording of the definitions was used; in other instances, abbreviated versions were employed; and in still other instances where definitions were not readily available, the terms were defined by the authors.



1A

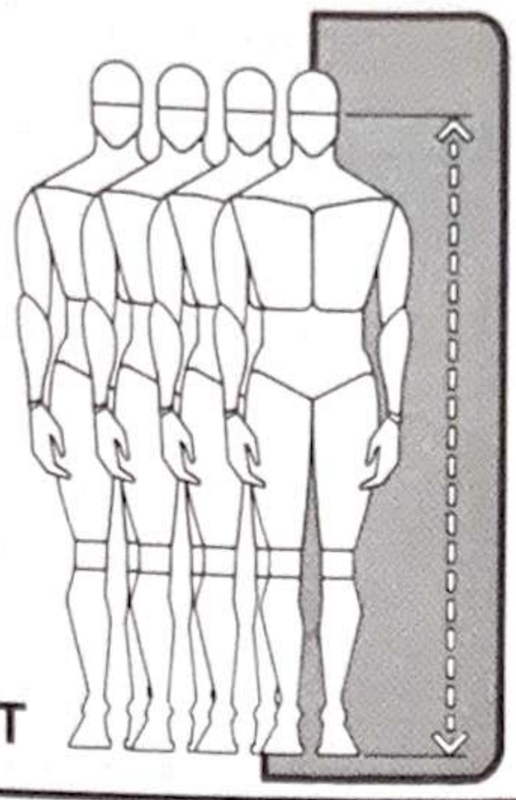
STATURE

DEFINITION
Stature is the vertical distance from the floor to the top of the head, measured while the subject stands erect, looking straight ahead.

APPLICABILITY
These data are useful in establishing minimum heights of openings and doors. Normally, however, building codes and/or the standard manufactured sizes of doors and frames are more than adequate to accommodate at least 99 percent of the user population. The data can be more useful in determining the minimum distances of overhead obstructions from the floor.

CONSIDERATIONS
Measurements are usually taken without shoes. Accordingly, appropriate compensation in the data should be made.

PERCENTILE SELECTION
Since clearance is the operative functional factor, the upper percentile range should be accommodated. Because ceiling heights are usually never critical dimensions, the designer should accommodate as close to 100 percent of the population as possible.



1B

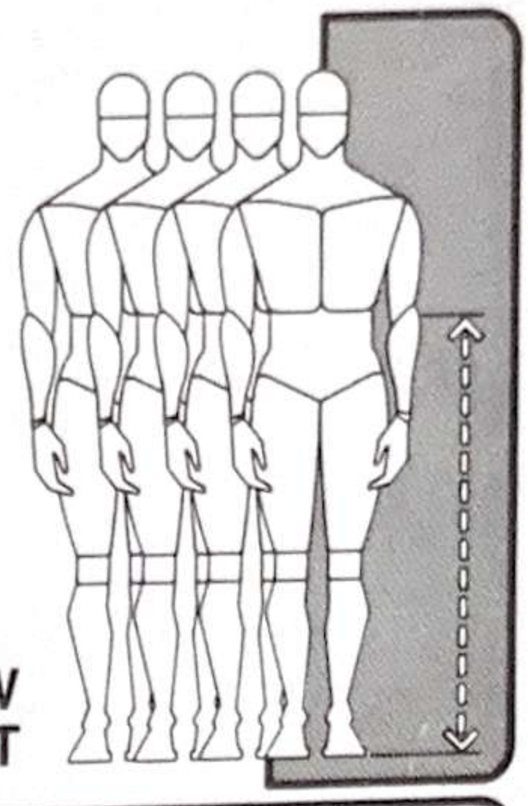
EYE HEIGHT

DEFINITION
Eye height is the vertical distance from the floor to the inner corner of the eye, measured with the subject looking straight ahead and standing erect.

APPLICABILITY
These data can be helpful in establishing sight lines in such facilities as theaters, auditoriums, conference rooms and in the placement of signage and other visual material. They can also be useful in establishing heights of privacy screens and low or open plan office partitions.

CONSIDERATIONS
Approximately 2.5 cm, or 1 in, should be added for men's shoes and 7.6 cm, or 3 in, for women's shoes, since measurements are normally taken with the subject barefooted. These data should be used in conjunction with neck flexion and rotation data, as well as sight angle information, to establish the range of visual field under varying conditions and head angles.

PERCENTILE SELECTION
Percentile selection will depend on a variety of factors. If, for example, the design problem involves determining the height of a partition or screen to ensure privacy of the person behind the screen, then screen height should relate to the eye height of the taller person (95th percentile or above). The logic is that if a tall person cannot see over the screen, then surely a short person cannot see over it. If the design problem, instead, is to allow a person to look over a screen, the reverse logic would hold true. The height of the screen should relate to the eye height of the shorter person (5th percentile or less). If a short person can see over the screen, then a tall person will be able to as well.



1C

ELBOW HEIGHT

DEFINITION
Elbow height is the distance measured vertically from the floor to the depression formed at the elbow where the forearm meets the upper arm.

APPLICABILITY
Elbow height data are essential in establishing comfortable heights for work counters, vanities, kitchen counters, work benches, and other work surfaces used while standing. Too often, heights of such surfaces have been established by chance, rule of thumb, or "trade practice." Scientific studies, however, place the most comfortable height at 3 in, or 7.6 cm, below elbow height, while a ballpark figure for a rest surface is of 1 to 1½ in, or 2.5 to 3.8 cm, below elbow height.

CONSIDERATIONS
The nature of activity should be considered in establishing height. In many instances this will take precedence over the suggested "elbow height less 3 in" (7.6 cm) recommendation.

PERCENTILE SELECTION
Assuming the work surface height is at the recommended 3 in, or 7.6 cm, below elbow height, a range from 38 in, or 96.5 cm (reflecting the 5th percentile measurement), to 43 in, or 109.2 cm (reflecting the 95th percentile measurement), should accommodate the middle 90 percent of the male user population. In view of the smaller elbow height 5th percentile dimension for females, a range from 35 in, or 88.9 cm, to 43 in, or 109.2 cm, is necessary to accommodate both sexes. These figures are all tentative, however, because of the number of variables involved, i.e., the specific function to be performed and differing opinions as to optimal height.

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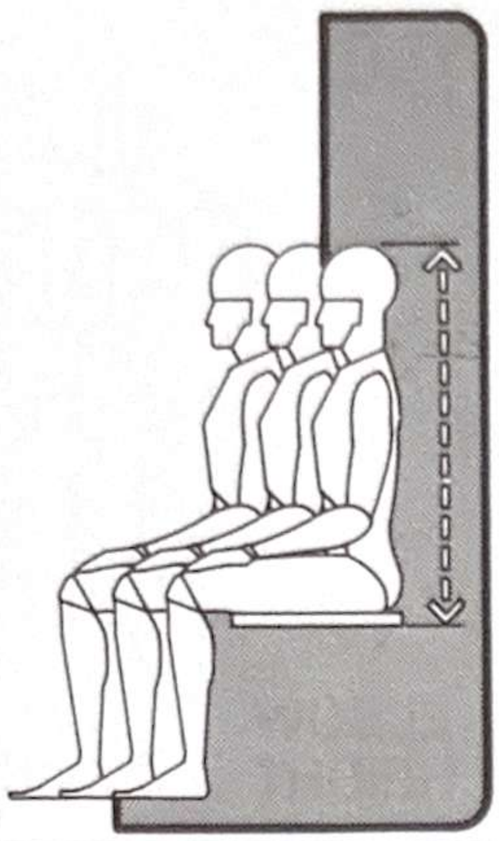
1D SITTING HEIGHT ERECT



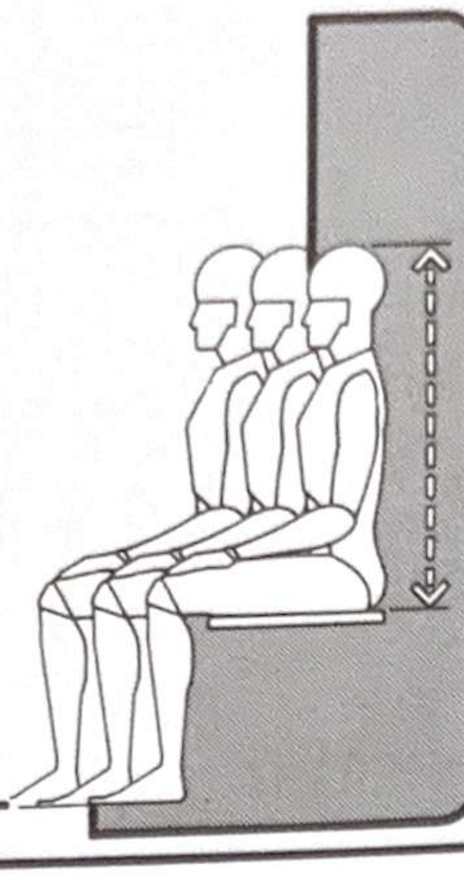
DEFINITION
Sitting height erect is the vertical distance from the sitting surface to the top of the head with the subject sitting erect.

APPLICATION
This measurement would be helpful in determining the allowable height of obstructions from the surface of a seat or, by adding the seat height, the height of the obstruction above the floor. Bunk bed arrangements and innovative space-saving designs, such as where the area under a loft bed is utilized as an eating or work area, could be predicated upon these critical data. The heights of low privacy partitions in offices or other spaces could also be established with the use of these measurements, as could the height of booth partitions in eating and drinking spaces.

CONSIDERATIONS
The slope of the seat, resiliency of the upholstery, clothing, and body movements getting in and out of the seat are all important factors to consider.

PERCENTILE SELECTION
The 95th percentile data are more appropriate due to the clearance factor involved.

1E SITTING HEIGHT NORMAL



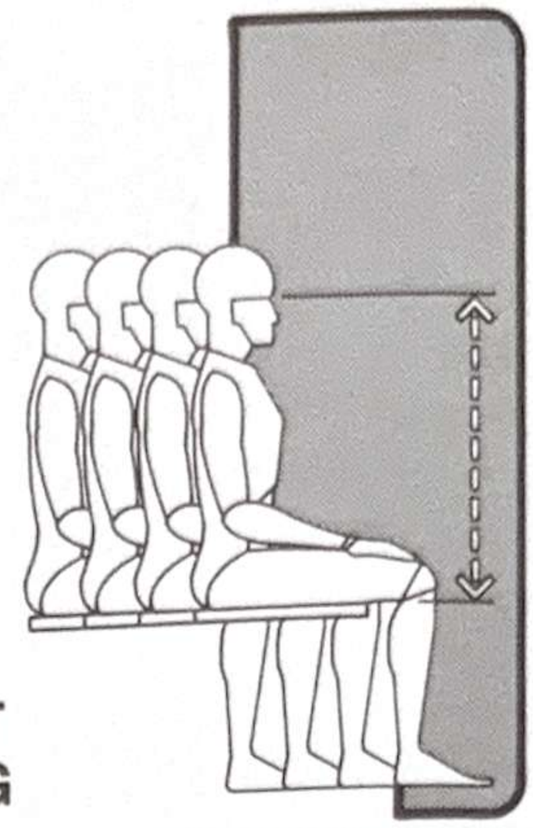
DEFINITION
Sitting height normal is the vertical distance from the sitting surface to the top of the head, measured with the subject sitting relaxed.

APPLICATION
This measurement would be helpful in determining minimum height of obstructions from the surface of a seat or, by adding the seat height, the minimum height of the obstruction above the floor. Bunk bed arrangements and innovative space-saving designs, such as where the area under a loft bed is utilized as an eating or work area, could be predicated upon these critical data. The heights of low privacy partitions in offices or other spaces could also be established with the use of these measurements, as could the height of booth partitions in eating and drinking spaces.

CONSIDERATIONS
The slope of the seat, resiliency of the upholstery, clothing, and the body movements getting in and out of the seat are all important factors to consider.

PERCENTILE SELECTION
The 95th percentile data are more appropriate due to the clearance factor involved.

1F EYE HEIGHT SITTING



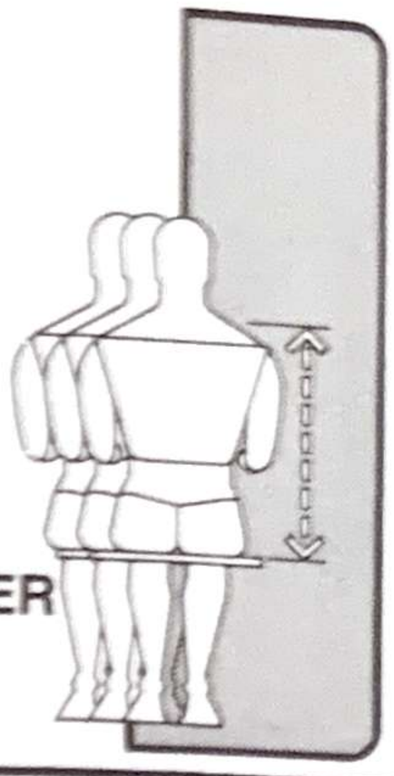
DEFINITION
Eye height is the vertical distance from the inner corner of the eye to the sitting surface.

APPLICATION
The primary value of this measurement would be in determining sight lines and optimum fields of vision where visibility is one of the central design considerations, such as in theaters, auditoriums, lecture rooms, and other interior spaces in which audiovisual activities are required.

CONSIDERATIONS
The range of head and eye movement discussed elsewhere in the book should be considered, as well as the resiliency of the seat upholstery, the height of the seat above the floor, and provisions for adjustability.

PERCENTILE SELECTION
Providing proper adjustability can permit a range of accommodation from 5th to 95th percentile or greater.

1G MIDSHOULDER HEIGHT SITTING



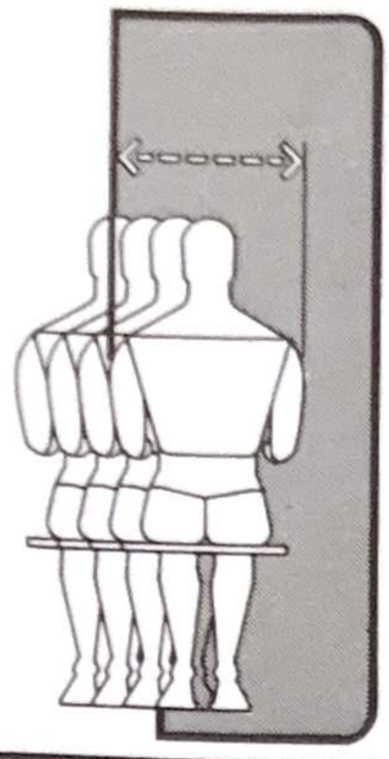
DEFINITION
Shoulder height is the distance taken vertically from the sitting surface to a point on the shoulder midway between the neck and acromion.

APPLICABILITY
These data are of most use in the design of tight work spaces in vehicle design and of limited use to the architect or interior designer. They can be of some help, however, in determining obstructions to visibility in the planning of spaces where audiovisual activities take place and perhaps in determining heights of seating booth and other similar design situations.

CONSIDERATIONS
The resiliency of the chair upholstery should be considered.

PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.

1H SHOULDER BREADTH



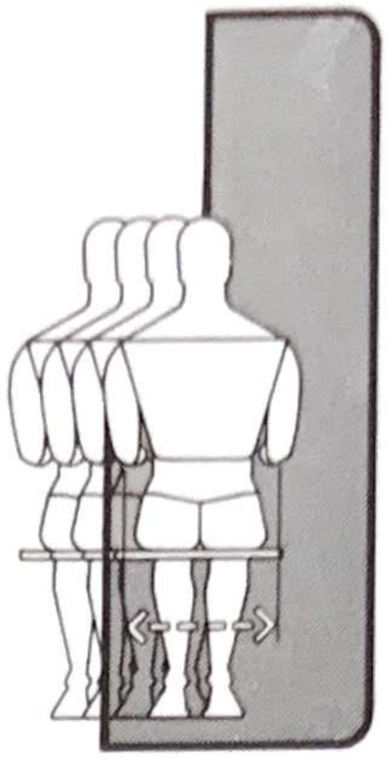
DEFINITION
Shoulder breadth is the maximum horizontal distance across the deltoid muscles.

APPLICABILITY
Shoulder breadth data are most useful to the interior designer or architect in helping to establish allowances for seating around tables and for row seating in theaters and auditoriums. They can also be useful in establishing clearances for circulation in public and private spaces.

CONSIDERATIONS
These data should be used cautiously in view of the many variables that can be involved. Allowances for clothing should be made, with 7.9 mm, or 5/16 in, for light clothing and about 7.6 cm, or 3 in, for heavy clothing. It should also be noted that the space required across the shoulder is increased by movements of the trunk and shoulder.

PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.

1I ELBOW-TO-ELBOW BREADTH



DEFINITION
Elbow to elbow is the distance across the lateral surfaces of the elbows measured with elbows flexed and resting lightly against the body with the forearms extended horizontally.

APPLICABILITY
These data could be helpful in determining allowances for seating around conference tables, dining tables, counters, card or game tables.

CONSIDERATIONS
These should be used in conjunction with shoulder breadth measurements as required.

PERCENTILE
Since clearance is the operative design factor, 95th percentile data should be used.

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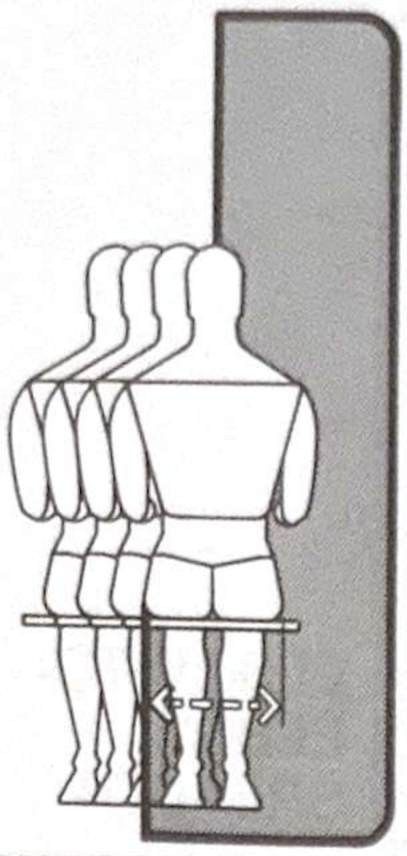
1J HIP BREADTH



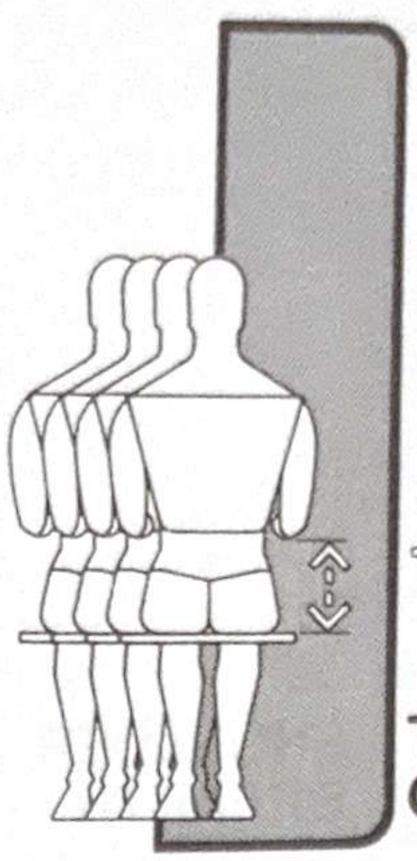
DEFINITION
Hip breadth is the breadth of the body as measured across the widest portion of the hips. Note that a hip breadth measurement can also be taken with the subject in a standing position, in which case the definition would be the maximum breadth of the lower torso. The data in subsequent tables, however, refer to the sitting position as indicated.

APPLICABILITY
These data could be extremely helpful in determining allowances for inside chair width dimensions, bar and counter seating, perch-type office stools.

CONSIDERATIONS
Depending on the particular application, these data should be used in conjunction with elbow to elbow and shoulder breadth dimensions as required.

PERCENTILE
Since clearance is the operative design factor, 95th percentile data should be used.

1K ELBOW REST HEIGHT



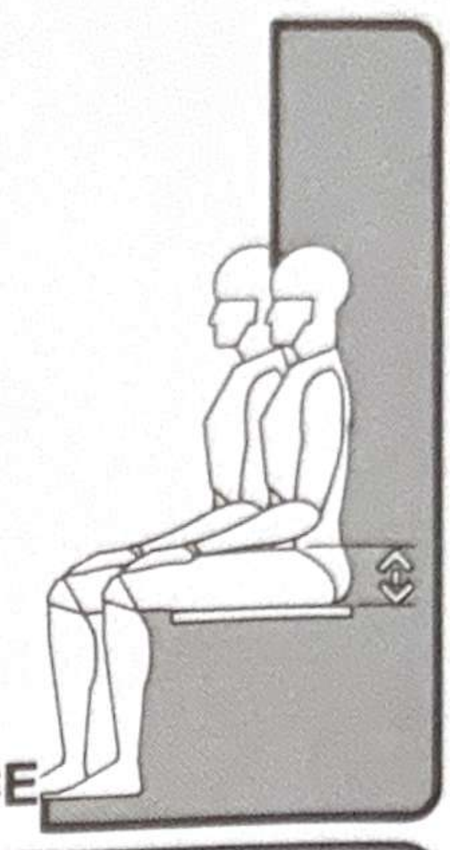
DEFINITION
Elbow rest height is the height from the top of the sitting surface to the bottom of the tip of the elbow.

APPLICABILITY
These data, together with other appropriate data and considerations, could be helpful in determining heights of armrests, work counters, desks, tables, special equipment.

CONSIDERATIONS
Resiliency of the chair upholstery, slope of seat, and body posture should all be taken into consideration.

PERCENTILE SELECTION
Elbow rest height is really neither a clearance situation nor a reach situation, particularly when an armrest is involved. The intent is for the arm to rest comfortably on a surface. Data around the 50th percentile would be appropriate. In any event a range between 14 and 27.9 cm, or 5½ and 11 in, should suit most users.

1L THIGH CLEARANCE

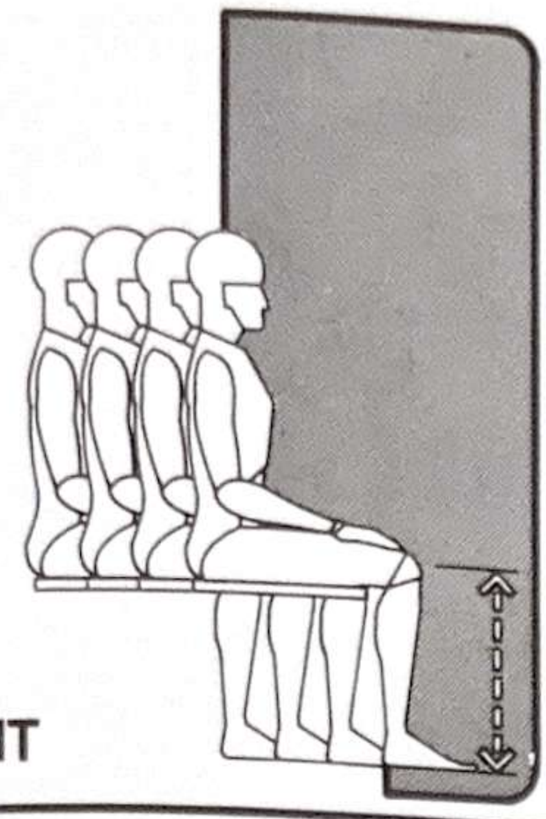


DEFINITION
Thigh clearance is the distance taken vertically from a sitting surface to the top of the thigh at the point where the thigh and the abdomen intersect.

APPLICABILITY
These data are critical in the design of interior elements such as counters, desks, conference tables, cabinetwork, or furniture that may require the user, while seated, to position his or her legs under the work surface. More specifically, the data are essential in order to establish the dimension of any apron or drawers situated directly below the work surface so that adequate clearance will be allowed between the top of the thigh and the bottom of any obstruction above it.

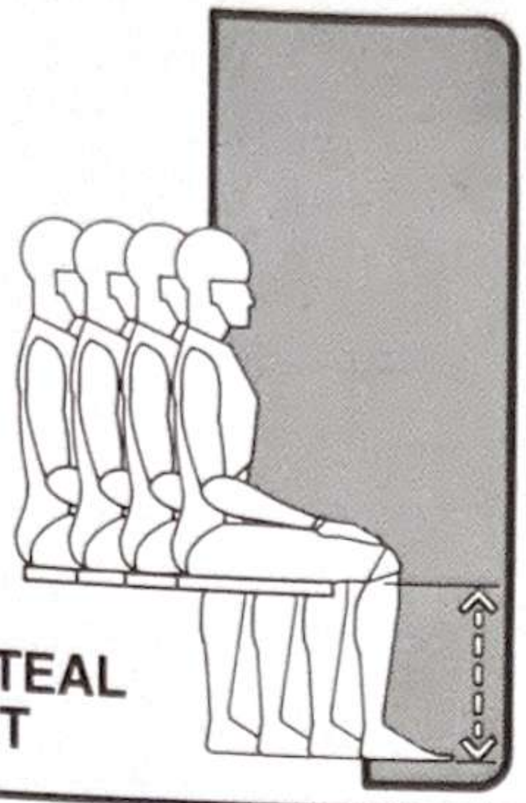
CONSIDERATIONS
In determining the maximum dimensions mentioned above, several other factors must also be considered such as popliteal height and the resiliency of the upholstery of the chair.

PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.



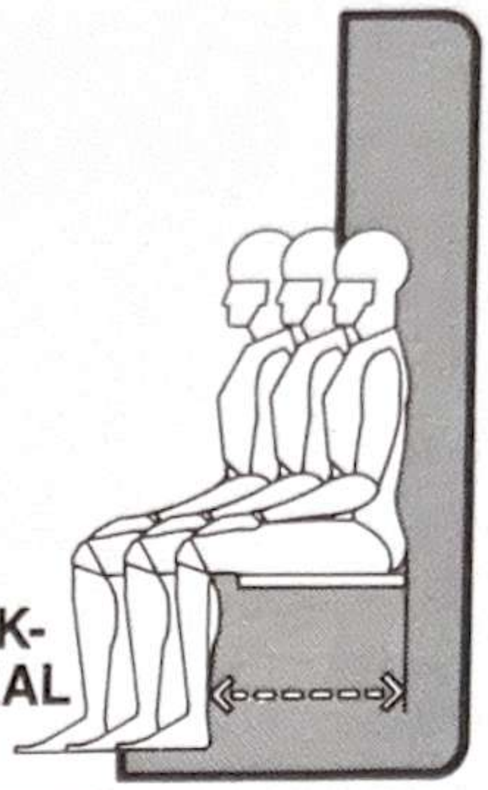
1M

KNEE HEIGHT



1N

POPLITEAL HEIGHT



10

BUTTOCK-POPLITEAL LENGTH

DEFINITION
Knee height is the vertical distance from the floor to the midpoint of the kneecap.

APPLICABILITY
These data are critical in establishing the distance from the floor to the underside of a desk, table, or counter, particularly where the seated user is required to have his lower body partially under the furniture. How close the seated user will be located to the object will dictate if the knee height dimension alone or the thigh clearance measurement will be the determining factor.

CONSIDERATIONS
The height of the seat as well as the resiliency of the upholstery should also be considered.

PERCENTILE SELECTION
To ensure clearance, 95th percentile data should be used.

DEFINITION
Popliteal height is the distance, taken vertically, from the floor to the underside of the portion of the thigh just behind the knee while the subject is seated with body erect. The knees and ankles are usually perpendicular, with the bottom of the thigh and the back of the knees barely touching the sitting surface.

APPLICABILITY
These data are critical in establishing the height of seating surfaces above the floor, particularly the highest point on the front of the seat.

CONSIDERATIONS
In applying the data, it is necessary to take into consideration the resiliency of the upholstered seat surface.

PERCENTILE SELECTION
In establishing seat height, 5th percentile data should be used. Pressure on the underside of the thigh is one of the causes of user discomfort. This condition occurs when the height of the seat is too great. A seat height that will accommodate the user with the smaller popliteal height will also suit the user with greater popliteal height.

DEFINITION
Buttock-popliteal length is the horizontal distance from the rearmost surface of the buttock to the back of the lower leg.

APPLICABILITY
These data are useful in connection with seating design, particularly location of legs, vertical surfaces of the front of benches, banquettes, etc., as well as determination of seat lengths.

CONSIDERATIONS
The angle of the seat should be considered.

PERCENTILE SELECTION
The 5th percentile data should be used. These will accommodate the greatest number of users: those with shorter buttock-popliteal lengths as well as those with greater lengths. If 95th percentile data are used, the design will accommodate the users with the larger measurements only, but not those with the smaller measurements.

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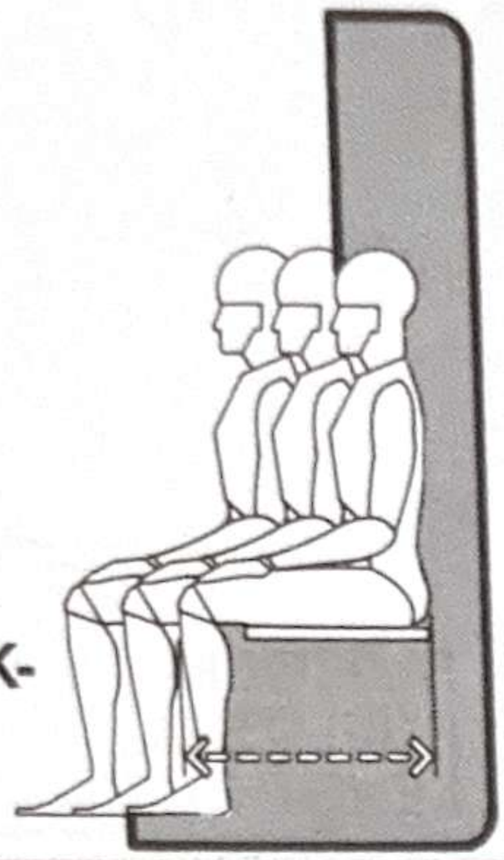


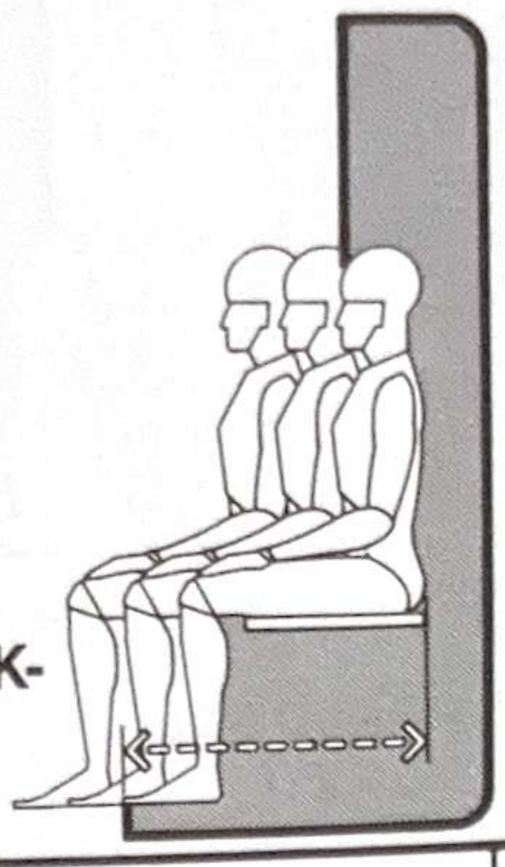
1P BUTTOCK-KNEE LENGTH

DEFINITION
Buttock-knee length is the horizontal distance from the rearmost surface of the buttocks to the front of the kneecaps.

APPLICABILITY
These data can be useful in determining the proper distance from the back of a seat to any physical obstruction or objects located in front of the knees. Fixed seating in auditoriums, theaters, and places of worship are space types where this would apply.

CONSIDERATIONS
The buttock-knee length dimension is less than the buttock-toe length. If no toe space is provided in the equipment, furniture, or other interior elements positioned in front of the seat, the buttock-toe length measurement must be used to allow for proper clearance.

PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.



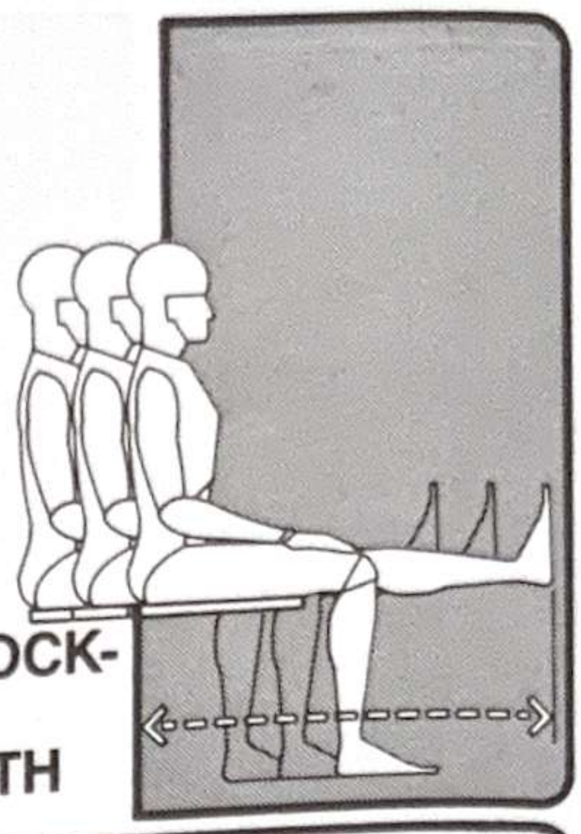
1Q BUTTOCK-TOE LENGTH

DEFINITION
Buttock-toe length is the horizontal distance from the rearmost surface of the buttocks to the tip of the toe.

APPLICABILITY
These data can be useful in determining the proper distance from the back of a seat to any physical obstruction or objects located in front of the knees. Fixed seating in auditoriums, theaters, and places of worship are space types in which this would apply.

CONSIDERATIONS
If toe space is provided in the equipment, furniture, or other interior elements positioned in front of the knee and spacing is critical, the buttock-knee length may be used, instead, in helping to determine proper clearances.

PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.



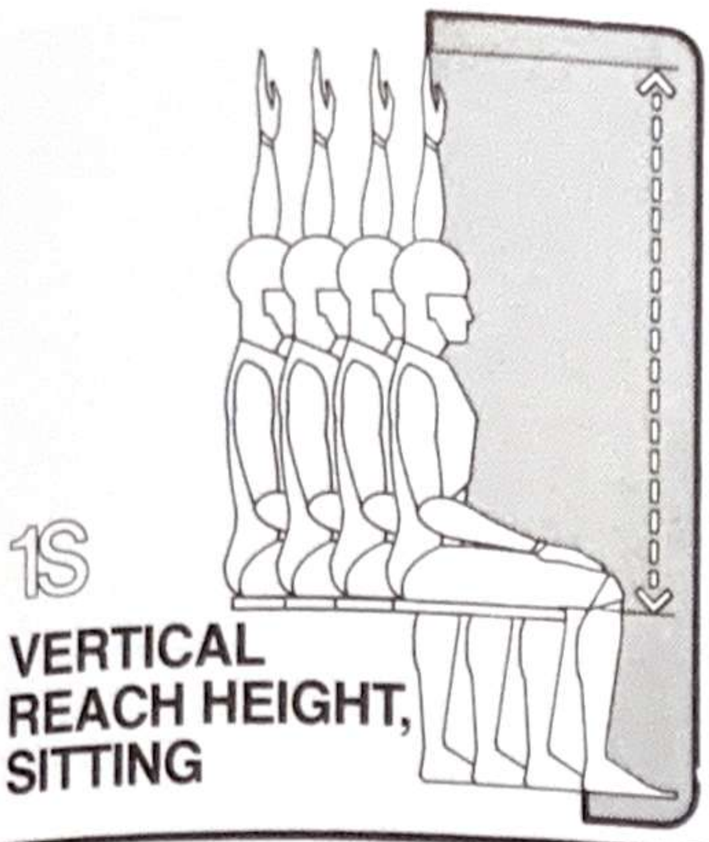
1R BUTTOCK-HEEL LENGTH

DEFINITION
Buttock-heel length is the horizontal distance from the base of the heel to a wall against which the subject sits erect with his leg maximally extended forward along the sitting surface. This is sometimes referred to as buttock-leg length.

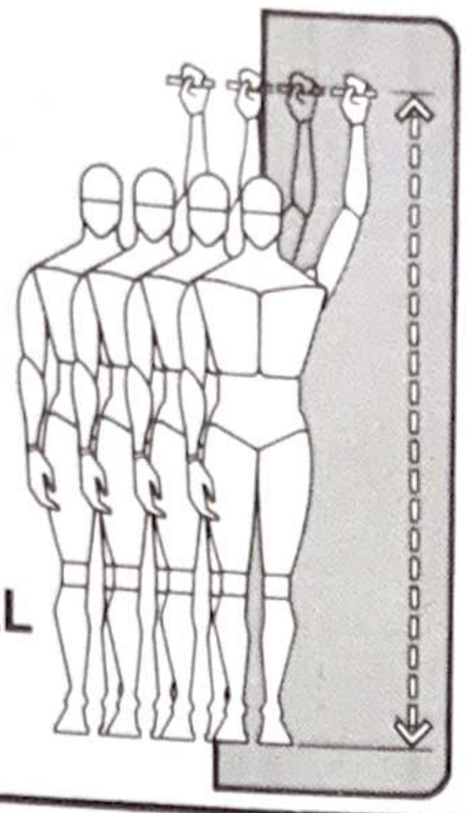
APPLICABILITY
These data generally would have limited applicability for the interior designer, with the exception of determining space requirements for lounge and informal seating arrangements. The data might, for example, be useful in determining combined space requirements for chair and ottoman arrangements as well as physical therapy or exercise equipment and space.

CONSIDERATIONS
The extent to which the buttock-leg length might be increased by any specialized footgear should be reflected in the clearances allowed in the design. In all cases about 1 in, or 2.5 cm, should be added for men's shoes and about 3 in, or 7.6 cm, for women's shoes.

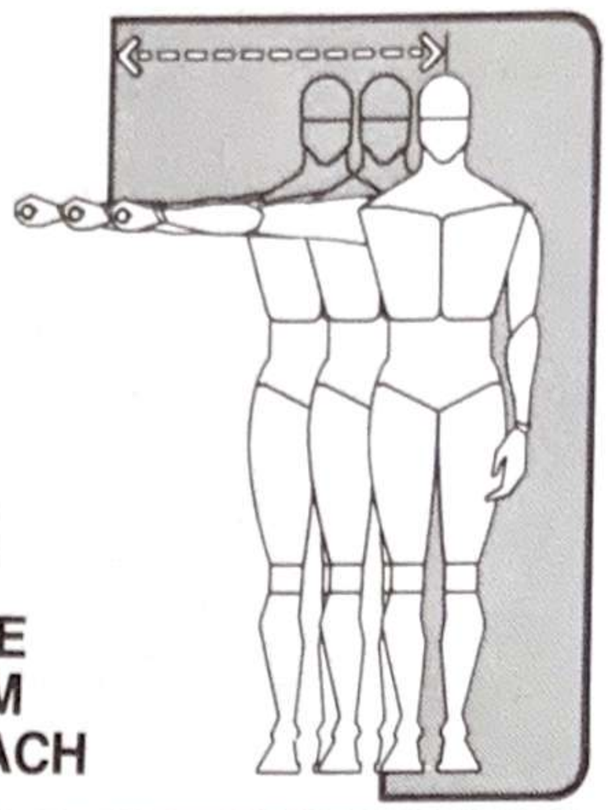
PERCENTILE SELECTION
Since clearance is the operative design factor, 95th percentile data should be used.



1S VERTICAL REACH HEIGHT, SITTING



1T VERTICAL GRIP REACH



1U SIDE ARM REACH

DEFINITION
Vertical reach is the height above the sitting surface of the tip of the middle finger when the arm, hand, and fingers are extended vertically.

APPLICABILITY
This measurement would be of primary value in establishing the location of overhead controls, buttons, etc., and accordingly would be of more use to an equipment designer.

CONSIDERATIONS
Angle of seat and resiliency of upholstery should be considered.

PERCENTILE SELECTION
The 5th percentile would be most appropriate. If a user with the shortest reach is accommodated, the one with the longest reach will be accommodated.

DEFINITION
Vertical grip reach is usually measured from the floor to the top of a bar grasped in the right hand while the subject stands erect and the hand within which the bar is grasped is raised as high as it can be conveniently without experiencing discomfort or strain.

APPLICABILITY
Perhaps the most useful application of these data is in establishing maximum heights above the floor for switches, controls, levers, handles, book shelves, hat shelves, etc.

CONSIDERATIONS
Measurements are usually taken without shoes. Accordingly, appropriate compensation in the data should be made.

PERCENTILE SELECTION
The operative functional factor is reach. If the higher percentile data are used, the design will accommodate those users with the greatest reach, but the user population with the smaller overhead reach will not be accommodated. A design based on the lower percentile range, however, will accommodate not only the smaller, but the larger user.

DEFINITION
Side arm reach is the distance from the center line of the body to the outside surface of a bar grasped in the right hand while the subject stands erect and the arm is conveniently outstretched horizontally without experiencing discomfort or strain.

APPLICABILITY
This measurement would prove more useful to the equipment designer in locating controls. It can be useful to the architect or interior designer, however, in the design of specialized spaces, such as hospital interiors or laboratories. If the user were in a seated position, the dimension, although possibly slightly changed, would still be useful in locating a bookshelf located to the side.

CONSIDERATIONS
If the activity involved requires the use of any specialized handgear, gloves, or any device that by its nature would extend the user's normal reach, the extent to which the reach may be increased should be taken into consideration.

PERCENTILE SELECTION
Since the operative functional factor is reach, this constitutes a classic situation where the users with the smallest arm reach dimension should be accommodated. Accordingly, 5th percentile data should be utilized.

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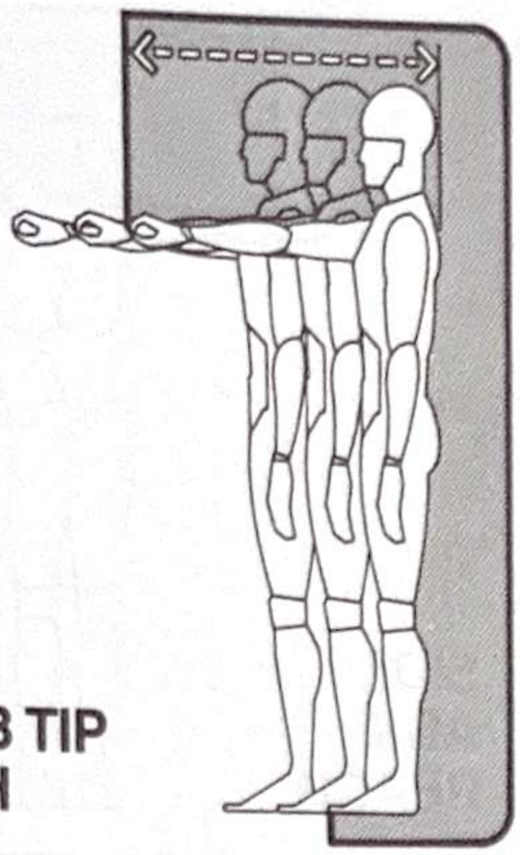
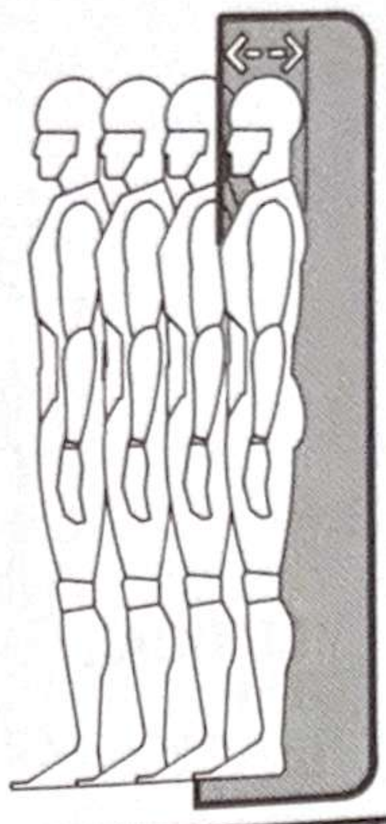


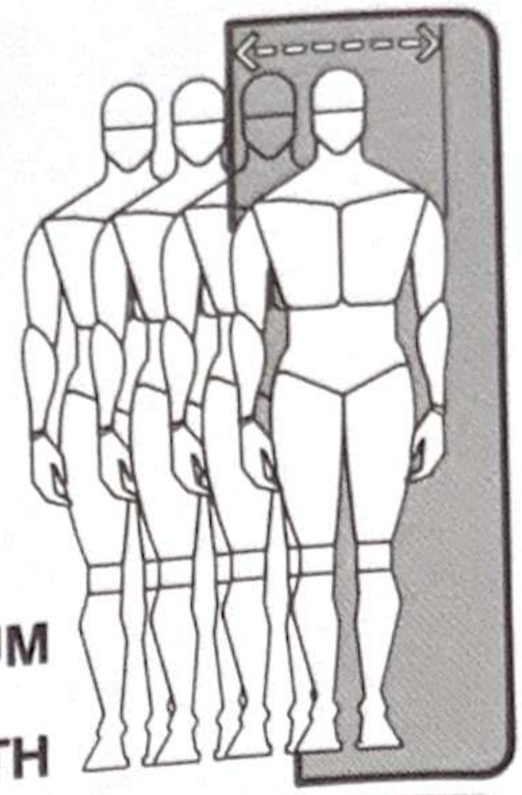
1V

THUMB TIP REACH



1X

MAXIMUM BODY DEPTH



1W

MAXIMUM BODY BREADTH

DEFINITION
Thumb tip reach is the distance from the wall to the tip of the thumb measured with the subject's shoulders against the wall, his arm extended forward, and his index finger touching the tip of his thumb.

APPLICABILITY
Perhaps the primary value of these data is in establishing a maximum dimension for obstructions over which a user might be compelled to reach to grasp an object or operate a piece of equipment. An example of such a design situation might be shelving over a workcounter or cabinets fastened to low office partitions in front of a desk.

CONSIDERATIONS
The specific nature of the operation or task should be considered.

PERCENTILE SELECTION
Since the operative functional factor is reach, this constitutes a classic situation where the users with the smallest arm reach dimension should be accommodated. Accordingly, 5th percentile data should be utilized.

DEFINITION
Maximum body depth is the horizontal distance between the most anterior point on the body to the most posterior. Anterior points are usually located on the chest or abdomen while the posterior points are usually found in the buttock or shoulder region.

APPLICABILITY
Although of more value to an equipment designer, this information could be useful to the architect in providing necessary clearances in extremely tight spaces or queuing situations.

CONSIDERATIONS
Type of clothing, sex of user, and hidden dimension, discussed in Section A, should all be considered.

PERCENTILE SELECTION
The 95th percentile data would be most appropriate.

DEFINITION
Maximum body breadth is the maximum distance, including arms, across the body.

APPLICABILITY
This measurement would be useful in planning aisle widths, corridor widths, door or access opening widths, public assembly areas, etc.

CONSIDERATIONS
Type of clothing, stride and other body movements, as well as hidden dimensions, discussed in Section A, should be considered.

PERCENTILE SELECTION
The 95th percentile data would be most appropriate.

2 ADULT MALE AND FEMALE

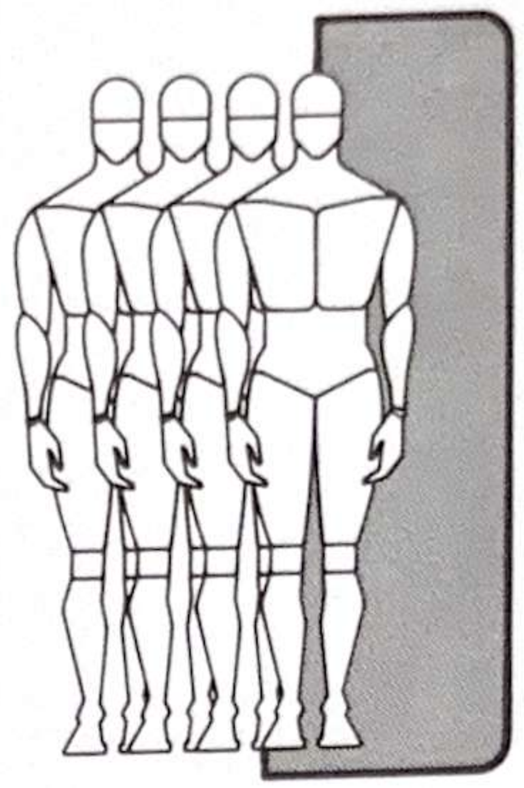
WEIGHT AND STRUCTURAL BODY DIMENSIONS

DESCRIPTION

This table is probably the most comprehensive and current source of available adult civilian anthropometric data. Prepared by Dr. Howard Stoudt, Dr. Albert Damon, and Dr. Ross McFarland formerly of the Harvard School of Public Health, in conjunction with Jean Roberts of the U.S. Public Health Service, it provides detailed body measurements for both sexes and is broken down by age categories (18–24, 25–34, 35–44, 45–54, 55–64, 65–74, and 75–79) as well as by percentiles. In addition to weight, eleven different body measurements are given: stature, sitting height erect, sitting height normal, elbow rest height, thigh clearance height, knee height, popliteal height, buttock-popliteal length, buttock-knee length, elbow-to-elbow breadth, and seat breadth. Proper allowances for clothing and shoes should be added to all data.

SOURCE

Howard W. Stoudt, Albert Damon, Ross McFarland, and Jean Roberts, "National Health Survey 1962: Weight, Height and Selected Body Dimensions of Adults, United States 1960–1962" (Washington, D.C.: U.S. Government Printing Office, Public Health Service Publication no. 1000 Series 11, no. 8, June 1965).



2A

WEIGHT

Adult Male and Female Weight* in Pounds and Kilograms by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
99	MEN	241	109.3	231	104.8	248	112.5	244	110.7	241	109.3	230	104.3	225	102.0	212	96.2
	WOMEN	236	107.0	218	98.9	239	108.4	238	108.0	240	108.9	244	110.7	214	97.1	205	93.0
95	**MEN**	**212**	**96.2**	**214**	**97.1**	**223**	**101.2**	**219**	**99.3**	**219**	**99.3**	**213**	**96.6**	**207**	**93.9**	**198**	**89.8**
	WOMEN	**199**	**90.3**	**170**	**77.1**	**191**	**86.6**	**204**	**92.5**	**205**	**93.0**	**211**	**95.7**	**196**	**88.9**	**193**	**87.5**
90	MEN	205	93.0	193	87.5	208	94.3	207	93.9	209	94.8	203	92.1	198	89.8	191	86.6
	WOMEN	182	82.6	157	71.2	173	78.5	184	83.5	190	86.2	195	88.5	183	83.0	178	80.7
80	MEN	190	86.2	180	81.6	195	88.5	193	87.5	194	88.0	190	86.2	183	83.0	170	77.1
	WOMEN	164	74.4	145	65.8	152	68.9	165	74.8	171	77.6	176	79.8	169	76.7	162	73.5
70	MEN	181	82.1	171	77.6	185	83.9	184	83.5	185	83.9	180	81.6	172	78.0	161	73.0
	WOMEN	152	68.9	137	62.1	143	64.9	153	69.4	158	71.7	165	74.8	160	72.6	155	70.3
60	MEN	173	78.5	164	74.4	177	80.3	177	80.3	178	80.7	172	78.0	166	75.3	150	68.0
	WOMEN	144	65.3	131	59.4	136	61.7	144	65.3	149	67.6	154	69.9	151	68.5	147	66.7
50	MEN	166	75.3	157	71.2	169	76.7	171	77.6	171	77.6	165	74.8	161	73.0	146	66.2
	WOMEN	137	62.1	126	57.2	130	59.0	137	62.1	143	64.9	146	66.2	145	65.8	137	62.1
40	MEN	159	72.1	151	68.5	162	73.5	164	74.4	163	73.9	158	71.7	153	69.4	141	64.0
	WOMEN	131	59.4	122	55.3	125	56.7	131	59.4	137	62.1	140	63.5	138	62.6	127	57.6
30	MEN	152	68.9	145	65.8	154	69.9	158	71.7	156	70.8	151	68.5	146	66.2	137	62.1
	WOMEN	125	56.7	117	53.1	120	54.4	125	56.7	130	59.0	134	60.8	132	59.9	119	54.0
20	MEN	144	65.3	140	63.5	146	66.2	151	68.5	149	67.6	143	64.9	138	62.6	132	59.9
	WOMEN	118	53.5	111	50.3	114	51.7	119	54.0	122	55.3	129	58.5	125	56.7	113	51.3
10	MEN	134	60.8	131	59.4	136	61.7	141	64.0	139	63.0	131	59.4	126	57.2	120	54.4
	WOMEN	111	50.3	104	47.2	107	48.5	113	51.3	113	51.3	120	54.4	114	51.7	105	47.6
5	**MEN**	**126**	**57.2**	**124**	**56.2**	**129**	**58.5**	**134**	**60.8**	**131**	**59.4**	**123**	**55.8**	**117**	**53.1**	**107**	**48.5**
	WOMEN	**104**	**47.2**	**99**	**44.9**	**102**	**46.3**	**109**	**49.4**	**106**	**48.1**	**112**	**50.8**	**106**	**48.1**	**95**	**43.1**
1	MEN	112	50.8	115	52.2	114	51.7	121	54.9	116	52.6	112	50.8	99	44.9	99	44.9
	WOMEN	93	42.2	91	41.3	92	41.7	100	45.4	95	43.1	95	43.1	92	41.7	74	33.6

*All measurements were made with the examinee stripped to the waist and without shoes, but wearing paper slippers and a lightweight, knee-length examining gown. Men's trouser pockets were emptied.
†Measurement below which the indicated percent of people in the given age group fall.

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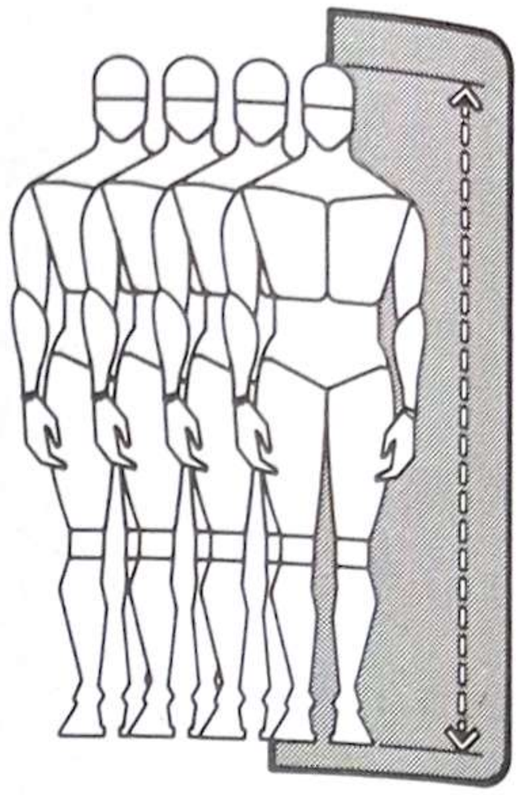


2B

STATURE

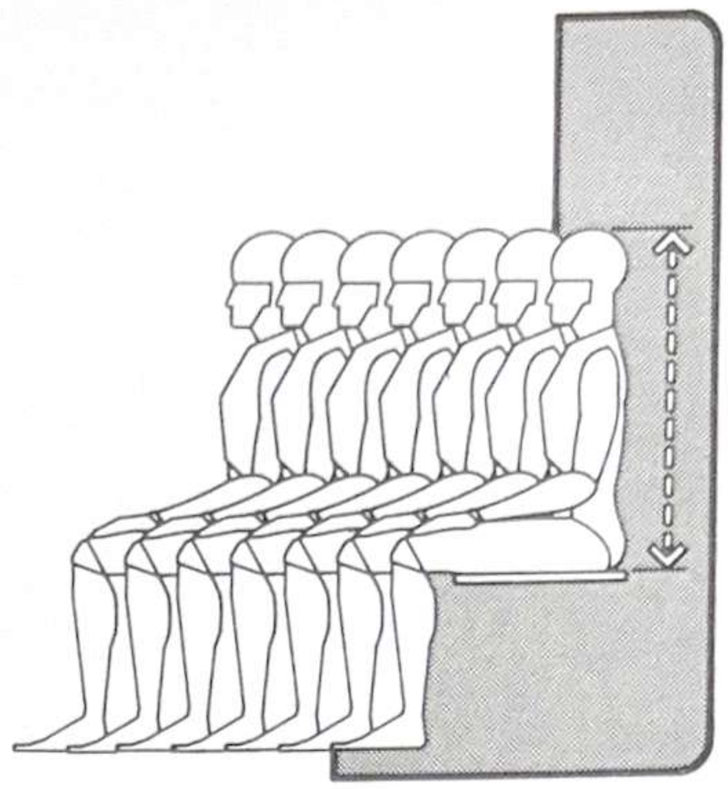
Adult Male and Female Stature* in Inches and Centimeters by Age, Sex and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	74.6	189.5	74.8	190.0	76.0	193.0	74.1	188.2	74.0	188.0	73.5	186.7	72.0	182.9	72.6	184.4
	WOMEN	68.8	174.8	69.3	176.0	69.0	175.3	69.0	175.3	68.7	174.5	68.7	174.5	67.0	170.2	68.2	173.2
95	**MEN**	**72.8**	**184.9**	**73.1**	**185.7**	**73.8**	**187.5**	**72.5**	**184.2**	**72.7**	**184.7**	**72.2**	**183.4**	**70.9**	**180.1**	**70.5**	**179.1**
	WOMEN	**67.1**	**170.4**	**67.9**	**172.5**	**67.3**	**170.9**	**67.2**	**170.7**	**67.2**	**170.7**	**66.6**	**169.2**	**65.5**	**166.4**	**64.9**	**164.8**
90	MEN	71.8	182.4	72.4	183.9	72.7	184.7	71.7	182.1	71.7	182.1	71.0	180.3	70.2	178.3	69.5	176.5
	WOMEN	66.4	168.7	66.8	169.7	66.6	169.2	66.6	169.2	66.1	167.9	65.6	166.6	64.7	164.3	64.5	163.8
80	MEN	70.6	179.3	70.9	180.1	71.4	181.4	70.7	179.6	70.5	179.1	69.8	177.3	68.9	175.0	68.1	173.0
	WOMEN	65.1	165.4	65.9	167.4	65.7	166.9	65.5	166.4	64.8	164.6	64.3	163.3	63.7	161.8	63.6	161.5
70	MEN	69.7	177.0	70.1	178.1	70.5	179.1	70.0	177.8	69.5	176.5	68.8	174.8	68.3	173.5	67.0	170.2
	WOMEN	64.4	163.6	65.0	165.1	64.9	164.8	64.7	164.3	64.1	162.8	63.6	161.5	62.8	159.5	62.8	159.5
60	MEN	68.8	174.8	69.3	176.0	69.8	177.3	69.2	175.8	68.8	174.8	68.3	173.5	67.5	171.5	66.6	169.2
	WOMEN	63.7	161.8	64.5	163.8	64.4	163.6	64.1	162.8	63.4	161.0	62.9	159.8	62.1	157.7	62.3	158.2
50	MEN	68.3	173.5	68.6	174.2	69.0	175.3	68.6	174.2	68.3	173.5	67.6	171.7	66.8	169.7	66.2	168.1
	WOMEN	62.9	159.8	63.9	162.3	63.7	161.8	63.4	161.0	62.8	159.5	62.3	158.2	61.6	156.5	61.8	157.0
40	MEN	67.6	171.7	67.9	172.5	68.4	173.7	68.1	173.0	67.7	172.0	66.8	169.7	66.2	168.1	65.0	165.1
	WOMEN	62.4	158.5	63.0	160.0	62.9	159.8	62.8	159.5	62.3	158.2	61.8	157.0	61.1	155.2	61.3	155.7
30	MEN	66.8	169.7	67.1	170.4	67.7	172.0	67.3	170.9	66.9	169.9	66.0	167.6	65.5	166.4	64.2	163.1
	WOMEN	61.8	157.0	62.3	158.2	62.4	158.5	62.2	158.0	61.7	156.7	61.3	155.7	60.2	152.9	60.1	152.7
20	MEN	66.0	167.6	66.5	168.9	66.8	169.7	66.4	168.7	66.1	167.9	64.7	164.3	64.8	164.6	63.3	160.8
	WOMEN	61.1	155.2	61.6	156.5	61.8	157.0	61.4	156.0	60.9	154.7	60.6	153.9	59.5	151.1	59.0	149.9
10	MEN	64.5	163.8	65.4	166.1	65.5	166.4	65.2	165.6	64.8	164.6	63.7	161.8	64.1	162.8	62.0	157.5
	WOMEN	59.8	151.9	60.7	154.2	60.6	153.9	60.4	153.4	59.8	151.9	59.4	150.9	58.3	148.1	57.3	145.5
5	**MEN**	**63.6**	**161.5**	**64.3**	**163.3**	**64.4**	**163.6**	**64.2**	**163.1**	**64.0**	**162.6**	**62.9**	**159.8**	**62.7**	**159.3**	**61.3**	**155.7**
	WOMEN	**59.0**	**149.9**	**60.0**	**152.4**	**59.7**	**151.6**	**59.6**	**151.4**	**59.1**	**150.1**	**58.4**	**148.3**	**57.5**	**146.1**	**55.3**	**140.5**
1	MEN	61.7	156.7	62.6	159.0	62.6	159.0	62.3	158.2	62.3	158.2	61.2	155.4	60.8	154.4	57.7	146.6
	WOMEN	57.1	145.0	58.4	148.3	58.1	147.6	57.6	146.3	57.3	145.5	56.0	142.2	55.8	141.7	46.8	118.9

*Height, without shoes. See Table 1A for definition of stature.
†Measurement below which the indicated percent of people in the given age group fall.

2C

SITTING HEIGHT ERECT



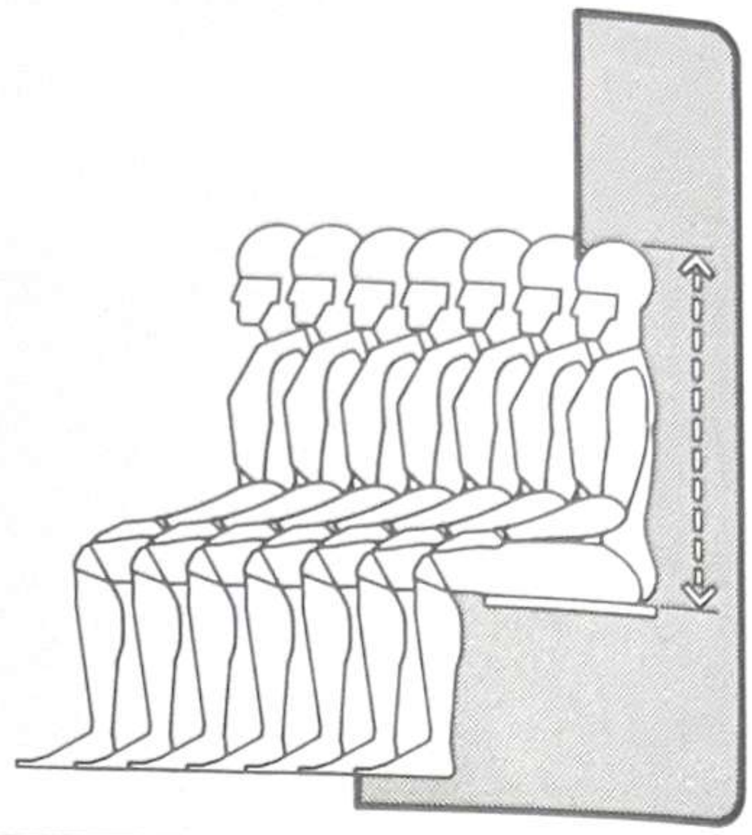
Adult Male and Female Sitting Height Erect* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	38.9	98.8	39.1	99.3	39.0	99.1	38.9	98.8	38.9	98.8	38.7	98.3	37.7	95.8	37.6	95.5
	WOMEN	36.6	93.0	36.7	93.2	36.8	93.5	36.8	93.5	36.4	92.5	36.4	92.5	35.8	90.9	35.7	90.7
95	**MEN**	**38.0**	**96.5**	**38.3**	**97.3**	**38.4**	**97.5**	**38.0**	**96.5**	**38.0**	**96.5**	**37.7**	**95.8**	**36.9**	**93.7**	**36.7**	**93.2**
	WOMEN	**35.7**	**90.7**	**35.9**	**91.2**	**35.5**	**90.9**	**35.8**	**90.9**	**35.6**	**90.4**	**35.4**	**89.9**	**34.5**	**87.6**	**34.8**	**88.4**
90	MEN	37.6	95.5	37.8	96.0	37.3	96.3	37.7	95.8	37.6	95.5	37.1	94.2	36.5	92.7	36.1	91.7
	WOMEN	35.2	89.4	35.4	89.9	34.9	90.2	35.4	89.9	35.0	88.9	34.8	88.4	33.9	86.1	34.0	86.4
80	MEN	36.9	93.7	37.1	95.8	36.9	94.7	37.1	95.8	36.9	93.7	36.6	93.0	35.9	91.2	35.3	89.7
	WOMEN	34.6	87.9	34.8	88.4	34.5	88.6	34.8	88.4	34.6	87.9	39.2	86.9	33.4	84.8	33.3	84.6
70	MEN	36.5	92.7	36.7	93.2	36.5	93.7	36.7	93.2	36.5	92.7	36.1	91.7	35.5	90.2	34.9	88.6
	WOMEN	34.2	86.9	34.4	87.4	34.1	87.6	34.4	87.4	34.1	86.6	33.8	85.9	32.9	83.6	32.8	83.3
60	MEN	36.0	91.4	36.3	92.2	36.1	92.7	36.3	92.2	36.0	91.4	35.7	90.7	35.1	89.2	34.6	87.9
	WOMEN	33.8	85.9	34.0	86.4	33.8	86.6	34.1	86.6	33.8	85.9	33.4	84.8	32.6	82.8	32.5	82.6
50	MEN	35.7	90.7	35.9	91.2	36.1	91.7	36.0	91.4	35.7	90.7	35.3	89.7	34.8	88.4	34.3	87.1
	WOMEN	33.4	84.8	33.7	85.6	33.8	85.9	33.7	85.6	33.5	85.1	33.0	83.8	32.2	81.8	32.1	81.5
40	MEN	35.3	89.7	35.4	89.9	35.7	90.7	35.6	90.4	35.3	89.7	35.0	88.9	34.4	87.4	34.1	86.6
	WOMEN	33.1	84.1	33.4	84.8	33.4	84.8	33.4	84.8	33.2	84.3	32.7	83.1	31.9	81.0	31.6	80.3
30	MEN	34.9	88.6	35.0	88.9	35.3	88.6	35.2	89.4	35.0	89.4	34.5	88.9	34.1	87.6	33.6	85.3
	WOMEN	32.6	82.8	33.0	83.8	33.1	82.8	33.1	89.1	32.8	83.3	32.3	82.0	31.5	80.0	31.1	79.0
20	MEN	34.4	87.4	34.5	87.6	34.9	87.1	34.8	88.4	34.5	87.6	34.1	86.6	33.7	85.6	33.2	84.3
	WOMEN	32.2	81.8	32.6	82.8	32.6	81.5	32.6	82.8	32.3	82.8	31.9	81.0	31.0	78.7	30.4	77.2
10	MEN	33.8	85.9	34.0	86.4	34.3	86.1	34.2	86.9	34.1	86.6	33.3	84.6	33.1	84.1	32.4	82.3
	WOMEN	31.4	79.8	32.1	81.5	32.1	78.8	32.1	81.5	31.7	80.5	31.2	79.2	30.3	77.0	29.2	74.2
5	**MEN**	**33.2**	**84.3**	**33.3**	**84.6**	**33.9**	**82.6**	**33.7**	**85.6**	**33.5**	**85.1**	**32.9**	**83.6**	**32.5**	**82.6**	**31.8**	**80.8**
	WOMEN	**30.9**	**78.5**	**31.4**	**79.8**	**31.4**	**78.8**	**31.5**	**80.0**	**31.2**	**79.2**	**30.7**	**78.0**	**29.7**	**75.4**	**28.1**	**71.4**
1	MEN	31.9	81.0	31.8	80.8	32.5	82.6	32.2	81.8	32.8	83.3	31.4	79.8	31.3	79.5	27.7	70.4
	WOMEN	29.5	74.9	30.4	77.2	30.3	77.0	30.3	77.0	30.1	76.5	30.0	76.2	28.6	72.6	17.8	45.2

*See Table 1D for definition of sitting height erect.
†Measurement below which the indicated percent of people in the given age group fall.

2D

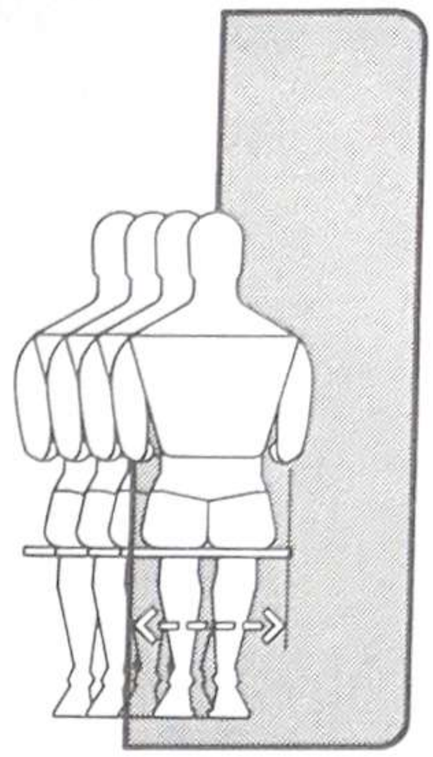
SITTING HEIGHT NORMAL



Adult Male and Female Sitting Height Normal* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	37.6	95.5	37.8	96.0	37.8	96.0	37.7	95.8	37.7	95.8	36.9	93.7	36.4	92.5	36.7	93.2
	WOMEN	35.7	90.7	35.7	90.7	35.9	91.2	35.8	90.9	35.5	90.2	35.4	89.9	34.9	88.6	35.0	88.9
95	**MEN**	**36.6**	**93.0**	**36.7**	**93.2**	**36.8**	**93.5**	**36.7**	**93.2**	**36.7**	**93.2**	**36.0**	**91.4**	**35.7**	**90.7**	**35.8**	**90.9**
	WOMEN	**34.7**	**88.1**	**34.8**	**88.4**	**34.9**	**88.6**	**34.9**	**88.6**	**34.6**	**87.9**	**34.4**	**87.4**	**33.9**	**86.1**	**33.4**	**84.8**
90	MEN	35.9	91.2	36.0	91.4	36.3	92.2	36.2	91.9	36.0	91.4	35.6	90.4	35.1	89.2	35.2	89.4
	WOMEN	34.1	86.6	34.3	87.1	34.5	87.6	34.4	87.4	34.0	86.4	33.8	85.9	33.1	84.1	32.8	83.3
80	MEN	35.3	89.7	35.4	89.9	35.6	90.4	35.5	90.2	35.5	90.2	35.0	88.9	34.6	87.9	34.6	87.9
	WOMEN	33.6	85.3	33.7	85.6	33.8	85.9	33.8	85.9	33.5	85.1	33.2	84.3	32.5	82.6	32.3	82.0
70	MEN	34.8	88.4	34.9	88.6	35.1	89.2	34.9	88.6	35.0	88.9	34.6	87.9	34.1	86.6	34.1	86.6
	WOMEN	33.1	84.1	33.4	84.8	33.4	84.8	33.3	84.6	33.0	83.8	32.8	83.3	31.9	81.0	31.8	80.8
60	MEN	34.5	87.6	34.5	87.6	34.8	88.4	34.6	87.9	34.6	87.9	34.3	87.1	33.8	85.9	33.7	85.6
	WOMEN	32.7	83.1	33.0	83.8	33.0	83.8	32.9	83.6	32.7	83.1	32.4	82.3	31.6	80.3	31.4	79.8
50	MEN	34.1	86.6	34.2	86.9	34.4	87.4	34.3	87.1	34.2	86.9	33.9	86.1	33.4	84.8	33.3	84.6
	WOMEN	32.3	82.0	32.6	82.8	32.6	82.8	32.6	82.8	32.3	82.0	32.1	81.5	31.2	79.2	31.0	78.7
40	MEN	33.7	85.6	33.8	85.9	34.0	86.4	34.0	86.4	33.8	85.9	33.5	85.1	33.1	84.1	32.9	83.6
	WOMEN	31.9	81.0	32.3	82.0	32.3	82.0	32.3	82.0	32.0	81.3	31.7	80.5	30.8	78.2	30.6	77.7
30	MEN	33.3	84.6	33.3	84.6	33.6	85.3	33.5	85.1	33.4	84.8	33.2	84.3	32.7	83.1	32.5	82.6
	WOMEN	31.5	80.0	31.9	81.0	31.9	81.0	31.9	81.0	31.5	80.0	31.3	79.5	30.4	77.2	30.1	76.5
20	MEN	32.9	83.6	32.9	83.6	33.2	84.3	33.1	84.1	32.9	83.6	32.6	82.8	32.4	82.3	32.1	81.5
	WOMEN	31.0	78.7	31.3	79.5	31.4	79.8	31.4	79.8	31.1	79.0	30.8	78.2	30.0	76.2	29.2	74.2
10	MEN	32.2	81.8	32.3	82.0	32.6	82.8	32.4	82.3	32.3	82.0	31.8	80.8	31.9	81.0	30.7	78.0
	WOMEN	30.2	76.7	30.6	77.7	30.7	78.0	30.8	78.2	30.3	77.0	30.2	76.7	29.3	74.4	27.6	70.1
5	**MEN**	**31.6**	**80.3**	**31.9**	**81.0**	**32.1**	**81.5**	**32.0**	**81.3**	**31.8**	**80.8**	**31.3**	**79.5**	**31.2**	**79.2**	**29.8**	**75.7**
	WOMEN	**29.6**	**75.2**	**30.1**	**76.5**	**30.1**	**76.5**	**30.2**	**76.7**	**29.7**	**75.4**	**29.7**	**75.4**	**28.7**	**72.9**	**27.1**	**68.8**
1	MEN	30.4	77.2	30.5	77.5	31.0	78.7	30.8	78.2	30.8	78.2	30.2	76.7	30.1	76.5	26.7	67.8
	WOMEN	28.2	71.6	29.2	74.2	28.9	73.4	29.2	74.2	28.7	72.9	28.3	71.9	27.0	68.6	14.8	37.6

*See Table 1E for definition of sitting height normal.
†Measurement below which the indicated percent of people in the given age group fall.



2E

ELBOW-TO-ELBOW BREADTH

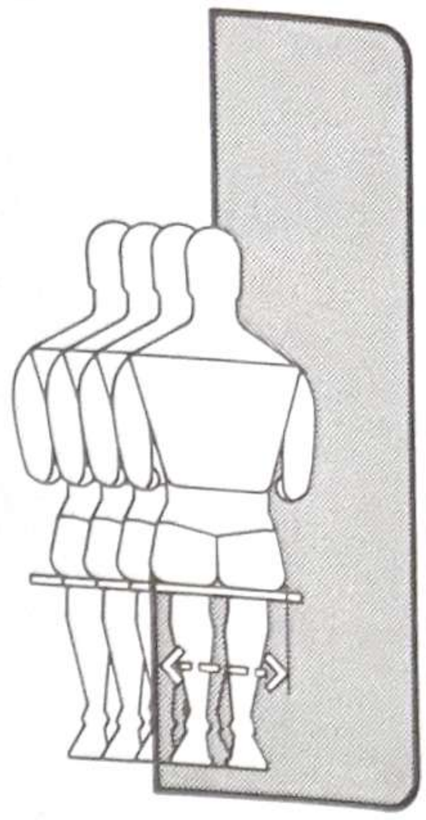
Adult Male and Female Elbow-to-Elbow Breadth* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	21.4	54.4	20.8	52.8	21.4	54.4	21.5	54.6	21.8	55.4	22.0	55.9	21.0	53.3	20.7	52.6
	WOMEN	21.2	53.8	20.0	50.8	20.6	52.3	21.5	54.6	21.7	55.1	21.8	55.4	20.8	52.8	19.8	50.3
95	**MEN**	**19.9**	**50.5**	**19.4**	**49.3**	**19.7**	**50.0**	**20.0**	**50.8**	**20.0**	**50.8**	**20.0**	**50.8**	**19.9**	**50.5**	**19.5**	**49.5**
	WOMEN	**19.3**	**40.9**	**16.9**	**42.9**	**18.3**	**46.5**	**19.3**	**49.0**	**19.7**	**50.0**	**20.2**	**51.3**	**19.7**	**50.0**	**19.1**	**48.5**
90	MEN	19.0	48.3	18.2	46.2	18.8	47.8	19.2	48.8	19.2	48.8	19.3	49.0	19.3	49.0	18.7	47.5
	WOMEN	18.3	46.5	16.0	40.6	17.3	43.9	18.2	46.2	18.7	47.5	19.3	49.0	18.8	47.8	18.1	46.0
80	MEN	18.1	46.0	17.2	43.7	17.8	45.2	18.3	46.5	18.4	46.7	18.3	46.5	18.5	47.0	17.8	45.2
	WOMEN	17.1	43.4	15.1	38.4	15.8	40.1	16.9	42.9	17.6	44.7	18.2	46.2	17.9	45.5	17.5	44.5
70	MEN	17.5	44.5	16.5	41.9	17.3	43.9	17.7	45.0	17.8	45.2	17.7	45.0	17.8	45.2	17.1	43.4
	WOMEN	16.3	41.4	14.6	37.1	15.2	38.6	16.0	40.6	16.8	42.7	17.4	44.2	17.4	44.2	16.9	42.9
60	MEN	17.0	43.2	15.9	40.4	16.8	42.7	17.2	43.7	17.3	43.9	17.2	43.7	17.3	43.9	16.7	42.4
	WOMEN	15.6	39.6	14.2	36.1	14.7	37.3	15.5	39.4	16.0	40.6	16.8	42.7	16.9	42.9	16.3	41.4
50	MEN	16.5	41.9	15.4	39.1	16.3	41.4	16.7	42.4	16.8	42.7	16.7	42.4	16.8	42.7	16.4	41.7
	WOMEN	15.1	38.4	13.8	35.1	14.2	36.1	14.9	37.8	15.5	39.4	16.3	41.4	16.4	41.7	15.7	39.9
40	MEN	16.0	40.6	15.0	38.1	15.9	40.4	16.3	41.4	16.3	41.4	16.1	40.9	16.3	41.4	16.0	40.6
	WOMEN	14.6	37.1	13.4	34.0	13.8	35.1	14.5	36.8	15.1	38.4	15.8	40.1	16.0	40.6	15.3	38.9
30	MEN	15.5	39.4	14.5	36.8	15.4	39.1	15.9	40.4	15.9	40.4	15.6	39.6	15.9	40.4	15.5	39.4
	WOMEN	14.1	35.8	13.1	33.3	13.5	34.3	14.1	35.8	14.6	37.1	15.2	38.6	15.5	39.4	14.7	37.3
20	MEN	15.0	38.1	14.1	35.8	15.0	38.1	15.3	38.9	15.3	38.9	15.2	38.6	15.3	38.9	14.9	37.8
	WOMEN	13.5	34.3	12.6	32.0	13.1	33.3	13.6	34.5	14.1	35.8	14.7	37.3	14.9	37.8	14.2	36.1
10	MEN	14.3	36.1	13.4	34.0	14.2	36.1	14.6	37.1	14.6	37.1	14.5	36.8	14.6	37.1	14.3	36.3
	WOMEN	12.9	32.8	12.1	30.7	12.5	31.8	13.1	33.3	13.3	33.8	14.0	35.6	14.2	36.1	13.5	34.3
5	**MEN**	**13.7**	**34.8**	**13.1**	**33.3**	**13.7**	**34.8**	**14.1**	**35.8**	**14.1**	**35.8**	**14.1**	**35.8**	**14.0**	**35.6**	**14.0**	**35.6**
	WOMEN	**12.3**	**31.2**	**11.7**	**29.7**	**12.2**	**31.0**	**12.5**	**31.8**	**12.7**	**32.3**	**13.4**	**34.0**	**13.7**	**34.8**	**13.1**	**33.3**
1	MEN	13.0	33.0	12.3	31.2	13.1	33.3	13.1	33.3	13.2	33.5	13.2	33.5	13.2	33.5	12.4	31.5
	WOMEN	11.4	29.0	11.0	27.9	11.4	29.0	11.7	29.7	11.6	29.5	12.3	31.2	12.4	31.5	12.3	31.2

*See Table 1I for definition of elbow-to-elbow breadth.
†Measurement below which the indicated percent of people in the given age group fall.

2F

HIP BREADTH



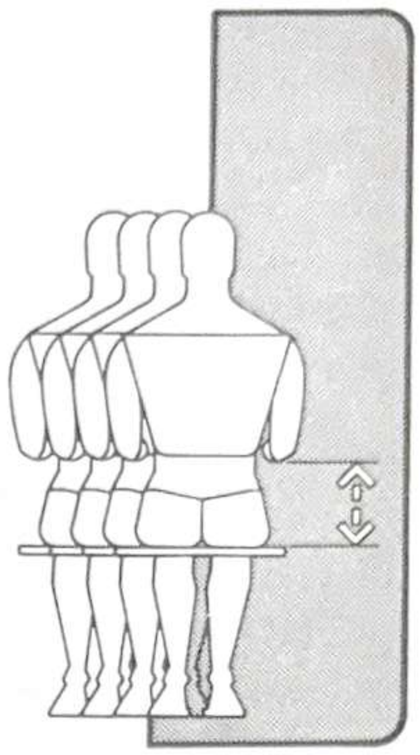
Adult Male and Female Hip Breadth* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	17.0	43.2	17.3	43.9	17.4	44.2	17.1	43.4	16.9	42.9	16.9	42.9	16.6	42.2	16.5	41.9
	WOMEN	18.8	47.8	18.4	46.7	19.0	48.3	19.2	48.8	19.0	48.3	18.7	47.5	18.2	46.2	17.1	43.4
95	**MEN**	**15.9**	**40.4**	**15.8**	**40.1**	**16.0**	**40.6**	**15.9**	**40.4**	**16.0**	**40.6**	**15.9**	**40.4**	**15.7**	**39.9**	**15.5**	**39.4**
	WOMEN	**17.1**	**43.4**	**15.9**	**40.4**	**16.8**	**42.7**	**17.3**	**43.9**	**17.6**	**44.7**	**17.4**	**44.2**	**17.3**	**43.9**	**16.8**	**42.7**
90	MEN	15.5	39.4	15.0	38.1	15.6	39.6	15.6	39.6	15.7	39.9	15.6	39.6	15.1	38.4	14.9	37.8
	WOMEN	16.4	41.7	15.4	39.1	16.0	40.6	16.5	41.9	16.7	42.4	16.8	42.7	16.7	42.4	16.5	41.9
80	MEN	14.9	37.8	14.6	37.1	14.9	37.8	15.0	38.1	15.1	38.4	15.0	38.1	14.7	37.3	14.5	36.8
	WOMEN	15.6	39.6	14.8	37.6	15.3	38.9	15.7	39.9	15.8	40.1	16.0	40.6	15.9	40.4	15.8	40.1
70	MEN	14.6	37.1	14.1	35.8	14.6	37.1	14.7	37.3	14.8	37.6	14.6	37.1	14.5	36.8	14.2	36.1
	WOMEN	15.1	38.4	14.4	36.6	14.8	37.6	15.1	38.4	15.4	39.1	15.6	39.6	15.4	39.1	15.0	38.1
60	MEN	14.3	36.3	13.8	35.1	14.3	36.3	14.4	36.6	14.5	36.8	14.3	36.3	14.2	36.1	13.9	35.3
	WOMEN	14.7	37.3	14.1	35.3	14.4	36.6	14.8	37.6	15.0	38.1	15.1	38.4	14.9	37.8	14.5	36.8
50	MEN	14.0	35.6	13.5	34.3	14.0	35.6	14.1	35.8	14.2	36.1	14.0	35.6	13.9	35.3	13.6	34.5
	WOMEN	14.3	36.3	13.8	35.1	14.0	35.6	14.5	36.8	14.6	37.1	14.7	37.3	14.6	37.1	14.0	35.6
40	MEN	13.7	34.8	13.3	33.8	13.7	34.8	13.8	35.1	13.9	35.3	13.7	34.8	13.6	34.5	13.4	34.0
	WOMEN	14.0	35.6	13.5	34.3	13.7	34.8	14.2	36.1	14.2	36.1	14.3	36.3	14.3	36.3	13.7	34.8
30	MEN	13.4	34.0	13.0	33.0	13.4	34.0	13.5	34.3	13.5	34.3	13.4	34.0	13.4	34.0	13.2	33.5
	WOMEN	13.6	34.5	13.2	33.5	13.4	34.0	13.8	35.1	13.8	35.1	13.9	35.3	14.0	35.6	13.3	33.8
20	MEN	13.1	33.3	12.6	32.0	13.1	33.3	13.3	33.8	13.2	33.5	13.1	33.3	13.1	33.3	12.9	32.8
	WOMEN	13.3	33.8	12.8	32.5	13.1	33.3	13.4	34.0	13.4	34.0	13.6	34.5	13.5	34.3	13.0	33.0
10	MEN	12.5	31.8	12.5	31.0	12.5	31.8	12.9	32.8	12.6	32.0	12.6	32.0	12.6	32.0	12.4	31.5
	WOMEN	12.7	32.3	12.3	31.2	12.6	32.0	12.9	32.8	13.0	33.0	13.2	33.5	12.9	32.8	12.2	31.0
5	**MEN**	**12.2**	**31.0**	**12.0**	**30.5**	**12.2**	**31.0**	**12.4**	**31.5**	**12.2**	**31.0**	**12.2**	**31.0**	**12.2**	**31.0**	**12.1**	**30.7**
	WOMEN	**12.3**	**31.2**	**12.1**	**30.7**	**12.2**	**31.0**	**12.4**	**31.5**	**12.4**	**31.5**	**12.9**	**32.8**	**12.4**	**31.5**	**11.7**	**29.7**
1	MEN	11.5	29.2	11.3	28.7	11.7	29.7	12.0	30.5	11.5	29.2	11.6	29.5	11.4	29.0	11.4	29.0
	WOMEN	11.7	29.7	11.3	28.7	11.5	29.2	12.0	30.5	12.0	30.5	12.1	30.7	12.1	30.7	9.8	24.9

*See Table 1J for definition of hip breadth.
†Measurement below which the indicated percent of people in the given age group fall.

2G

ELBOW REST HEIGHT

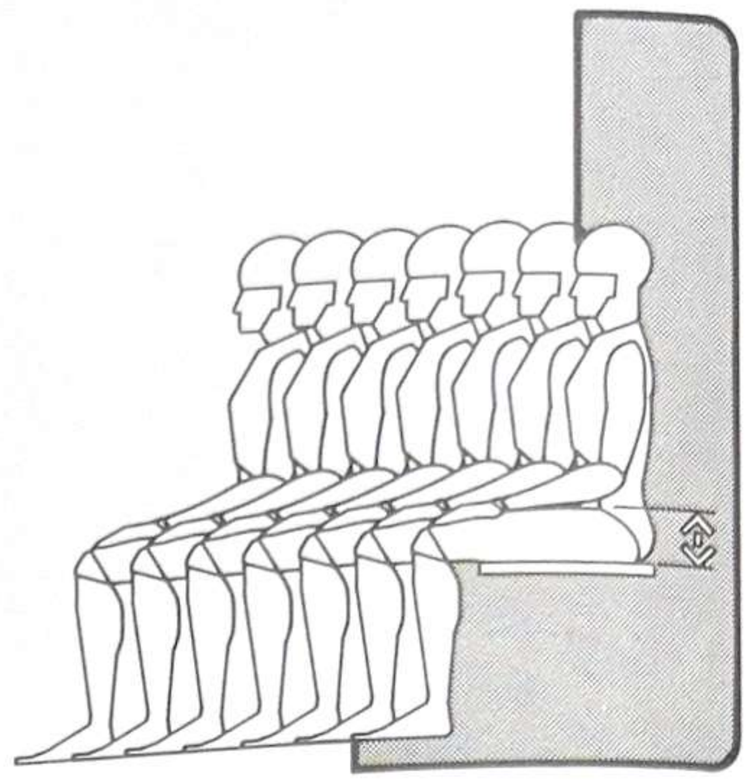


Adult Male and Female Elbow Rest Height* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	12.5	31.8	12.8	32.5	12.6	32.0	12.6	32.0	12.0	24.1	12.2	23.6	11.9	22.9	11.0	21.8
	WOMEN	11.9	30.2	11.8	30.0	11.9	30.2	12.0	30.5	12.1	30.7	11.9	30.2	11.3	28.7	10.7	27.2
95	**MEN**	**11.6**	**29.5**	**11.9**	**30.2**	**11.7**	**29.7**	**11.8**	**30.0**	**11.5**	**30.5**	**11.4**	**30.0**	**10.9**	**27.7**	**10.6**	**26.9**
	WOMEN	**11.0**	**27.9**	**10.8**	**27.4**	**11.1**	**28.2**	**11.3**	**28.7**	**11.0**	**27.9**	**10.9**	**27.7**	**10.2**	**25.9**	**10.0**	**25.4**
90	MEN	11.0	27.9	11.4	30.0	11.1	28.2	11.3	28.7	11.0	27.9	10.9	27.7	10.6	26.9	10.2	25.9
	WOMEN	10.7	27.2	10.5	26.7	10.8	27.4	10.8	27.4	10.7	27.2	10.6	26.9	9.8	24.9	9.8	24.9
80	MEN	10.6	26.9	10.7	27.2	10.7	27.2	10.7	27.2	10.5	26.7	10.4	26.4	10.0	25.4	9.7	24.6
	WOMEN	10.1	25.7	9.9	25.1	10.3	26.2	10.3	26.2	10.3	26.2	10.0	25.4	9.5	24.1	9.4	22.9
70	MEN	10.2	25.9	10.3	26.2	10.3	26.2	10.4	26.4	10.1	25.7	9.9	25.1	9.6	24.4	9.3	23.6
	WOMEN	9.7	24.6	9.6	24.4	9.9	25.1	9.9	25.1	9.9	25.1	9.6	24.4	9.1	23.1	9.1	23.1
60	MEN	9.8	24.9	9.9	25.1	10.0	25.4	10.0	25.4	9.8	24.9	9.6	24.4	9.3	23.6	8.9	22.6
	WOMEN	9.5	24.1	9.4	23.9	9.6	24.4	9.7	24.6	9.6	24.4	9.3	23.6	8.8	22.4	8.7	22.1
50	MEN	9.5	24.1	9.6	24.4	9.7	24.6	9.7	24.6	9.6	24.4	9.3	23.6	9.0	22.9	8.6	21.8
	WOMEN	9.2	23.4	9.1	23.1	9.3	23.6	9.4	23.9	9.3	23.6	9.0	22.9	8.5	21.6	8.4	21.3
40	MEN	9.2	23.4	9.4	23.9	9.4	23.9	9.4	23.9	9.3	23.6	9.0	22.9	8.7	22.1	8.2	20.8
	WOMEN	8.9	22.6	8.8	22.4	9.1	23.1	9.2	23.4	9.0	22.9	8.6	21.8	8.2	20.8	8.0	20.3
30	MEN	8.9	22.6	9.1	23.1	9.1	23.1	9.1	23.1	9.1	23.1	8.6	21.8	8.4	21.3	7.8	19.8
	WOMEN	8.5	21.6	8.5	21.6	8.7	22.1	8.9	22.6	8.7	21.8	8.3	21.1	7.8	19.8	7.7	19.6
20	MEN	8.5	21.6	8.6	21.8	8.7	22.1	8.7	22.1	8.7	22.1	8.3	21.1	8.0	20.3	7.5	19.1
	WOMEN	8.2	20.8	8.2	20.8	8.4	21.3	8.5	21.6	8.3	21.1	8.0	20.3	7.4	18.8	7.4	18.8
10	MEN	8.0	20.3	8.1	20.6	8.3	21.1	8.2	20.8	8.2	20.8	7.7	19.6	7.4	18.8	7.1	18.0
	WOMEN	7.6	19.3	7.6	19.3	8.0	20.3	8.0	20.3	7.8	19.8	7.4	18.8	7.0	17.5	7.0	17.5
5	**MEN**	**7.4**	**18.8**	**7.6**	**19.3**	**8.0**	**20.3**	**7.8**	**19.8**	**7.7**	**19.6**	**7.2**	**18.3**	**7.1**	**18.0**	**6.5**	**16.5**
	WOMEN	**7.1**	**18.0**	**7.2**	**18.3**	**7.4**	**18.8**	**7.5**	**19.1**	**7.3**	**19.8**	**7.1**	**18.0**	**6.4**	**16.3**	**6.4**	**16.3**
1	MEN	6.3	16.0	6.3	16.0	7.0	17.8	6.5	16.5	7.0	17.8	6.0	17.8	6.1	15.5	5.7	14.5
	WOMEN	6.1	15.5	6.2	15.7	6.1	15.5	6.7	17.0	6.4	16.3	6.4	16.3	5.4	13.7	2.8	7.1

*See Table 1K for definition of elbow rest height.
†Measurement below which the indicated percent of people in the given age group fall.

2H



THIGH CLEARANCE

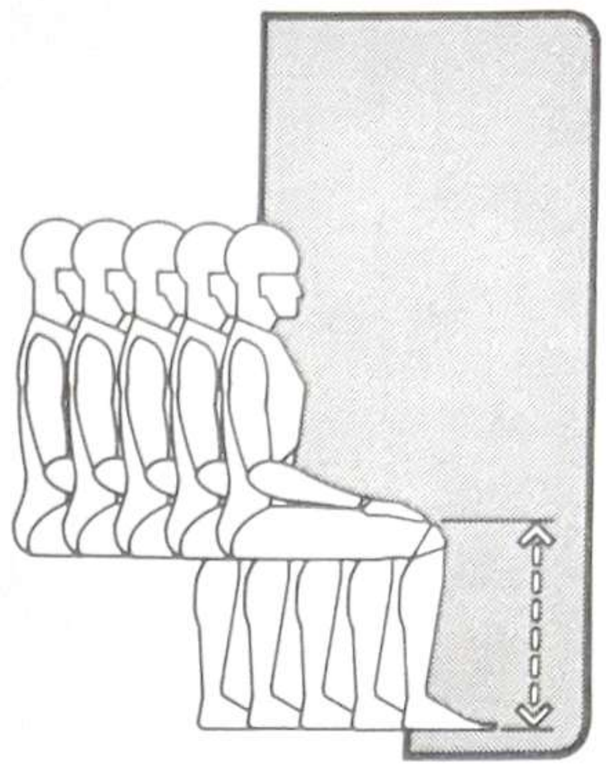
Adult Male and Female Thigh Clearance* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	7.7	19.6	7.7	19.6	7.9	20.1	7.8	19.8	7.1	18.0	7.4	18.8	7.0	17.8	7.2	18.3
	WOMEN	7.7	19.6	7.0	17.8	7.7	19.6	7.8	19.8	7.7	19.6	8.3	21.1	7.0	17.8	6.9	17.5
95	**MEN**	**6.9**	**17.5**	**6.9**	**17.5**	**7.0**	**17.8**	**7.0**	**17.8**	**6.9**	**17.5**	**6.8**	**17.3**	**6.7**	**17.0**	**6.6**	**16.8**
	WOMEN	**6.9**	**17.5**	**6.7**	**17.0**	**6.9**	**17.5**	**7.0**	**17.8**	**6.9**	**17.5**	**6.9**	**17.5**	**6.6**	**16.8**	**6.5**	**16.5**
90	MEN	6.7	17.0	6.8	17.3	6.9	17.5	6.8	17.3	6.7	17.0	6.6	16.8	6.5	16.5	6.1	15.5
	WOMEN	6.6	16.8	6.3	16.0	6.6	16.8	6.7	17.0	6.6	16.8	6.6	16.8	6.2	15.7	6.1	15.5
80	MEN	6.4	16.3	6.4	16.3	6.6	16.8	6.5	16.5	6.3	16.0	6.1	15.5	6.0	15.2	5.8	14.7
	WOMEN	6.0	15.2	5.9	15.0	6.0	15.2	6.3	16.0	6.1	15.5	6.0	15.2	5.9	15.0	5.8	14.7
70	MEN	6.0	15.2	6.1	15.5	6.3	16.0	6.2	15.7	6.0	15.2	5.9	15.0	5.8	14.7	5.6	14.2
	WOMEN	5.8	14.7	5.7	14.5	5.8	14.7	5.9	15.0	5.9	15.0	5.8	14.7	5.7	14.5	5.6	14.2
60	MEN	5.8	14.7	5.9	15.0	6.0	15.2	6.0	15.2	5.8	14.7	5.7	14.5	5.6	14.2	5.4	13.7
	WOMEN	5.6	14.2	5.5	14.0	5.6	14.2	5.7	14.5	5.7	14.5	5.6	14.2	5.5	14.0	5.4	13.7
50	MEN	5.7	14.5	5.7	14.5	5.8	14.7	5.8	14.7	5.6	14.2	5.5	14.0	5.4	13.7	5.2	13.2
	WOMEN	5.4	13.7	5.4	13.7	5.4	13.7	5.5	14.0	5.5	14.0	5.4	13.7	5.3	13.5	5.2	13.2
40	MEN	5.5	14.0	5.5	14.0	5.6	14.2	5.6	14.2	5.5	14.0	5.3	13.5	5.3	13.5	5.0	13.0
	WOMEN	5.2	13.2	5.2	13.2	5.2	13.2	5.3	13.5	5.3	13.5	5.2	13.2	5.1	13.0	4.9	12.4
30	MEN	5.3	13.5	5.3	13.5	5.4	13.7	5.4	13.7	5.3	13.5	5.2	13.2	5.1	13.0	4.7	11.9
	WOMEN	5.1	13.0	5.0	13.0	5.1	13.0	5.1	13.0	5.1	13.0	5.0	13.0	4.9	12.4	4.7	11.9
20	MEN	5.1	13.0	5.1	13.0	5.2	13.2	5.2	13.2	5.1	13.0	4.9	12.4	4.8	12.2	4.5	11.4
	WOMEN	4.7	11.9	4.7	11.9	4.7	11.9	4.9	12.4	4.8	12.2	4.7	11.9	4.6	11.7	4.4	11.2
10	MEN	4.7	11.9	4.7	11.9	4.9	12.4	5.0	13.0	4.9	12.4	4.5	11.4	4.4	11.2	4.2	10.7
	WOMEN	4.3	10.9	4.3	10.9	4.9	12.4	4.4	11.2	4.4	11.2	4.3	10.9	4.2	10.7	4.1	10.4
5	**MEN**	**4.3**	**10.9**	**4.3**	**10.9**	**4.5**	**11.4**	**4.4**	**11.2**	**4.2**	**10.7**	**4.2**	**10.7**	**4.2**	**10.7**	**4.1**	**10.4**
	WOMEN	**4.1**	**10.4**	**4.1**	**10.4**	**4.2**	**10.7**	**4.2**	**10.7**	**4.1**	**10.4**	**4.1**	**10.4**	**4.1**	**10.4**	**4.0**	**10.1**
1	MEN	4.1	10.4	4.1	10.4	4.1	10.4	4.1	10.4	4.0	10.1	4.0	10.1	4.0	10.1	3.9	9.9
	WOMEN	3.8	9.7	3.6	9.1	4.0	10.1	4.0	10.1	3.5	8.9	3.5	8.9	3.4	8.6	3.2	8.1

*See Table 1L for definition of thigh clearance.
†Measurement below which the indicated percent of people in the given age group fall.

21

KNEE HEIGHT



Adult Male and Female Knee Height* in Inches and Centimeters by Age, Sex, and Selected Percentiles†

		18 to 79 (Total)		18 to 24 Years		25 to 34 Years		35 to 44 Years		45 to 54 Years		55 to 64 Years		65 to 74 Years		75 to 79 Years	
		in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm	in	cm
99	MEN	24.1	61.2	23.9	60.7	24.6	62.5	24.4	70.0	23.9	60.7	24.0	61.0	23.7	61.0	23.3	59.9
	WOMEN	22.4	56.9	22.7	57.7	22.5	57.2	22.4	56.9	22.5	57.2	21.9	55.6	22.0	55.9	21.5	54.6
95	**MEN**	**23.4**	**59.4**	**23.4**	**59.4**	**23.7**	**61.0**	**23.4**	**59.4**	**23.3**	**59.9**	**23.1**	**58.7**	**22.9**	**58.7**	**22.7**	**57.7**
	WOMEN	**21.5**	**54.6**	**21.6**	**54.9**	**21.6**	**54.9**	**21.5**	**54.6**	**21.6**	**54.9**	**21.4**	**54.4**	**21.0**	**53.3**	**20.9**	**53.1**
90	MEN	22.9	58.7	22.9	58.7	23.3	59.9	22.9	58.7	22.8	57.9	22.8	57.9	22.5	57.2	22.2	56.4
	WOMEN	21.0	53.3	21.0	53.3	21.0	53.3	21.0	53.3	21.0	53.3	20.9	53.1	20.7	52.6	20.7	52.6
80	MEN	22.4	57.0	22.5	57.2	22.7	57.7	22.5	57.2	22.4	57.0	22.2	56.4	21.9	55.6	21.7	55.1
	WOMEN	20.5	52.1	20.6	52.3	20.6	52.3	20.6	52.3	20.5	52.1	20.4	51.8	20.1	51.1	20.2	51.3
70	MEN	22.0	55.9	22.1	56.1	22.2	56.4	22.1	56.1	22.0	55.9	21.8	55.4	21.6	54.9	21.4	54.4
	WOMEN	20.1	51.1	20.3	51.6	20.3	51.6	20.2	51.3	20.1	51.1	20.0	50.8	19.8	50.3	19.9	50.5
60	MEN	21.7	55.1	21.8	55.4	21.9	55.6	21.8	55.4	21.7	55.1	21.4	54.4	21.3	54.1	21.0	53.3
	WOMEN	19.8	50.3	20.0	50.8	20.0	50.8	19.9	50.5	19.8	50.3	19.7	50.0	19.5	49.5	19.6	49.8
50	MEN	21.4	54.4	21.5	54.6	21.6	54.9	21.5	54.6	21.4	54.4	21.1	53.6	21.0	53.3	20.7	52.6
	WOMEN	19.6	49.8	19.7	50.0	19.7	50.0	19.6	49.8	19.5	49.5	19.5	49.5	19.2	48.8	19.4	49.3
40	MEN	21.1	53.6	21.2	53.8	21.3	54.1	21.2	53.5	21.1	53.6	20.8	52.8	20.7	52.6	20.4	51.8
	WOMEN	19.3	49.0	19.5	49.5	19.4	49.3	19.4	49.3	19.2	48.8	19.2	48.8	19.0	48.3	19.2	48.8
30	MEN	20.7	52.6	20.8	52.8	21.1	53.6	20.8	52.8	20.7	52.6	20.5	52.1	20.5	52.1	20.0	50.8
	WOMEN	19.1	48.5	19.2	48.8	19.2	48.8	19.1	48.5	19.0	48.3	19.0	48.3	18.7	47.5	18.9	48.0
20	MEN	20.4	51.8	20.5	52.1	20.6	52.3	20.4	51.8	20.3	51.6	20.2	51.3	20.2	51.3	19.6	49.8
	WOMEN	18.6	47.2	18.9	48.0	18.8	47.8	18.8	47.8	18.5	47.0	18.6	47.2	18.4	46.7	18.4	46.7
10	MEN	20.0	50.8	20.1	51.1	20.2	51.3	20.0	50.8	19.9	50.5	19.6	49.8	19.9	50.5	19.2	48.8
	WOMEN	18.2	46.2	18.4	46.7	18.3	46.5	18.3	46.5	18.1	46.0	18.2	46.2	18.1	46.0	18.0	45.7
5	**MEN**	**19.3**	**49.0**	**19.4**	**49.3**	**19.8**	**50.3**	**19.4**	**49.3**	**19.3**	**49.0**	**19.1**	**48.5**	**19.2**	**48.8**	**19.0**	**48.3**
	WOMEN	**17.9**	**45.5**	**18.1**	**46.0**	**18.0**	**45.7**	**18.0**	**45.7**	**17.6**	**44.7**	**17.8**	**45.2**	**17.8**	**45.2**	**17.3**	**43.9**
1	MEN	18.3	46.5	18.3	46.5	19.0	48.3	18.4	46.7	18.2	46.2	18.1	46.0	18.2	46.2	18.0	45.7
	WOMEN	17.1	43.4	17.3	43.9	17.2	43.7	17.2	43.7	17.1	43.4	16.6	42.2	17.1	43.4	16.3	41.4

*See Table 1M for definition of knee height.
†Measurement below which the indicated percent of people in the given age group fall.