

Guidelines for Using Anthropometric Data in Product Design

HFES 300 Committee

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Guidelines for Using Anthropometric Data in Product Design

HFES 300 Committee

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Submitted:

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Preface

The Human Factors and Ergonomics Society formed the ANSI/HFES 300 “Anthropometry and Biomechanics” Committee in 1996. The committee’s founding charge was to author an American standard for the application of anthropometric data to ergonomic design. The 300 Committee’s inception coincided with revision of the ANSI 100 standard, “Human Factors Engineering of Visual Display Terminal Workstations”, in order, among other things, to provide a foundation for statistical techniques used in the 100 standard. Over the course of development of this document, it was decided that publishing it as a HFES Best Practices publication would be more appropriate.

Chaired by Robin Herron from 1996-1998, by Claire C. Gordon from 1999-2002, and by Mark Strauss in 2003, the Committee at various times included Tom Albin, Marvin Dainoff, Claire Gordon, Robin Herron, Hongzheng “Cindy” Lu, Kristie Nemeth, Kathleen Robinette, and Mark Strauss. This diverse and talented committee often discussed the technical level at which the document should be targeted, given the complexity of the ergonomic design process and the relative novelty of statistical approaches required.

After much discussion, the committee concluded that there was so little published regarding the role and proper integration of sophisticated anthropometric methods within an ergonomic design framework that the initial target audience for this Best Practices document should be ourselves – professional ergonomists, engineers, and statisticians who apply anthropometry to product development. The decision to target a professional audience permitted the committee to address perceived knowledge gaps within our community and to produce a document that hopefully provokes both scientific discussion and greater application of anthropometric methods in product design. However, as most consumer products are neither designed nor tested by professional ergonomists, this document includes extensive examples, a glossary, and a bibliography for further reading.

In addition to the perseverance of the committee members, a number of people and institutions contributed directly and indirectly to the production of this document. Both Robert Beaton and Lynn Strother were instrumental in establishing and supporting the Committee. Marvin Dainoff served as the Committee’s secretary throughout, recording and organizing meeting minutes and keeping copies of early drafts. The University of Illinois (thanks to Mark Strauss) provided server space and software guidance for electronic archiving and exchange of drafts among committee members. The U.S. Air Force (thanks to Kathleen Robinette) and Lucent Technologies (thanks to Hongzheng Lu) provided telephone conferencing facilities that permitted the committee to conduct many “meetings” at no cost to the Society. The U.S. Army (thanks to Claire Gordon) provided access to a professional editor, Marcia Lightbody, whose unique talents and extensive background in technical editing have substantially improved the clarity and readability of our work. Respected members of HFES acted as reviewers and whose efforts enhanced the final product.

1. Introduction

An important purpose of all persons working in ergonomics is to design tools, workplaces and environments so that humans can function most effectively. In other words, we want to optimize human performance and well-being by achieving the best possible fit between the *human operator*, the *equipment*—hardware and software, and the working *environment*—physical and psychosocial. This fit is often referred to as "the human-machine interface." Anthropometry plays a major role in achieving this goal because variations in body shape and size affect the manner by people perform tasks, how efficiently the tasks are performed as well as the safety of the worker. Thus, anthropometry has an important influence on whether the human-machine interface is a good one.

1.1 Scope

This document is intended to aid the user in selecting, developing and applying anthropometric information for workstation and other product design, based on current scientific knowledge and best practices in ergonomics and human factors. The document is for anyone who is interested in using, or understanding the basis for using, anthropometry in design. The results should be workstations and other products that better fit their intended users.

1.2 Background

The breadth of opportunities for anthropometry to improve the human-machine interface is remarkably wide—including industrial equipment, clothing and furniture, surgical tools, farm implements, aircraft controls, and virtually every item in the environment with which humans interact. Over the years, engineers, designers, architects and others who design products have increasingly recognized the need for body measurement data on the users of their creations.

1.3 Defining the Design Problem

Of course, the type of anthropometric data required varies greatly from one product to another. The fit of a bathrobe, for example, can be quite loose and still serve its intended purpose. However a respirator for protection against breathing toxic fumes must conform closely to the geometry of the face in order to maintain adequate contact and prevent leakage. In the case of the bathrobe, data on the intended users' height and a few body girth measurements may be all the information needed to ensure adequate body coverage for a good interface. However, for the users of the respirators, it may be necessary to obtain detailed measurements of individual facial geometry to ensure a satisfactory fit. Thus, the function of a product not only influences our definition of "fit", but also determines what anthropometric information is needed to ensure an effective user-product interface.

Defining the design problem, including the concepts of fit and relevant body dimensions, is a critical first step in any ergonomic application of anthropometry in the

design process, and one that may call for considerable insight and analytical skill. This part of the ergonomic design process is taken up in Chapter 2 of these guidelines, Statement of the Design Problem.

1.4 Who Are the Users?

Another critical, but often overlooked, step in the ergonomic design process is determining “who” the product’s intended users are. In this document, we will be referring to a product’s intended users as the “target audience” or “target population”. Target audiences can vary dramatically in their age, sex, racial/ethnic composition, and physical health characteristics, depending upon a product’s function and the manufacturer’s marketing strategy. All of these demographic and health-related factors influence the users’ body size distributions, thus it is important to know as much as possible about the target audience in advance.

One would not, for example, find anthropometric data on men useful in the design of jogging bras for women. By the same token, standard anthropometric data may be virtually useless in the design of living spaces for those who use wheelchairs.

Apart from product function, marketing strategies can also influence target audiences and their body size distributions. A manufacturer may choose to fit only “tall” men, or “petite” women. Sometimes a particular design is intended for sale only in a particular country or geographical region – as is the case with many automobiles. Other products may have worldwide sales at the foundation of their marketing plan, and their designers need to consider worldwide anthropometric distributions. Failure of designers to consider the differences in body size distributions in fitting products to different target audiences is likely to be costly in terms of customer satisfaction, in sales, and production efficiency. The steps needed to define a product’s target audience are thus discussed in Chapter 3, Defining the Target Population.

1.5 Using Anthropometric Databases

Once we know the design problem, its relevant body dimensions, and the target audience, a truly difficult third step faces the designer: identification of an appropriate anthropometric database. By anthropometric database, we mean a set of body dimensions measured on a sample of people. As discussed above, the ergonomic design process requires body dimensions relevant to the design’s function and fit concept. However, these dimensions will only be helpful if they are measured on a sample that represents the body size variation to be expected in the target audience. It is a rare case indeed when a product designer can afford to measure exactly the dimensions needed on exactly the intended target audience, though we may all have had clothes altered. Thus, Chapter 4, Anthropometric Databases, discusses the decision-making processes, methodologies, and trade-offs that come with locating and using existing anthropometric databases.

Of course, having the right anthropometric database is really only the beginning of an ergonomic design solution. The designer must somehow use the information in the database to establish the design parameters of the product – its dimensions, its adjustment ranges, and whether more than one size will be needed. Although there are many different statistical approaches used to relate body size variation to product design

decisions, they all share a common basis: a desire to know what the “average” and “worst-case” users’ critical design dimensions are, and something about the variability of users in between.

1.6 Case Selection

Case selection is the process of choosing realistic combinations of body dimensions that must be accommodated simultaneously for a design to fit its target audience. A key aspect of case selection and application to design is that the critical body dimensions of each case must be accommodated *as a combination*. For example, if a case has a short eye-height sitting and a long leg-length, then a computer monitor must be positioned low enough so that the case’s eye-height sitting is accommodated, and the desk/chair system must also give sufficient clearance for the case’s long legs underneath the desk. Chapter 5, Representing Body Size Variability Using Cases, describes how body size variability in an anthropometric database can be represented by cases, and Chapter 6 describes how product designers and developers can use selected cases to guide the ergonomic design and evaluation process.

1.7 Information Distillation

As may be evident already, an ergonomic design process that uses anthropometric data is “front heavy”. That is, there is a great investment of problem-oriented thought before one actually relates critical anthropometric cases to the design itself. In fact, ergonomic application of anthropometric data could be considered primarily a four-stage distillation process, such as described below and illustrated in Figure 1.

- State 0: we are at the initial state of information. At this state we are without a product concept or target audience, and virtually all body dimensions on anyone are potentially helpful.
- State 1: we address and state the problem, and we employ the product’s concept of use and fit to restrict our attention to only those body dimensions critical to design success.
- State 2: we identify the target audience, and our attention focuses on only a subset of people in the world – the intended users of the product.
- State 3: we acquire a set of relevant body dimensions— or multivariate summary statistics — for a specific sample of people representing the body size variation of our target audience.
- State 4: we now can reduce our attention even further to selected cases with combinations of body dimensions that will drive the design and testing of the product.

It would be a mistake, however, to conclude that ergonomic design using anthropometric data is primarily an exercise in statistics. Indeed, we should use statistics to inform design choices, not to make design choices. Chapter 5, Representing Body Size Variability Using Cases, and Chapter 6, Transitioning Cases to Products, address the appropriate choice and application of statistical methods. At the end, Chapter 7, Anthropometry in Design: Examples and Summary, illustrates each stage of the process with concrete examples that emphasize the reasoning behind potential methodological alternatives. A Glossary and annotated Bibliography of related

publications not cited in the chapters' references are provided at the end of the manuscript.

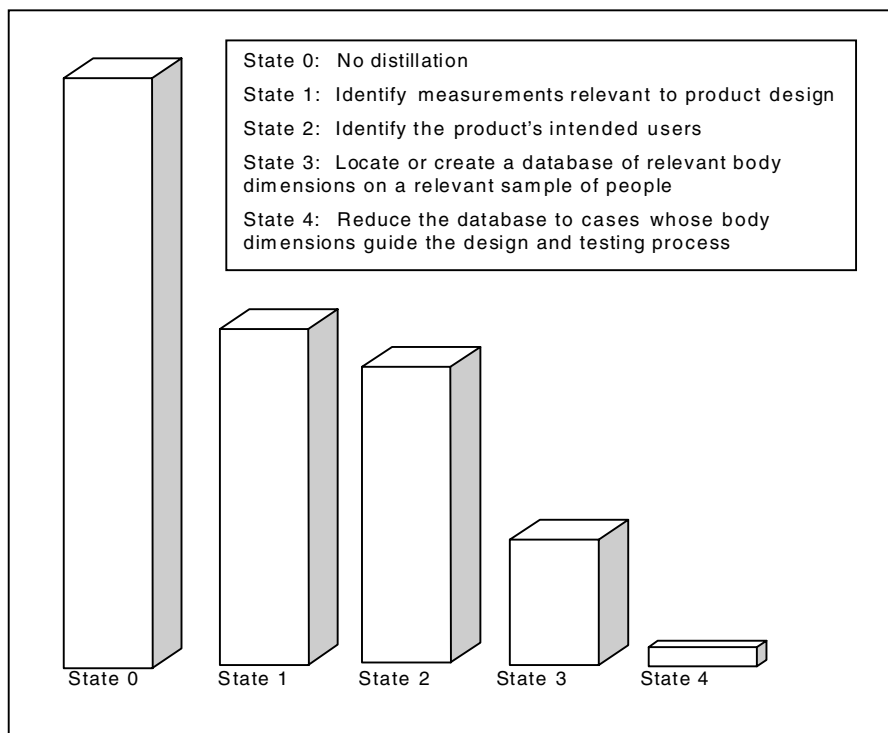


Figure 1. The information distillation process

1.8 Guidelines Contents

Table 1 below can be used to quickly identify which chapters of the document address particular stages in the ergonomic design process.

Table 1. Stages of the ergonomic design process by chapter

Stage	Chapter
Problem definition and relevant measures	2
Target audience definition	3
Database identification and considerations	4
Case selection	5
Application of cases in design	6
Anthropometry in Design: Examples	7
Glossary	
Bibliography	

2. Statement of the Design Problem

This chapter discusses basic concepts of ergonomic design. These concepts potentially apply to all people and all measurements. In later sections, the discussion becomes progressively more specific as we elaborate the nature of the design problem.

Broadly stated, we can conceptualize ergonomic product design as the design/organization/arrangement of various constraints so as to ensure an optimal fit between human operator, equipment, and the physical and psychosocial working environment. This chapter discusses the general nature of constraints on design, and how these constraints relate to fit as a design goal.

2.1 Constraints on Design

The human body can be considered a biomechanical system with multiple degrees-of-freedom. That is, in principle, each muscle-joint combination can be independently controlled by the brain-nervous system, resulting in a virtually infinite number of body postures. Each such posture represents an equilibrium state (balance of internal, applied, and reactive forces) acting against external forces. In practice, the large number of degrees-of-freedom is greatly reduced by a series of constraints. These constraints, as described below, can be categorized as task-, environmental- or human-based.

Task Constraints: The demands of each individual task naturally specify certain postural requirements. Consider, for example, a computer workstation. For those people who have use of their hands, a data-entry task requires that the fingers be in operational contact with a keyboard. For those people with vision, the copy and screen should be within the central field-of-vision. A lathe operator, on the other hand, usually maintains a standing posture such that his/her hands and arms are in appropriate relationship to the cutting tool and other controls. These task constraints significantly reduce the number of possible postural orientations that allow successful completion of the task.

Environmental Constraints: The number of possible postural orientations is further reduced by the design limitations of the objects, tools, or furniture within a user's environment. For an office environment, for example, the linear and angular dimensions, geometrical configuration, and degree of adjustability of chair, work surfaces, keyboards, etc., constrain operating postures. For the case of data entry, a standing user's workstation (e.g., airline reservation desk) allows a rather limited range of postural variations (slumping, bending, moving the legs). On the other hand, nonadjustable chairs and workstations allow a different but also limited range of postural shifts. Equipment maintenance and repair tasks that entail very precise orientation of tools (e.g., screwdrivers) often result in extremely limited postural options.

Other types of environmental constraints that are relevant to workstation design include temperature, humidity, noise, and lighting. The force of gravity is one of the most powerful environmental constraints, due to its impact on working posture.

Human Constraints: Finally, the personal characteristics, preferences and abilities of each individual determine the postures that can be seen in the workplace. These characteristics can be divided into two categories:

1. Physical: These constraints are anthropometric dimensions, strength, range of limb motion (relevant to operating controls), and somatic/physiological status (e.g., loss of sensation for persons with spinal cord trauma.)

2. Psychological: Such factors include current state of discomfort/fatigue, awareness of feedback signals from muscles and joints resulting from awkward posture, and willingness to shift body positions to relieve fatigue. Additionally, they include specific knowledge and skill related to the use of ergonomic aids, such as adjustability mechanisms on office chairs, or power-assisted lifts for materials handling. Finally, the question of the operator's intention and motivation is crucial. The operator is goal directed, embarking on a series of perception-action dialogues with her/her work-environment in which a continuous series of actions are performed in response to information about the world. In this context, the operator's knowledge of how ergonomic aids should be used and why their use is important must be combined with motivation to act if these adjustable mechanisms are to be used effectively.

2.2 Fit as an Ergonomic Goal

The concept of fit is most commonly associated with clothing. The expression "fits like a glove" conveys an intuitive sense of the meaning. A systematic analysis of fit with respect to clothing is helpful in generalizing this concept. Consider, for example, a surgical glove. This glove provides a "tight fit" to the user's hand in the sense that almost every movement or manipulation that can be carried out by combinations of fingers and thumbs when the glove is *not* present is also possible when the glove is worn. In a more abstract sense, the variability or available degrees-of-freedom present in the fingers and thumb are almost perfectly matched by those present with the glove's inherent flexibility. Thus, achieving appropriate fit between user and tool/environment can be characterized, in more general terms, as a problem of coordination among comparable sets of degrees-of-freedom. (This approach relies on the seminal work of N. Bernstein, 1967.)

Poor fit, or mismatches between comparable degrees-of-freedom, can be seen in the following example. If a shoe is too large, the foot can rotate within the shoe; if a helmet is too large, the helmet can rotate around the head. Each of these rotations is undesirable, representing a lack of correspondence between comparable degrees-of-freedom.

External constraints can heavily influence the definition of fit. In the example of surgery, task constraints require both the full range of manipulation of the fingers, and at the same time the protection of the open wound from possible contamination from those same fingers. A different set of task constraints, e.g., operating heavy machinery out-of-doors in an arctic environment, would dictate a mitten or glove with both insulation and limited but sufficient manipulation range. In a mitten, the four fingers are constrained to move essentially as a single unit. The advantage of this design is the reduction of surface area and the corresponding minimization of heat loss. The disadvantage, of course, is in restricting the number of hand postures that can be achieved. Accordingly, design of equipment for cold weather use needs to take gloved

hand maneuverability into account. For some tasks, such as operating the trigger of a weapon, the use of a finger is typically required. A best fit is achieved by evaluating developments in fabric and insulation that afford movement of individual fingers while maintaining heat retention.

In general terms, fit can be conceptualized in terms of *compatibility* relationships among task, environmental and human constraints. (See Karwowski, 2000.)

Compatibility implies the appropriate coordination of degrees-of-freedom among different constraints such that the user can accomplish effective performance.

2.3 Translating Ergonomic Concepts of Fit to Critical Design Dimensions

For the purpose of focus in this document, in the following sections, the primary human constraint will be anthropometric variation. The goal will be to relate the degrees-of-freedom associated with this variation with compatible workplace dimensions. It is assumed that reducing load associated with awkward postures will result in increased biomechanical efficiency. Biomechanical efficiency will lead to:

- reduced muscular fatigue;
- decreased perception of discomfort/pain;
- improved work performance.

A further assumption is that symptoms of perceived discomfort/pain can be precursors of musculoskeletal disorders. Comfort is herein conceptualized as the relative absence of discomfort/pain, though other factors arguably influence its perception. This is a complex concept, one that is simplified here only for the sake of maintaining clarity of the main discussion.

The term “awkward posture” may be broadly interpreted as postures or actions that increase the worker’s energy expenditure, inhibit desired physiological functions, such as circulation, or place higher biomechanical loading on the body than is advisable. An awkward posture makes the worker work harder than necessary to accomplish the task. As there is no value added for this extra work, the product design is less efficient than it could (and should) be.

For example, some less-than-desirable working postures require long-term, static exertion of force. This exertion is commonly referred to as “static loading.” Static muscle load places muscles into a constant state of contraction and should be avoided. Static muscle loading inhibits circulation and hastens muscle fatigue.

The discussion of task analysis allows us to refine the design problem to a point where we identify specific tools (environmental constraints) and processes (task constraints). We likewise refine the concept of fit to reflect appropriate postures that are the outcome of proper design of tools and procedures. It must be emphasized that although the following discussion presents a certain logical flow, in actuality, the process is highly iterative. Discovery of incompatibilities later in the design process may require revisiting earlier assumptions.

What Are We Designing? As in the earlier example of the fitting of gloves, the concept of fit between user and work environment (including tools) can be characterized in terms of the matching of corresponding degrees-of-freedom. The computer operator can translate his/her finger flexion/extension into vertical movements of keys. The equipment technician can translate his/her rotary grip movements via a screwdriver into helical motion of a screw. To the extent that the user

can carry out these effector movements efficiently in terms of the overall postural orientation of the body (without excessive loading), these postures are permissible and fit is achieved.

The problem occurs when anthropometric variation enters the picture. If the keyboard is placed on a work surface of fixed height, some fraction of the user population will be unable to attain a working posture that is acceptable, because the working height will be too high for some people and too low for others. For these people, hands and wrists and arms will be in suboptimal (awkward) postures, resulting in less efficient execution of required keying movements. In the case of equipment repair, proper orientation of the tool is essential for successful completion. Awkward posture in this case can be a safety as well as a fatigue issue if, for example, the screwdriver slips and penetrates an adjacent hazard area (e.g., a high voltage source).

Satisfactory Fit And Individual Variability: The designer's challenge is to achieve satisfactory fit while accommodating individual variability. We can attain specific designs and specifications of workstation components and arrangements, in principle by combining "the envelope" of permissible environmentally constrained postures and the set of task constraints (determined above) with a set of specific individual physical constraints. A critical component of this process is that we characterize anthropometric variability among those body dimensions that are relevant to the task and environment under consideration.

However, at the same time, it is essential to keep separate the distinction between *body dimensions* and *object dimensions* (workstation/clothing, etc.). This distinction is captured in the concept of *affordance* (Gibson, 1979; Norman, 1988; Mark et al., 1991; Dainoff et al., 1999), which refers to attributes of the (physical) environment that have consequences for goal-directed actions of the person.

Take, for example, an ordinary kitchen chair. Let us look briefly at just one of the object dimensions- seat height. This dimension is not arbitrary, but bears some relationship to the lower leg lengths of the users for whom the chair was designed. This relationship is neatly conceptualized in the term *affordance*. Thus, the chair will afford a certain action—sitting—for a certain group of users, namely, adults. More precisely, the chair is an *affordance* for sitting in the sense that the user's buttocks are supported by the seat surface (seatpan) while the feet are supported by the floor. That same chair will not afford sitting for a *different* group of users, small children, whose lower leg lengths, as well as Seated Eye Height, are too small to use the ordinary kitchen chair *effectively*. For children seated on a kitchen chair, their feet are not supported and they would be unable to easily make eye contact with adults while seated at a kitchen table. To achieve the overall goal of allowing children to comfortably and effectively sit at the table with adults, a different kind of *affordance*—a highchair—must be designed. The highchair would not only raise the child up to the kitchen table surface, but could provide foot support to enhance comfort and torso stability. Hence, the concept of *affordance* allows us to understand that object and body dimensions are separate entities, which become matched through the design process. Simply put, what designers should design are *affordances* based on human-object compatibility relationships.

It is also important to realize that these relationships are not simply one-to-one. In the case of the kitchen chair, for example, seat height is a critical object dimension as it

defines the capability (affordance) of allowing the legs to reach the floor while seated. A typical kitchen chair might have a seat height of 460 mm (ca. 18 inches). The corresponding relevant body dimension is lower leg length. That is, to a first approximation, fit can be defined in terms of the relationship between lower leg length and seat height. If we now identify an anthropometric database of adult users (e.g., Gordon et al., 1989), it can be seen that lower leg length is most closely approximated by the body measurement “Popliteal Height” (see Figure 2), though this neglects the use of slippers or other footwear.

Examining the distribution of Popliteal Height values in this database, we see that a person with a small Popliteal Height (5th percentile) is 351 mm while the corresponding value for a large Popliteal Height (95th percentile) is 476 mm. The relevant object dimension—seat height—is thus located within the range of variability of the corresponding body dimension—Popliteal Height.

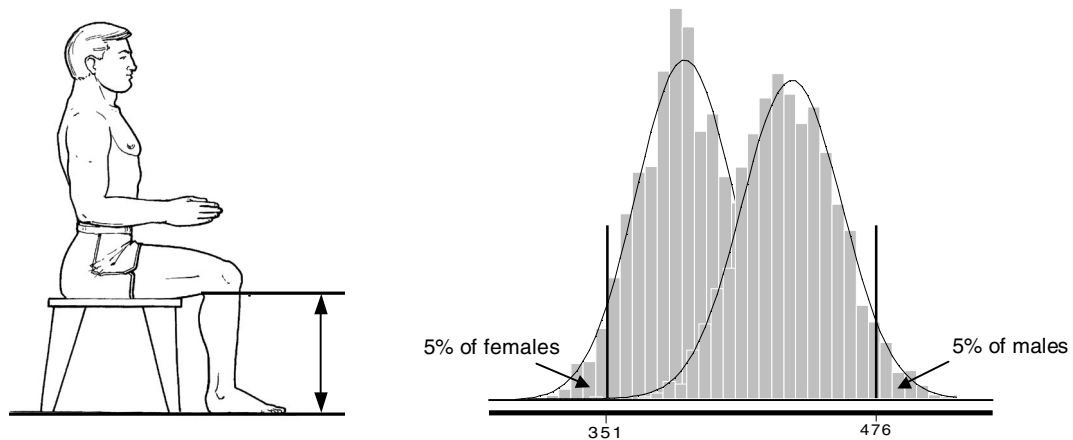


Figure 2. Popliteal height (in mm)

Consequently, fit, in this case, is only approximate. Even with footwear adding 25 mm, the small person’s legs are too short to reach the floor. To use this chair comfortably, this person would need to either use some sort of footrest or wrap his/her legs around the chair supports. The large individual’s legs are too long for sitting with legs perpendicular to the floor. This person may need to angle their legs either backward or forward to use the chair at a table. Notice that, in this particular case, the seat height is located more towards the upper end of the distribution depicted in Figure 2. For kitchen chairs, this may be a reasonable compromise in that it is easier for users with smaller legs to achieve a reasonably comfortable fit (add some sort of foot rest) than for those with longer legs.

The intent of this discussion is to emphasize the variable nature of the fit between object and body dimensions. Most users of the kitchen chair, as described above, would require some awkwardness of leg posture to sit in the chair, since the chair precisely fits only those with Popliteal Heights of 460 mm, assuming no footwear. However, this lack of precision in fit is not particularly bothersome given the overall goal-directed actions of most users of kitchen chairs, i.e., to sit for a relatively short

period of time to eat a meal. (The 90 degree trunk-thigh angle depicted in Figure 2 is only meant for illustration of body dimensions and should not be taken to be indicative of "proper" seated posture.)

If, on the other hand, the intention is to use the kitchen chair (and table) as a computer workstation for one's home office, the lack of affordance becomes more of an issue. Given that the duration of use increases dramatically (minutes to hours), the negative consequences of awkward posture correspondingly increase. What is now required is a different affordance—adjustability of the seat height—allowing for a greater correspondence between seat height and Popliteal Height (with and without footwear). In particular, we would require a chair whose seat height is adjustable throughout the range of variation of Popliteal Height. Other affordances related to appropriate working height of the keyboard and viewing angle of the display screen and copy also come into consideration. These issues are discussed in detail in subsequent sections.

Consequently, in the design process, it is essential that the designers clearly understand what product features are required and those that are only desired. Certain features are critical for the users to perform their tasks and other features may be considered luxuries. Having these prioritized is important when design trade-offs must be made due to space conflict or cost concerns. Realistic design solutions must also consider regulations, marketing issues, technology employed, safety and design conventions, among other factors.

2.4 Task Analysis

The logical first step in implementing a specific solution to the design problem is through the use of task analysis. While there are multiple approaches to task analysis (Vicente, 1999; Rasmussen et al., 1994; Meister, 1958), the following basic principles are common to all:

Step 1: The initial step of task analysis involves specification of goals and priorities in general terms. For example, a company wants to improve its order-entry process in which information about customers' orders is entered quickly and accurately into a database. Priorities associated with the goal include consideration of *time* to accomplish, *funding* available, *personnel*, *space* and *equipment* requirements.

Step 2: The next step is to describe the functional components of the task, ideally in technology-independent terms. In the order-entry task, these components include a source of customer information, a standardized repository for this information, and a method for translating the former into the latter.

Subsequent Steps: Once these functions are specified, a parallel set of decisions must be made to implement them. One set of decisions relates to the physical *tools* (supplies, equipment, work environments); the second set relates to *procedures* (tasks) to be accomplished by the human operator. Together, tools and tasks provide a specific implementation that will satisfy the functional requirements. In the order-entry case, the tools might consist of a standardized paper order form, a computerized database with predefined fields for information, and a computer workstation (display monitor, keyboard, mouse, copyholder). The associated procedures for data entry would require human operators with certain skills and abilities. Hence, we can begin to define the population of interest.

To attain a sense of the fine structure of the task, we decompose functional components into subtasks. At this level, we should describe the supporting tools and equipment.

Thus, the first subtask might be receiving a batch of paper order forms from a co-worker, and placing them on a copyholder. The second subtask might be keying data into the appropriate fields. This step might include screen navigation instructions and sources of help in ambiguous cases. The next subtask might be verification of critical information. The final subtask might be placing the paper form in a completed work tray.

2.5 Fit as Related to Workstation Design

In this section we apply a) the concept of fit as a relationship between corresponding task, environmental and human degrees-of-freedom, and b) affordance, as the design solution that achieves fit, to the case of workstation (product) design.

Consider an astronaut floating freely in zero gravity. With no task or environmental constraints, the number of postural orientations possible is enormous, limited only by the inherent biomechanical constraints of the human body. If the astronaut is assigned a task (e.g., operating a telescope), the number of working postures that allow him/her to satisfactorily complete the task is greatly reduced—although still probably larger than when gravity is present. Thus, one approach to conceptualizing fit is to start with the completely unconstrained human body (as in zero g) and then successively apply both task and environmental constraints.

Within these constraints, possible postural orientations can be considered permissible to the extent that they minimize biomechanical load on the musculoskeletal system (i.e., “awkward” postures) while allowing the person to accomplish the task in an efficient manner. Consequently, fit can now be interpreted more directly in terms of compatibility relationships between the combination of a) task constraints (e.g., procedures), and b) environmental constraints (e.g., required force to operate controls) with human constraints (e.g., variation in human characteristics including anthropometry), which leads to the determination of permissible postural orientations.

Certain task and environmental constraints afford greater degrees-of-freedom than others. In the data-entry example considered above, a well-designed workstation product will provide a reasonable fit for persons of the target population. The design may allow these people a relatively large range of permissible postures while doing the required tasks. On the other hand, data-entry work carried out by a person who has cerebral palsy, and who uses a mouthstick to type, requires a tightly linked keyboard-head-display-eye coupling, with a consequent reduction in the person’s permissible postures.

2.6 Selection of Relevant Dimensions

It is imperative that the designer identifies the basic postures and movements necessary to complete the intended tasks, and how such postures and movements relate to the supporting tools and equipment. Understanding these relationships allows the selection of relevant anthropometric dimensions. It is helpful, in this process, to identify what Pheasant (1986) has called the cardinal anthropometric relationships between user action and objects in the environment: *reach, clearance, and strength*.

Traditional ergonomic guidance for designers was that within the specified user population, accommodation could be achieved if the *smallest* person could reach (the desired object), the *largest* person could clear (any opening or aperture) and the *weakest* person could lift/operate (the target load/control). In general, all design solutions should follow the three principles of reach, clearance, and strength. Alternatively, we achieve design accommodation if the design affords reaching, clearance and lifting/operating by *all or a specified percentage of members of the target population*.

In the order-entry example, reach and clearance criteria are most relevant. Following the detailed task analysis described above, the permissible postures must include: a) reach capabilities for the hands, arms, shoulder and trunk such that the fingers can make contact with the keyboards, paper forms and other supplementary materials without excessive bending; b) reach capabilities for the legs and lower trunk such that the feet are able to rest firmly on the floor or footrest and the lower trunk can be firmly supported by the seat and backrest; and c) clearance for the legs so that the thighs are able to be placed under the work surface without encountering obstacles. Finally, the requirement to be able to view the monitor screen and copy while maintaining a reasonable head and neck posture can be considered an aspect of visual “reach”. The design solution for the order-entry workstation entails that each of these criteria be accomplished through selection of appropriate critical body dimensions (with possible shoes or other clothing adjustments), which will, in turn, be used as a basis for workstation design dimensions (affordances).

Table 2 illustrates examples of the correspondence between affordance criteria and body dimensions for the order-entry workstation. This table is meant to be illustrative rather than exhaustive. A detailed discussion and example of workstation design is found in Chapter 7. More thorough discussions of ergonomic guidelines for workstation design may be found in the following references: American National Standards Institute (1988), Chaffin et al. (1999), Karwowski and Marras (1999), and Karwowski and Salvendy (1998).

Table 2. Correspondence between affordance criteria and body dimensions for an order-entry workstation

<i>Affordance criteria for object dimensions</i>	<i>Body dimensions</i>
Keyboard working height	Elbow Height, Seated
Seat height	Popliteal Height, Seated
Seat width	Hip Breadth, Seated
Seat depth	Buttock-Popliteal Distance, Seated
Clearance under the workstation	Thigh Height, Seated
	Knee Height, Seated
	Buttock-Knee Distance, Seated
	Eye Height, Seated
Monitor viewing distance and angle	

The next chapter discusses the start of the design process, where designers must decide and determine for whom they are designing.

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3. Defining the Target Population

It is costly to manufacture designs that poorly “fit” their users, and it is even more costly to retrofit designs that fail to accommodate their intended market. It is thus incumbent upon the designer to consider who the intended users of a design might be. Design optimization requires knowledge of user variation in such physical characteristics as body size and proportions, body strength and flexibility, reach capability, and endurance. Physical characteristics vary among people of different biological and cultural backgrounds, gender, age, and health; hence, it is essential both to define the intended market for a design, and to know as much as possible about its demographics.

3.1 Marketing Strategy

Definition of the “target population” for a design begins with consideration of a few simple questions. Who will be using the design? Where will the design be sold and/or used? Are there plans to expand the market in the future? In the case of a workstation, these questions might elicit responses as general as “the entire office furniture market in North America” or as specific as “American architects willing to spend more than \$5000 for a personal workstation.”

3.2 Demography of the Intended Market

Once we obtain a general description of the intended market, it is necessary to obtain more detailed information on characteristics that influence anthropometry. Nationality, race/ethnicity, gender, and age, for example, comprise the primary demographic variables that drive anthropometric distributions, and so we need these data to define a market for ergonomic design (Annis, 1978; Walker, 1993; Donelson & Gordon, 1996). Anthropometric distributions are also influenced by nutritional and epidemiological conditions, which impact growth (Eveleth & Tanner, 1976; Kouchi, 1983; Falkner & Tanner, 1986; Lasker & Mascie-Taylor, 1989). As a result, proxy variables—such as income or education level—are also sometimes included in market descriptions. Determination of the relative frequency of these demographic and market subgroups facilitates more accurate estimates of optimum anthropometric design values, and more intelligent design trade-off decisions.

Data on groups of people who comprise design markets are available from professional/occupational societies, U.S. Census publications (www.census.gov), the NHANES¹ data sets for U.S. civilian population (www.cdc.gov), or market surveys. Information on how to weight the samples to match the target demographics can also be found in these references. The prevalence of various disabilities among potential customers is another type of information important to defining the physical characteristics of the market for which we are designing.

¹ The National Health and Nutrition Examination Surveys (NHANES), conducted by the National Center for Health Statistics, Centers for Disease Control (NCHS/CDC), are designed to assess the health and nutritional status of adults and children in the United States through interviews and direct physical examinations.

3.3 Application of Demographic Data in the Design Process

Knowing the relative frequencies of demographic subgroups in an intended market can inform designers about anthropometric aspects of the intended user. If no anthropometric data already exist that are appropriate to the design problem, demographic data are used to construct sampling strategies for new data collection (Botman et al., 2000; Robinette, 2000; Gordon et al., 1989; Donelson & Gordon, 1996). If some, albeit marginal, data exist, and time/resource considerations preclude a survey, then demographically-driven analytical and statistical adjustments to existing databases may provide adequate characterization of the intended user (Kinghorn & Bittner, 1995). If appropriate anthropometric data already exist, then we may be able to use the demographic data to statistically weight the subjects in existing databases in order to approximate best the distributions of physical characteristics in the intended market (Botman et al., 2000; Donelson & Gordon, 1996; Gordon, 1996; Potter & Iannacchione, 1998). Details on the sampling and weighting of anthropometric databases appear in Chapter 4, Anthropometric Databases. In addition, demographic features of the intended design population can also be very helpful in selecting subjects to evaluate design prototypes and in planning and evaluating test marketing schemes (Chapter 6).

3.4 Defining the Target Population

It can be very difficult, and sometimes impossible, to achieve optimal fit in all features of a design for 100% of the intended market. Often in order to keep a design simple, easily manufactured, and moderate in price, we must tolerate less than optimal fit for some percentage of the intended market for some design features or tasks associated with the product.

When poor fit (and associated degradation in task completion and/or personal comfort) results in immediate or cumulative personal injury or risk to the user, we should seek maximum accommodation of the intended market. It is essential that full accommodation exist for life safety designs, such as an escape hatch being large enough so that the largest foreseeable user could pass through it.

When design limitations do not influence personal risk but may influence efficient completion of critical or primary product tasks, less than maximum accommodation of the intended market may be tolerable. When this situation arises, knowing the relative frequency of customers not accommodated by various compromises can be very helpful in evaluating the merits of design trade-offs.

Generally, when less than maximum accommodation of the intended design population is tolerable, some percentage of the population is targeted for optimal compatibility. In terms of anthropometric distributions, we might envision optimal fit for the central 90%-95% of the intended design population, with suboptimal fit tolerable on the “tails” of the body size/shape distributions where customer density is low and engineering costs to accommodate them are high (McConville & Churchill, 1976). Although criteria of this type have traditionally been quantified in terms of univariate percentiles, such as “5th-to-95th percentile accommodation,” in practice this approach introduces serious ergonomic design deficiencies (Bittner, 1976; Robinette & McConville, 1982). It is better, instead, to define the target population as a minimal percentage to be accommodated. An example of a more appropriate statement might be,