5 Anthropometry

5.1 LEARNING GOALS

The objective of this chapter is to introduce the study of anthropometrics and teach principles that can be used to support anthropometric design. Anthropometric history, terminology and application is presented. The process for data collection, calculation of statistics, and identification of appropriate data sources will also be covered.

5.2 KEY TOPICS

- History of anthropometry
- Anthropometric design principles
- Principles of universal design
- The myth of the "average" human
- Anthropometric terminology
- Anthropometric measurement
- Static and dynamic dimensions
- Variability
- Anthropometric data
- Anthropometric tools
- Anthropometric data sources
- Design using anthropometric data
- Anthropometrics and biomechanics
- Anthropometric application

5.3 INTRODUCTION AND BACKGROUND

Prior to World War II, most of the work that was intended to be ergonomic was primarily focused on tests for selecting the proper people for jobs and on the development of improved training procedures. The focus was clearly on fitting the person to the job, which is the opposite of the goal of ergonomics to: "Fit the task to the person." However, growth of the field in the ergonomics occurred near the end of World War II in 1945 when engineering psychological laboratories were established by the U.S. Air Force and U.S. Navy. This was the result of observing that no matter how much training and job selection went into task performance, the complex equipment still exceeded the capabilities of the people who had to operate it. Thus, they were forced to reconsider fitting the equipment to the person. This was also known as the "knob and dial" era. Much research was conducted during this time to develop optimal design parameters for displays and controls.

The word *anthropometry*, from anthro (man) and meter (measure), is defined as the "measurement and study of the human body and its parts and capacities"

(WorldNet, 2011). An early use of anthropometry is recorded by the savant Alphonse Bertillon in 1883 for criminal record purposes. He found that by collecting a series of specific measurements like the length of a middle finger, or the width of the head from temple to temple, he could consistently distinguish individuals from one another without error (Sutherland, 1937). By 1894, this method was replaced by finger printing, at the recommendation of Francis Galton, who was, incidentally, a cousin of Charles Darwin (O'Connor, 2011). During the 1930s, anthropometric approaches were used in Nazi Germany in order to determine which races were "inferior" and, more importantly, to distinguish Aryans from Jews (MSNBC).

Today anthropometry is used in a variety of fields including engineering, anthropology, ergonomics, and physical therapy. For instance, anthropometrists can study correlations in the body dimensions of different races based on human evolution and migratory patterns of ancient hominids. Human characteristics, like physical stature, can demonstrate the health of a society. According to such studies, American soldiers during the Revolutionary War were, on average, 2 in. taller than their British counterparts; this suggests that the New World was a better socioeconomic environment for humans at the time. Another historical example of generational or societal body dimension differences is that the average weight of a student entering West Point Military Academy in antebellum America was under 128 lb, and 25% were under 110 lb—a reflection on the general socioeconomic well-being of the general population. Studies also show that illiterate men were smaller in stature than literate men (Komlos, 1992).

Another common, modern use of anthropometry is for product optimization. Clothing companies consult anthropometric trends to determine the distributions of sizes clothing to manufacture. Just recently, for instance, in response to what seems to be a first world obesity epidemic, a British retailer for plus-sized clothing has released the largest clothing size yet: XXXXL, four Xs. This type of anthropometric phenomenon would not likely have occurred at any other point in human history (Huff, 2010).

The three primary factors that differentiate humans in measurement are gender, ethnicity, and age (Wang etal., 2006). Large differences in body size due to gender and genetics are common. For instance, men are, on average, 13 cm (5 in.) taller than women, as well as larger in most other body measures, particularly in upper body strength capabilities. Ethnicity differences have been found when comparing individuals living in different countries. For example, the average male stature in the United States is 167 cm (66 in.), while the average male stature in Vietnam is 152 cm (60 in.). For these reasons, it is important to understand the process of anthropometric data collection, analysis, and application.

5.4 WHAT IS ANTHROPOMETRY?

The study of anthropometrics, or human measurement, is concerned with the physical sizes and shapes of humans. Anthropometrics is a very important branch of ergonomics (Pheasant, 1996) in research and application. This science deals with the measurement of size, mass, shape, and inertial properties of the human body. Anthropometry relies on sophisticated methods to measure physical dimensions including static and dynamic measurements of specific populations. The results obtained from these methods are statistical data that can be applied in the design of products, clothing, occupational, and recreational environments. Also, anthropometric data is essential in developing biomechanical models to predict human movement, reach, force, and space requirements.

Static or structural anthropometry is focused on specific skeletal dimensions when the body is not in motion, while dynamic or functional anthropometry measures distances and ranges of motion while the body is moving or involved in physical activities. Anthropometric design principles should be applied in design for a large cross section of the population to promote physical comfort in the workplace, recreational, and service environments. Ignoring these physical requirements can create bad postures that lead to fatigue, loss of productivity, and sometimes injury. Furthermore, anthropometry not only deals with establishing appropriate working heights, but also facilitating access to controls and input devices for users.

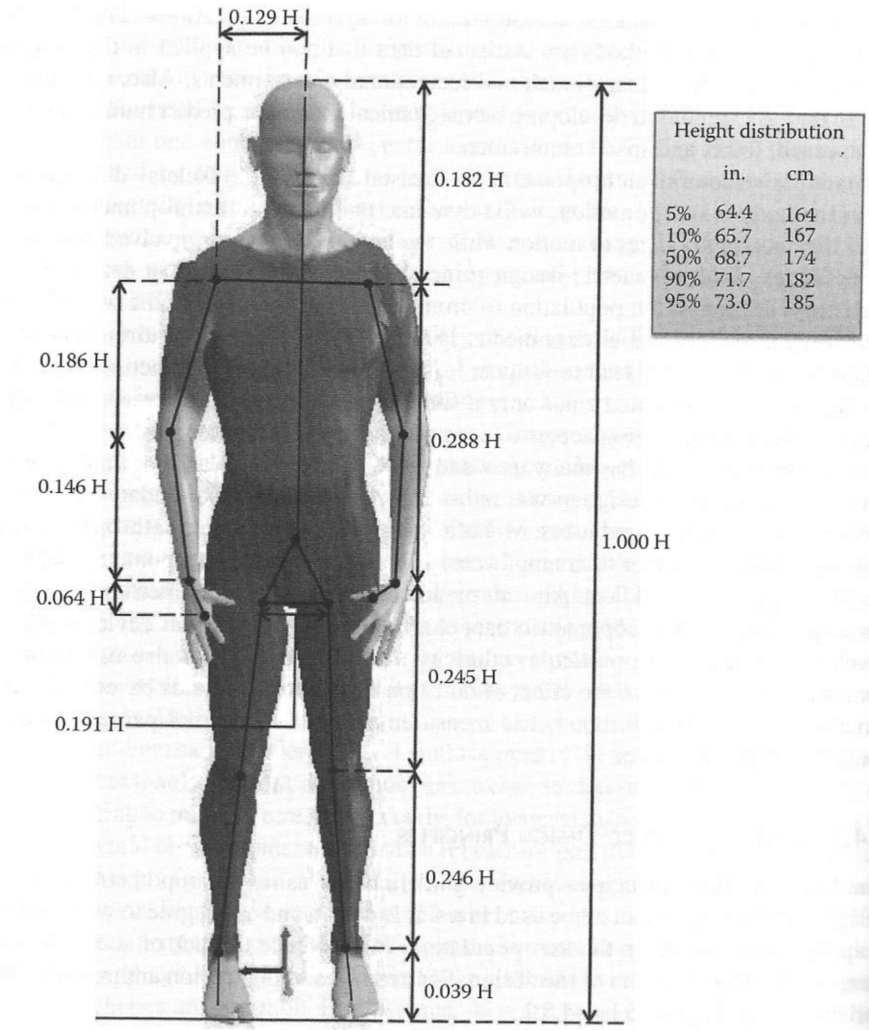
Anthropometric data has many uses and can be applied in a variety of industries. For instance, furniture designers use anthropometric data to accommodate the variations of a wide range of end users. Manufacturing facilities can use anthropometrics to design workstations for their employees. The military uses anthropometric data to design equipment for soldiers. Aircraft manufacturers use anthropometrics to design passenger seating. Anthropometric data can be used in the medical device field to develop prostheses for a particular ethnicity. Anthropologists can also use anthropometric data to compare the effect of nutrition on different cultures based on body dimensions. Typical anthropometric measurements and associated percentiles are contained in the appendix.

5.4.1 Anthropometric Design Principles

The following three principles provide guidelines for using anthropometric data in design. The principles can all be used in a single design and the degree to which each is applied will depend on the user population, consequence for lack of accommodation, and economic factors of the design. For examples of population anthropometric percentiles see Figures 5.1 and 5.2.

5.4.1.1 General Guidelines

1. Design for adjustable ranges
   a. Provide a range of adjustments, particularly when health and safety issues are involved (i.e., driving a car, working in office).
   b. Mitigate the likelihood of eliminating sections of the user population due to design limitations, by increasing ranges through adjustability.
2. Design for extremes
   a. Design for *maximum* value of design features (i.e., height of doors, size of buttons) or design for *minimum* value of design features (i.e., distance from controls).
   b. Traditionally, extremes have been addressed by designing for
      i. 5th percentile female
      ii. 95th percentile male



Height distribution

	in.	cm
5%	64.4	164
10%	65.7	167
50%	68.7	174
90%	71.7	182
95%	73.0	185

FIGURE 5.1 Provides an example of stature and seated mesurment for American male.

3. Design for average users
   a. Use 50th percentile figures for relevant dimensions.
   b. This strategy is only acceptable when you are primarily concerned with one dimension and health and safety is not a significant issue (i.e., auditorium seats); legislations such as the Americans with Disabilities Act (ADA) require additional accommodation in some environments.

5.4.1.2 Principles of Universal Design

Universal design is defined as designing products, buildings, and exterior spaces to be usable by all people to the greatest extent possible. The use of anthropometric

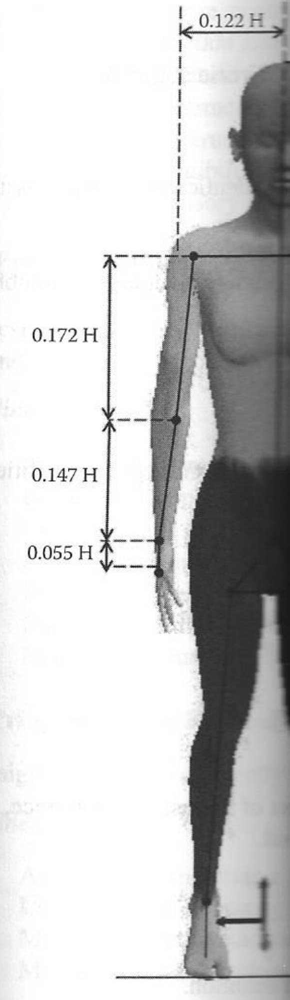
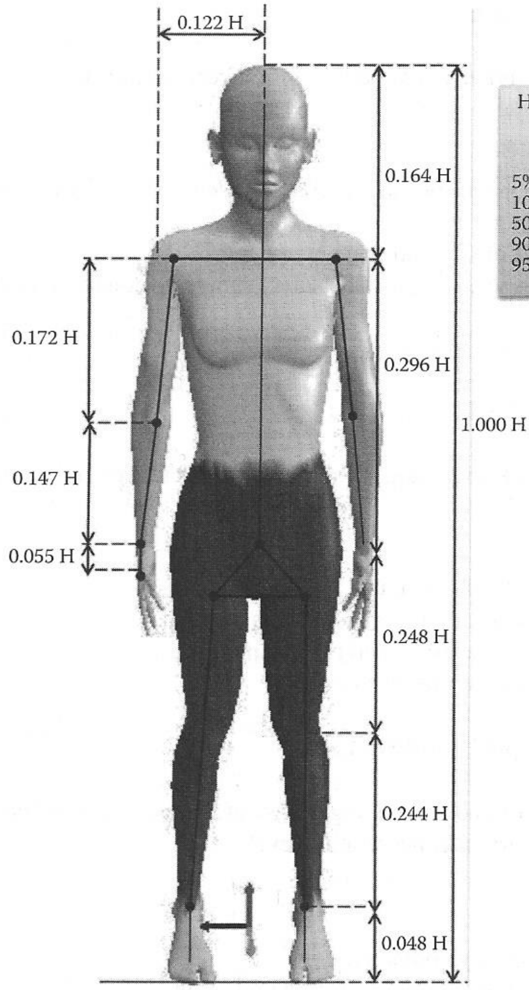


FIGURE 5.2 Provides an example ... Japanese American female.

data to accommodate a global ... These concepts were developed by ... engineers, and environmental desi... to establish broad principles that ... ucts, and communications (Mace et ...

These seven principles may also ... development of instructional mater... however, it should be pointed out ... designs. The Center for Universal D... design principles and associated gu...



Height distribution	in.	cm
5%	59.9	152
10%	60.8	154
50%	63.8	162
90%	66.8	170
95%	67.7	172

FIGURE 5.2 Provides an example of stature and seated measurement for a 40 year old Japanese American female.

data to accommodate a global society benefits from universal design principles. These concepts were developed by a working group of architects, product designers, engineers, and environmental design researchers. This working group collaborated to establish broad principles that can be used in the design of environments, products, and communications (Mace et al., 1996).

These seven principles may also be applied to the assessment of existing designs, development of instructional material, and in consumers' evaluations of products; however, it should be pointed out that all guidelines may not be relevant to all designs. The Center for Universal Design at North Carolina State University lists the design principles and associated guidelines as follows (CUD, NCSU, 2011):

- **Principle 1: Equitable Use**

The design is useful and marketable to people with diverse abilities.

Guidelines

1a. Provide the same means of use for all users, identical whenever possible, equivalent when not.
1b. Avoid segregating or stigmatizing any users.
1c. Provisions for privacy, security, and safety should be equally available to all users.
1d. Make the design appealing to all users.

- **Principle 2: Flexibility in Use**

The design accommodates a wide range of individual preferences and abilities.

Guidelines

2a. Provide choice in methods of use.
2b. Accommodate right- or left-handed access and use.
2c. Facilitate the user's accuracy and precision.
2d. Provide adaptability to the user's pace.

- **Principle 3: Simple and Intuitive Use**

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines

3a. Eliminate unnecessary complexity.
3b. Be consistent with user expectations and intuition.
3c. Accommodate a wide range of literacy and language skills.
3d. Arrange information in order of its importance.
3e. Provide effective prompting and feedback during and after task completion.

- **Principle 4: Perceptible Information**

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines

4a. Use different sensory modes (visual (pictorial), auditory (verbal), tactile) for redundant presentation of essential information.

4b. Provide adequate contrast between essential information and supplemental information and backgrounds.
4c. Maximize "legibility" of essential information.
4d. Differentiate elements in ways that can be easily clarified (i.e., make it easy to give instructions or directions).
4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

- **Principle 5: Tolerance for Error**

The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Guidelines

5a. Arrange elements to minimize hazards and errors; that is, make the most used elements the most accessible. Arrange the more hazardous elements in an isolated or shielded manner, or ideally, eliminate access to these elements.
5b. Provide warnings of hazards and errors.
5c. Provide fail-safe features.
5d. Discourage unconscious action in tasks that require vigilance.

- **Principle 6: Low Physical Effort**

The design can be used efficiently and comfortably, while minimizing fatigue.

Guidelines:

6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.
6d. Minimize sustained physical effort.

- **Principle 7: Size and Space for Approach and Use**

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Guidelines

7a. Provide a clear line of sight to important elements for any seated or standing user.
7b. Design reach to all components accessible and comfortable for any seated or standing user.
7c. Accommodate variations in hand and grip size.
7d. Provide adequate space for the use of assistive devices or personal assistance.

5.4.1.3 Myth of the Average Human

The average user is often referred to as a mythical being, because there is no known person whose body dimensions per segment, all fall within the 50th percentile. Body dimensions are not linearly correlated so, for example, a person who has long arms does not necessarily mean that they will have a long neck or long legs. Thus, the goal to design for the average user should be abandoned and statistical ranges or percentiles should be used to guide design decisions.

5.4.2 Anthropometric Terminology

In order to further understand traditional anthropometric measurement procedures and techniques, it is important to first define some specific terminology measuring conventions and definitions (Table 5.1).

5.4.2.1 Definitions of Measurements

The following terms are used in anthropometric discussion. The relevant definition is provided for each as it relates the measuring the human body.

- *Height* is a straight line, point-to-point vertical measurement, and *breadth* is a straight line, point-to-point horizontal measurement running across the body or a segment.
- *Depth* is a straight line, point-to-point horizontal measurement running fore and aft the body.
- *Distance* is a straight line, measurement between landmarks on the body.
- *Curvature* is a point-to-point measurement following a contour, and this measurement is typically neither closed nor circular.
- *Circumference* is a closed measurement that follows a body contour and, therefore, is not circular.
- *Reach* is a point-to-point measurement following the long axis of the arm or leg.

5.4.2.2 Anthropometric Planes

The three planes that are more commonly used in obtaining anthropometric measurements are the sagittal, coronal, and transverse planes (Figure 5.3). Each is described as follows:

- *Sagittal plane*—the plane dividing the body in the median plane. The mid-sagittal plane divides the body into equal left and right parts in the median plane. The terms "medial" and "lateral" relate to this plane.
- *Coronal (frontal) plane*—the plane dividing the body into equal or unequal front (anterior) and back (posterior) parts.
- *Transverse (cross sectional) plane*—the horizontal plane that divides the body into unequal upper (cranial) and lower (caudal) parts.

Several movements take place within each of these planes and it is important to understand these actions. A few of these movements are summarized in the following text with respect to the given planes:

TABLE 5.1
Common Body Measures and T

	Dimensions
1.	*Stature* The vertical distance from the floor of the head, when standing
2.	*Eye height, standing* The vertical distance from the floor outer comer of the right eye, when
3.	*Shoulder height (acromion), standi* The vertical distance from the floor (acromion) of the shoulder, when [2]
4.	*Elbow height, standing* The vertical distance from the floor lowest point of the right elbow, w standing, with the elbow flexed at
5.	*Hip height (trochanter), standing* The vertical distance from the floor trochanter landmark on the upper right thigh, when standing
6.	*Knuckle height, standing* The vertical distance from the floor knuckle (metacarpal bone) of the finger of the right hand, when stan
7.	*Fingertip height, standing* The vertical distance from the floor of the extended index finger of the hand, when standing
8.	*Sitting height* The vertical distance from the sitti to the top of the head, when sitting
9.	*Sitting eye height* The vertical distance from the sitti to the outer comer of the right eye sitting
10.	*Sitting shoulder height (acromion* The vertical distance from the sitti to the tip (acromion) of the should sitting
11.	*Sitting elbow height* The vertical distance from the sitti to the lowest point of the right elb sitting, with the elbow flexed at 9

TABLE 5.1
Common Body Measures and Their Applications

Dimensions	Applications
1. *Stature* The vertical distance from the floor to the top of the head, when standing	A main measure for comparing population samples. Reference for the minimal height of overhead obstructions. Add height for more clearance, hat, shoes, stride
2. *Eye height, standing* The vertical distance from the floor to the outer comer of the right eye, when standing	Origin of the visual field of a standing person. Reference for the location of visual obstructions and of targets such as displays; consider slump and motion
3. *Shoulder height (acromion), standing* The vertical distance from the floor to the tip (acromion) of the shoulder, when standing [2]	Starting point for arm length measurements; near the center of rotation of the upper arm. Reference point for hand reaches; consider slump and motion
4. *Elbow height, standing* The vertical distance from the floor to the lowest point of the right elbow, when standing, with the elbow flexed at 90°	Reference for height and distance of the work area of the hand and the location of controls and fixtures; consider slump and motion
5. *Hip height (trochanter), standing* The vertical distance from the floor to the trochanter landmark on the upper side of the right thigh, when standing	Traditional anthropometric measure, indicator of leg length and the height of the hip joint. Used for comparing population samples
6. *Knuckle height, standing* The vertical distance from the floor to the knuckle (metacarpal bone) of the middle finger of the right hand, when standing	Reference for low locations of controls, handles, and handrails; consider slump and motion of the standing person
7. *Fingertip height, standing* The vertical distance from the floor to the tip of the extended index finger of the right hand, when standing	Reference for the lowest location of controls, handles, and handrails; consider slump and motion of the standing person
8. *Sitting height* The vertical distance from the sitting surface to the top of the head, when sitting	Reference for the minimal height of overhead obstructions. Add height for more clearance, hat, trunk motion of the seated person
9. *Sitting eye height* The vertical distance from the sitting surface to the outer comer of the right eye, when sitting	Origin of the visual field of a seated person. Reference point for the location of visual obstructions and of targets such as displays; consider slump and motion
10. *Sitting shoulder height (acromion)* The vertical distance from the sitting surface to the tip (acromion) of the shoulder, when sitting	Starting point for arm length measurements; near the center of rotation of the upper arm. Reference for hand reaches; consider slump and motion
11. *Sitting elbow height* The vertical distance from the sitting surface to the lowest point of the right elbow, when sitting, with the elbow flexed at 90°	Reference for the height of an armrest, of the work area of the hand, and of keyboard and controls; consider slump and motion of the seated person

(continued)

TABLE 5.1 (continued)
Common Body Measures and Their Applications

	Dimensions	Applications
12	*Sitting thigh height (clearance)* The vertical distance from the sitting surface to the highest point on the top of the horizontal right thigh, with the knee flexed at 90°	Reference for the minimal clearance needed between seat pan and the underside of a structure, such as a table or desk; add clearance for clothing and motions
13.	*Sitting knee height* The vertical distance from the floor to the top of the right kneecap, when sitting, with the knees flexed at 90°	Traditional anthropometric measure for lower leg length. Reference for the minimal clearance needed below the underside of a structure, such as a table or desk; add height for shoe
14.	*Sitting popliteal height* The vertical distance from the floor to the underside of the thigh directly behind the right knee; when sitting, with the knees flexed at 90°	Reference for the height of a seat; add height for shoe
15.	*Shoulder-elbow length* The vertical distance from the underside of the right elbow to the right acromion, with the elbow flexed at 90° and the upper arm hanging vertically	Traditional anthropometric measure for comparing population samples
16.	*Elbow-fingertip length* The distance from the back of the right elbow to the tip of the extended middle finger, with the elbow flexed at 90°	Traditional anthropometric measure. Reference for fingertip reach when moving the forearm in the elbow
17.	*Overhead grip reach, sitting* The vertical distance from the sitting surface to the center of a cylindrical rod firmly held in the palm of the right hand	Reference for the height of overhead controls operated by a seated person. Consider ease of motion, reach, and finger/hand/arm strength
18.	*Overhead grip reach, standing* The vertical distance from the standing surface to the center of a cylindrical rod firmly held in the palm of the right hand	Reference for the height of overhead controls operated by a standing person. Add shoe height. Consider ease of motion, reach, and finger/hand/arm strength
19.	*Forward grip reach* The horizontal distance from the back of the right shoulder blade to the center of a cylindrical rod firmly held in the palm of the right hand	Reference for forward reach distance. Consider ease of motion, reach, and finger/hand/arm strength
20.	*Arm length, vertical* The vertical distance from the tip of the right middle finger to the right acromion, with the arm hanging vertically	A traditional measure for comparing population samples. Reference for the location of controls very low on the side of the operator. Consider ease of motion, reach, and finger/hand/arm strength
21.	*Downward grip reach* The vertical distance from the right acromion to the center of a cylindrical rod firmly held in the palm of the right hand, with the arm hanging vertically	Reference for the location of controls low on the side of the operator. Consider ease of motion, reach, and finger/hand/arm strength

TABLE 5.1 (continued)
Common Body Measures and Their Applications

	Dimensions	Applications
22.	*Chest depth* The horizontal distance from the back to the right nipple	A traditional measure for comparing population samples. Reference for the clearance between seat backrest and the location of obstructions in front of the trunk
23	*Abdominal depth, sitting* The horizontal distance from the back to the most protruding point on the abdomen	A traditional measure for comparing population samples. Reference for the clearance between seat backrest and the location of obstructions in front of the trunk
24.	*Buttock-knee depth, sitting* The horizontal distance from the back of the buttocks to the most protruding point on the right knee, when sitting with the knees flexed at 90°	Reference for the clearance between seat backrest and the location of obstructions in front of the knees
25.	*Buttock-popliteal depth, sitting* The horizontal distance from the back of the buttocks to back of the right knee just below the thigh, when sitting with the knees flexed at 90°	Reference for the depth of a seat
26.	*Shoulder breadth (biacromial)* The distance between the right and left acromion	A traditional measure for comparing population samples. Indicator of the distance between the centers of rotation of the two upper arms
27.	*Shoulder breadth (bideltoid)* The maximal horizontal breadth across the shoulders between the lateral margins of the right and left deltoid muscles	Reference for the lateral clearance required at shoulder level. Add space for ease of motion and tool use
28.	*Hip breadth, sitting* The maximal horizontal breadth across the hips or thighs, whatever is greater, when sitting	Reference for seat width. Add space for clothing and ease of motion
29.	*Span* The distance between the tips of the middle fingers of the horizontally outstretched arms and hands	A traditional measure for comparing population samples. Reference for sideway reach
30.	*Elbow span* The distance between the tips of the elbows of the horizontally outstretched upper arms when the elbows are flexed so that the fingertips of the hands meet in front of the trunk	Reference for the lateral space needed at upper body level for ease of motion and tool use
31.	*Head length* The distance from the glabella (between the browridges) to the most rearward protrusion (the occiput) on the back, in the middle of the skull	A traditional measure for comparing population samples. Reference for headgear size

(continued)

TABLE 5.1 (continued)
Common Body Measures and Their Applications

	Dimensions	Applications
32.	*Head breadth* The maximal horizontal breadth of the head above the attachment of the ears	A traditional measure for comparing population samples. Reference for headgear size
33.	*Hand length* The length of the right hand between the crease of the wrist and the tip of the middle finger, with the hand flat	A traditional measure for comparing population samples. Reference for hand tool and gear size. Consider manipulations, gloves, tool use
34	*Hand breadth* The breadth of the right hand across the knuckles of the four fingers	A traditional measure for comparing population samples. Reference for hand tool and gear size, and for the opening through which a hand may fit. Consider manipulations, gloves, tool use
35.	*Foot length* The maximal length of the right foot, when standing	A traditional measure for comparing population samples. Reference for shoe and pedal size
36.	*Foot breadth* The maximal breadth of the right foot, at right angle to the long axis of the foot, when standing	A traditional measure for comparing population samples. Reference for shoe size, spacing of pedals
37.	*Weight (kg)* Nude body weight taken to the nearest tenth of a kilogram	A traditional measure for comparing population samples. Reference for body size, clothing, strength, health, etc. Add weight for clothing and equipment worn on the body

Source: Adapted from Kroemer, K.H.E., *The Occupational Ergonomics Handbook*, Taylor & Francis, Boca Raton, FL, 2006.

Note: Descriptions of dimensions from Gordon et al. (1989) [26] with their reference numbers in brackets.

- Sagittal plane
  - *Flexion*—angle between two body segments is decreased.
  - *Extension*—angle between two body segments is increased.
  - *Dorsiflexion*—bringing the top of the foot toward the shin.
  - *Plantarflexion*—movement of the top of the foot away from the shin.
- Coronal plane
  - *Adduction*—movement toward the midline of the body.
  - *Abduction*—movement away from the midline of the body.
  - *Inversion*—lifting the medial border of the foot.
  - *Eversion*—lifting the lateral border of the foot away from the medial plane.
  - *Elevation*—moving to a superior position at the scapula.
  - *Depression*—moving to an inferior position at the scapula.
- Transverse plane
  - *Rotation*—external or internal turning on the vertical axis of a bone.

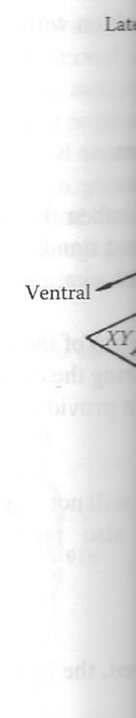


FIGURE 5.3 Anatomical landm
Integration Standards, *Anthropom*

- *Pronation*—rotation
  elbow.
- *Supination*—rotation

5.4.3 Anthropometric Me

Measurements of anthropometr
height, weight, volume, density
tance between two landmarks
measured, such as hearing abil
sidered in assessing a populatio
in anthropometrics have been
al. (1989); Hertzberg (1968); K
Webb (1978); Pheasant (1986);
publications provide detailed in
and techniques.

5.4.3.1 Stature Measureme

When taking stature measurem
four traditional positions detail

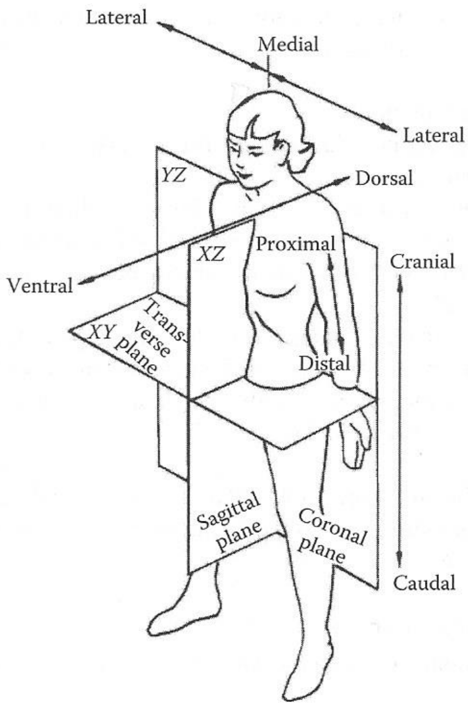


FIGURE 5.3 Anatomical landmarks used in measurement. (From NASA, Man-Systems Integration Standards, *Anthropometry and Biomechanics*, Volume I, Section 3, 2000.)

- *Pronation*—rotation of the hands and forearms medially from the elbow.
- *Supination*—rotation of the hands and forearms laterally from the elbow.

5.4.3 Anthropometric Measurements

Measurements of anthropometric data are typically physical in nature, for example, height, weight, volume, density, range of motion, strength capabilities, and the distance between two landmarks on the body. However, sensory abilities may also be measured, such as hearing ability, sight, and the ability to sense touch may be considered in assessing a population. Specific terminology and measuring conventions in anthropometrics have been described by Garrett and Kennedy (1971); Gordon et al. (1989); Hertzberg (1968); Kroemer et al. (1990); Lohman et al. (1988); NASA/Webb (1978); Pheasant (1986); Roebuck (1993); and Roebuck et al. (1975). These publications provide detailed information about traditional measurement procedures and techniques.

5.4.3.1 Stature Measurements

When taking stature measurements, it is essential that the subject takes on one of four traditional positions detailed in the following text. Regardless of the position in which the subject is measured, consistency of this position within the sample group for which measurements are taken is critical.

- Standing upright naturally
  - Slumping effect is included in measurements.
- Standing upright erect
  - Measurements can have a 2 cm difference when the subject standing either stretches to a fully erect position or just stands upright naturally.
- Standing against a wall with shoulder blades, buttocks, and back of the head touching the wall
  - Extending a book or straight edge from the top of the head to the wall, making a mark on the wall, and then measuring the distance to the floor helps ensure the subject is fully upright and provides a mechanism for consistency between subjects.
- Lying supine
  - Provides the tallest measurement as gravity will not compress the spine.
  - Taking measurements in the morning also provides the tallest measurement.

5.4.3.2 Seated Measurements

When taking measurements while the subject is seated, the following steps need to be considered:

- The seat and floor need to be parallel and horizontal.
- The knees need to be bent at a 90° angle.
- Thighs need to be placed in a horizontal position and the lower legs need to be placed in a vertical position.
- The feet have to be horizontally flat on the ground.

5.4.3.3 Measurements of Physical Properties of Body Segments

In ergonomic or biomechanical analysis when a person is performing a task, the human body is simplified to a system of mechanical links, each of known physical size and form.

Anthropometry defines these sizes and forms and seeks to determine various relevant properties such as length, volume, weight, location of the center of mass, and inertial properties. Each of these properties can be used in anthropometric design and biomechanical analysis. These values can also be estimated using body weight and statue. Figure 5.4a and 5.4b provide estimated segment length for males and females as a function of height (h).

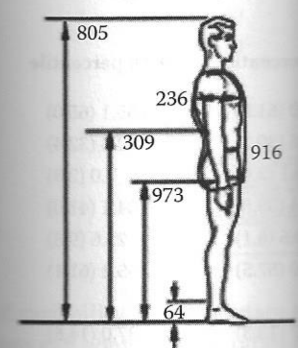
The lengths of these segments can be estimated as a function of total stature.

5.4.4 Static and Dynamic Dimensions

Anthropometry can be divided into two sections: physical anthropometry, which consists of the basic dimensions of the human body in both standing and sitting

positions, and functional anth
Both physical and functional
dynamic manner. Static anal
segment lengths in fixed posit
This is not always a valid ass
other factors, such as age, ger
cific population group and hi
changes as a result of aging, g
listed in Table 5.2 (Kroemer,

Body size of the 40-y



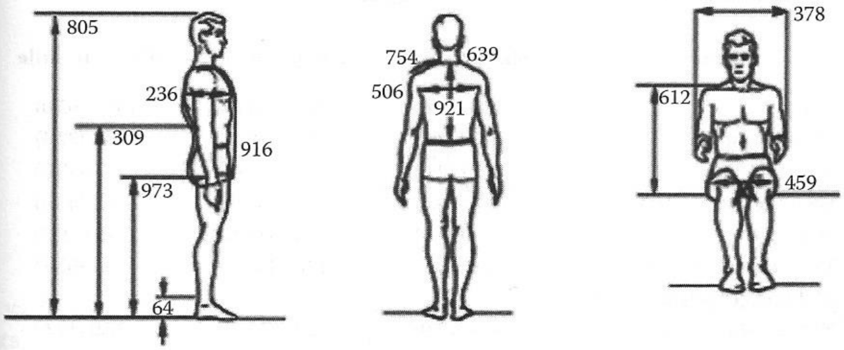
Dimension

Stature
Wrist height
Ankle height
Elbow height
Bust depth
Vertical trunk circumference
Midshoulder height, sitting
Hip breadth, sitting
Waist back
Interscye
Neck circumference
Shoulder length
Forearm-forearm breadth
Values in cm with inches in pare

FIGURE 5.4 (a) Anthropometr
Dimensional Data for American
Source: Johnson Space Center, NA

positions, and functional anthropometry, which deals with task-oriented movements. Both physical and functional anthropometry can be regarded in either a static or dynamic manner. Static analysis suggests that only the measurements of the body segment lengths in fixed positions need to be considered in the design of workplaces. This is not always a valid assumption. Static dimensions are related to and vary with other factors, such as age, gender, ethnicity, occupation, and percentile within a specific population group and historical period (i.e., diet and living conditions). Stature changes as a result of aging, gravity, and approximate changes in stature with age are listed in Table 5.2 (Kroemer, 1994).

Body size of the 40-year-old American male for year 2000 in one gravity conditions



Dimension	5th percentile	50th percentile	95th percentile
Stature	169.7 (66.8)	179.9 (70.8)	190 1 (74.8)
Wrist height			
Ankle height	12.0 (4.7)	13.9 (5.5)	15.8 (6.2)
Elbow height			
Bust depth	21.8 (8.6)	25.0 (9.8)	28.2 (11.1)
Vertical trunk circumference	158.7 (62.5)	170.7 (67.2)	182.6 (71.9)
Midshoulder height, sitting	60.8 (23.9)	65.4 (25.7)	70.0 (27.5)
Hip breadth, sitting	34.6 (13.6)	38.4 (15.1)	42.3 (16.6)
Waist back	43.7 (17.2)	47.6 (18.8)	51.6 (20.3)
Interscye	32.9 (13.0)	39.2 (15.4)	45.4 (17.9)
Neck circumference	35.5 (14.0)	38.7 (15.2)	41.9 (16.5)
Shoulder length	14.8 (5.8)	16.9 (6.7)	19.0 (7.5)
Forearm-forearm breadth	48.8 (19.2)	55.1 (21.7)	61.5 (24.2)

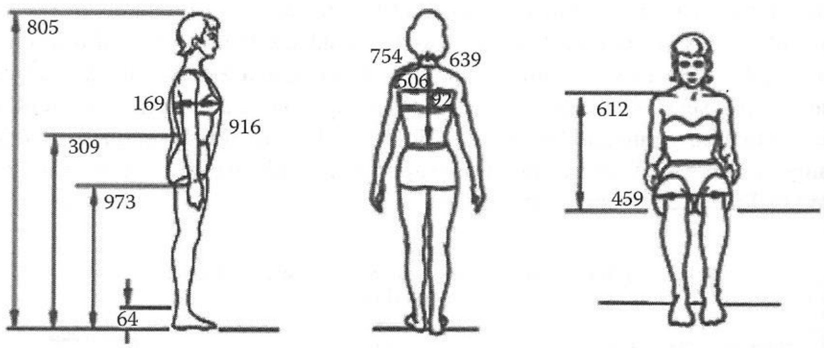
Values in cm with inches in parentheses

FIGURE 5.4 (a) Anthropometric Dimensional Data for American Male, (b) Anthropometric Dimensional Data for American Female

Source: Johnson Space Center, NASA: msis.jsc.nasa.gov. Accessed August 15, 2011

(continued)

Body size of the 40-year-old Japanese female for year 2000 in one gravity conditions



Dimension	5th percentile	50th percentile	95th percentile
Stature	148.9 (58.6)	157.0 (61.8)	165.1 (65.0)
Wrist height	70.8 (27.9)	76.6 (30.2)	82.4 (32.4)
Ankle height	5.2 (2.0)	6.1 (2.4)	7.0 (2.8)
Elbow height	92.8 (38.5)	98.4 (38.8)	104.1 (41.0)
Bust depth	17.4 (6.8)	20.5 (8.1)	23.6 (9.3)
Vertical trunk circumference	136.9 (53.9)	146.0 (57.5)	155.2 (61.1)
Midshoulder height, sitting			
Hip breadth, sitting	30.4 (12.0)	33.7 (13.3)	37.0 (14.6)
Waist back	35.2 (13.9)	38.1 (15.0)	41.0 (16.1)
Interscye	32.4 (12.8)	35.7 (14.1)	39.0 (15.4)
Neck circumference	34.5 (13.6)	37.1 (14.5)	39.7 (15.6)
Shoulder length	11.3 (4.4)	13.1 (5.1)	14.8 (5.8)

Values in cm with inches in parentheses

FIGURE 5.4 (continued)

On the other hand, dynamic analysis implies that the acceptability of a workplace design has to be evaluated with respect to the needed movements of the body from one position to another. Also, dynamic analysis takes into account clearance and reaching considerations. An example of important dynamic data that is frequently used in the design of workplaces is the range of joint mobility. Dynamic data is more costly and time-consuming to measure, which sometimes constrains occupational environments to using static measurement workplace designs.

In dynamic anthropometrics joint range of motion is an essential element in design. Figure 5.5 provide joint movement ranges for males and females for common actions.

5.4.4.1 Variability

As anthropometric data is collected, it is common to experience variability; however, if subjects are from the same population, consistency with anthropologic norms should be seen in the data as a normal distribution is expected. In the cases

TABLE 5.2
Approximate Changes in Stature with Age

	Change (cm)	
Age (Years)	**Females**	**Males**
1–5[a]	+36	+36
5–10	+27	+25
10–15	+22	+30
15–20	+7	+11
20–35[b]	−1	0
35–40	−1	0
40–50	−1	−1
50–60	−1	−1
60–70	−1	−1
70–80	−1	−1
80–90	−1	−1

Source: Kroemer et al., 1994.
[a] Average stature at age 1: females 72 cm, males 74 cm.
[b] Average maximal stature: females 163 cm, males 176 cm.

of variability, it is important to understand and to explain variation. Anthropometric data can contain three types of variability:

- Intraindividual variability
  - Changes in the individual over time due to age, health, diet
  - Traced through longitudinal studies
- Interindividual variability
  - Natural variation from individual to individual
  - Measured by a cross-section study (i.e., different individuals are measured at the same moment of time)
- Secular variability
  - Difference between generations
  - Evidence that people are larger than individuals 100 years ago

In some cases, the source of the variability may be because participants do not belong to the population of interest. Measurement variability can also result from inconsistent measuring techniques or equipment. For that reason, it is crucial to take multiple readings (at least three) of the same measurements. Additionally, when calculating descriptive statistics for evaluating the data, measures of central tendency, variation, and outliers should be identified.

5.4.5 Anthropometric Tools

Classical measurement techniques, some of which are rudimentary, are still widely used in anthropometric measurement calculations.

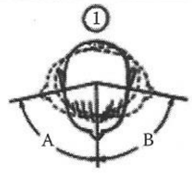
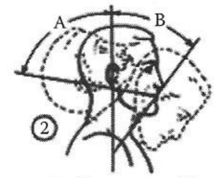
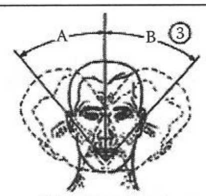
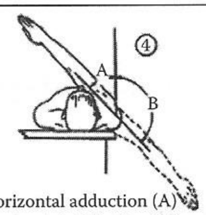
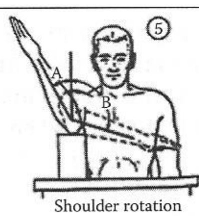
Figure	Joint movement (note b)	Range of motion (degrees)			
		Males (note a)		Female (note a)	
		5th percentile	95th percentile	5th percentile	95th percentile
 Neck rotation right (A) left (B)	Neck, rotation right (A)	73.3	99.6	74.9	108.8
	Neck, rotation left (B)	74.3	99.1	72.2	109.0
 Neck extension (A) Flexion (B)	Neck, flexion (B)	34.5	71.0	46.0	84.4
	Neck, extension (A)	65.4	103.0	4.9	103.0
 Neck lateral bend right (A) left (B)	Neck, lateral bend right (A)	34.9	63.5	37.0	63.2
	Neck, lateral bend left (B)	35.5	63.5	29.1	77.2
 Horizontal adduction (A) Horizontal abduction (B)	Shoulder, abduction	173.2	188.7	172.6	192.9
 Shoulder rotation lateral (A) medial (B)	Shoulder, rotation lateral (A)	46.3	96.7	53.8	85.8
	Shoulder, rotation medial (B)	90.5	126.6	95.8	130.9

FIGURE 5.5 Joint Movement Ranges for Males and Females
Source: Johnson Space Center, NASA: msis.jsc.nasa.gov. Accessed August 15, 2011.

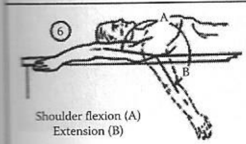
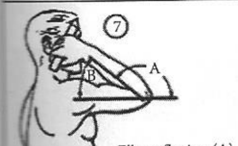
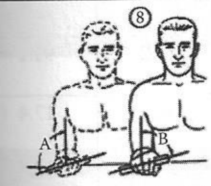
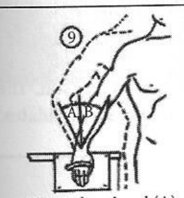
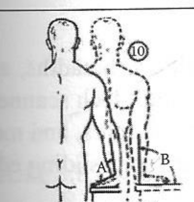
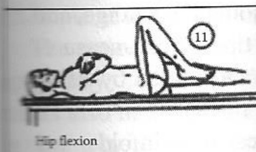
Figure	Joint
 Shoulder flexion (A) Extension (B)	Sho flexi
	Sho exte
 Elbow flexion (A) Extension (B)	Elb flex
 Forearm supination (A) Pronation (B)	For pro
	For sup
 Wrist ulnar bend (A) Radial bend (B)	Wr ber
	Wr ber
 Wrist flexion (A) Extension (B)	Wr (A)
	Wr ext
 Hip flexion	Hi

FIGURE 5.5 (continued)

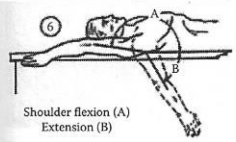
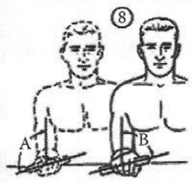
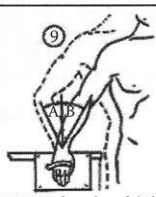
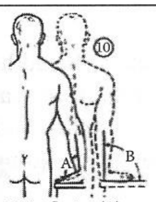
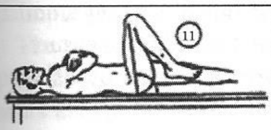
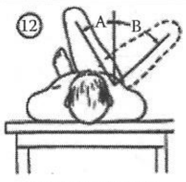
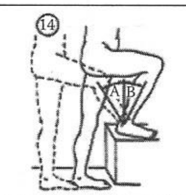
Figure	Joint movement (note b)	Range of motion (degrees)			
		Males (note a)		Female (note a)	
		5th percentile	95th percentile	5th percentile	95th percentile
 Shoulder flexion (A) Extension (B)	Shoulder, flexion (A)	164.4	210.9	152.0	217.0
	Shoulder, extension (B)	39.6	83.3	33.7	87.9
 Elbow flexion (A) Extension (B)	Elbow, flexion (A)	140.5	159.0	144.9	165.9
 Forearm supination (A) Pronation (B)	Forearm, pronation (B)	78.2	116.1	82.3	118.9
	Forearm, supination (A)	83.4	125.8	90.4	139.5
 Wrist ulnar bend (A) Radial bend (B)	Wrist, radial bend (B)	16.9	36.7	16.1	36.1
	Wrist, ulnar bend (A)	18.6	47.9	21.5	43.0
 Wrist flexion (A) Extension (B)	Wrist, flexion (A)	61.5	94.8	68.3	98.1
	Wrist, extension (B)	40.1	78.0	42.3	74.7
 Hip flexion	Hip, flexion	116.5	148.0	118.5	145.0

FIGURE 5.5 (continued)

Figure	Joint movement (note b)	Range of motion (degrees)			
		Males (note a)		Female (note a)	
		5th percentile	95th percentile	5th percentile	95th percentile
 Hip adduction (A) Abduction (B)	Hip, abduction (B)	26.8	53.5	27.2	55.9
 Knee flexion, prone	Knee, flexion	118.4	145.6	125.2	145.2
 Ankle plantar extension (A) Dorsi flexion	Ankle, plantar extension (A)	36.1	79.6	44.2	91.1
	Ankle, dorsi flexion (B)	8.1	19.9	6.9	17.4

Notes:
a. Data was taken 1979 and 1980 at NASA-JSC by Dr. William Thornton and John Jackson. The study was made using 192 males (mean age 33) 22 females (mean age 30) astronaut candidates.
b. Limb range is average of right and left limb movement.

FIGURE 5.5 **(continued)**

Anthropometric instruments are used to obtain lengths, widths, breadths, and joint angles of the human anatomy. Some of these tools include high-tech scanners, photometric equipment, and hand tools, such as anthropometers, calipers, and measuring tapes. An anthropometer is a 2 m long, graduated rod that has a sliding edge at a right angle.

- Spreading calipers have two curved branches that are joined in a hinge, and a scale is used to measure the distance between the tips. Short measurements, such as finger length or finger thickness, are calculated by using small sliding calipers.
- Special calipers are employed to measure the thickness of skinfolds, and cones are used to measure the diameter around which a finger can close. Another instrument, which is used to measure the external diameter of a finger, is a tool that has circular holes of different sizes drilled in a thin plate.
- Circumferences and curvature measurements are obtained by using tapes.

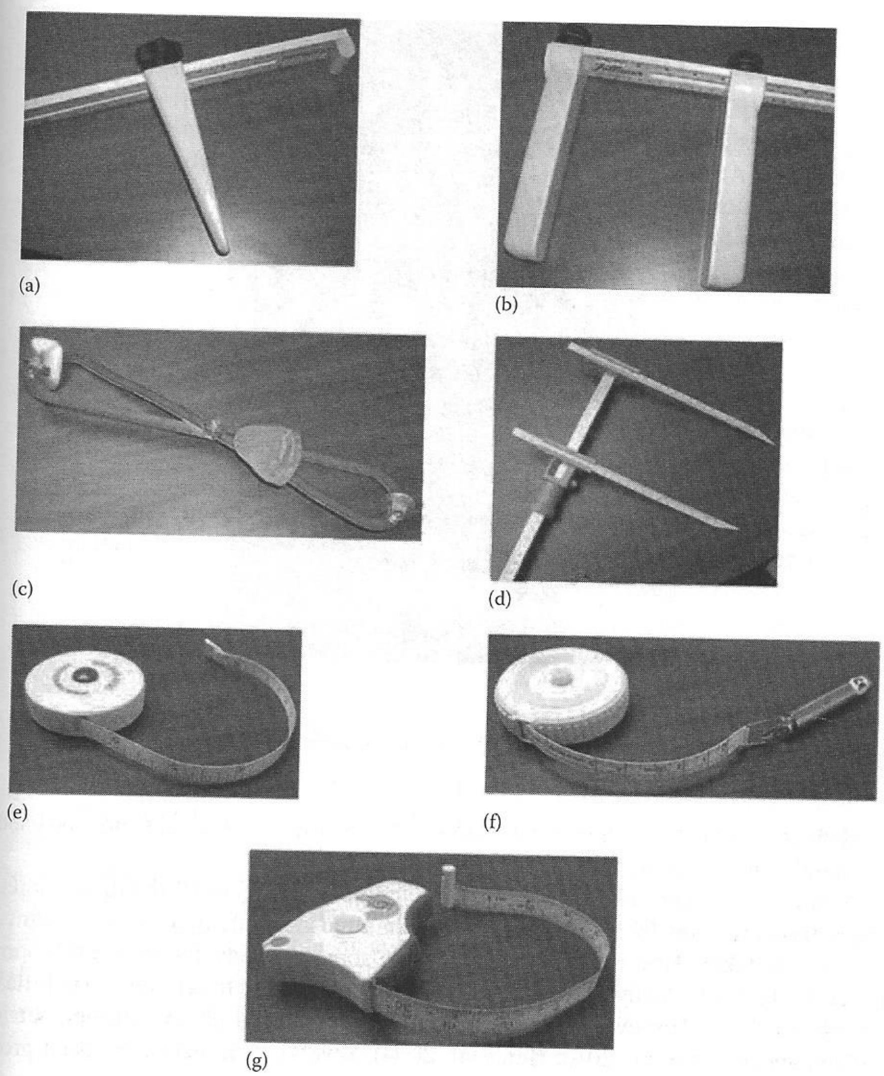


FIGURE 5.6 Manual anthropometric tools.

Example of these manual anthropometric tools are shown in Figure 5.6.

The majority of the conventional tools used for anthropometric measurements are applied by the measurer's hand to the body of the subject. Hand measurement instruments also have several shortcomings. Some of these tools are not practical for use in taking measurements on certain parts of the body, such as the eyes. They are also slow, cumbersome, and can be prone to human error. It is important to remember that anthropometric data always needs to be handled cautiously, and any data that was not gathered during the test session cannot be inferred and must remain unknown, until such time that additional measurements can be made. Also, because anthropometric

FIGURE 5.7 Air force.
Source: Air Force Research Laboratory, Wright Patterson Air Force Base.

guidelines represent averages of populations, this information should simply be used as a guideline, not as an absolute in design.

New measurement techniques, such as photographs, can record three-dimensional characteristics of the human body, allowing an almost infinite number of measurements to be taken. However, photographs can also have disadvantages in anthropometrics. The human body is portrayed in two dimensions and thus scale and parallax errors can occur. However, this is changing with enhanced photo-anthropometric technology (Davis et al., 2010; Hungetal, 2004). Several techniques have been proposed in order to acquire three-dimensional anthropometric data.

The Air Force Research Laboratory at Wright Patterson Air Force Base uses 3D anthropometric full-body scanner in human factors research. This 3D automatic full body scanner works while a test subject model poses in the standing scan position in the scanner (Figure 5.7). Researchers place 72 white stickers at key anatomical sites on the body of the test subject. The subject is fully scanned and the site stickers allow researchers to take additional measurments from scanned data, using the stickers as reference points. An example is the laser, which is used to measure the shape of irregular bodies. Laser-based anthropometry provides fast, accurate, and multiple three-dimensional readings. However, this technique can be very costly. A recently developed automated measuring tool is provided in the following section.

5.4.5.1 Automated Anthrop

As new technologies emerge, an
automation. The use of automate
pometric measuring tools that in
Once such product is the anthr
Ergonomic Technologies (Ergot
dimension-measuring instrumer
tronically transfers it to a perso
ing item sizes are allocated ac
(Ergonomic Technologies, 2010
issuance of clothing to defense p

Human Systems Integration
Crew System Ergonomics Inform
Systems Integration (HSI) infor
design, development, test, and
website, 2011). In a report publi
system that is in development, th
tem (AADMS). Both of these sy
measuring tools currently in use
automated measuring tools for a

5.4.6 Anthropometric Des

Anthropometric design aids can
three-dimensional surface mode
rely on historic data on human b
are available to serve as baseline
design. The compatibility of the
must be considered in selecting a
databases are provided in the foll
imize the value or significance
appropriate in specific applicatio

5.4.6.1 Civilian American a

The Civilian American and Eur
began as a partnership betwee
sampling of consumer body m
cation. The project collected d
2000 European civilians and a
International, 2010).

The CAESAR database con
ages 18–65. A broad range of
various weights, ethnic groups,
tus. The study was conducted fr

5.4.5.1 Automated Anthropometric Measurement Tools

As new technologies emerge, anthropometric measurement tools are moving toward automation. The use of automated technologies has led to the development of anthropometric measuring tools that increase precision and efficiency while reducing error. Once such product is the anthropometric measurement system (AMS) created by Ergonomic Technologies (Ergotech, 2011). The AMS is an electromechanical body dimension-measuring instrument that measures critical body dimensions and electronically transfers it to a personal computer-based software system, where clothing item sizes are allocated according to the body dimensions of the individual (Ergonomic Technologies, 2010). The main purpose of AMS is to ensure proper issuance of clothing to defense personnel.

Human Systems Integration Information Analysis Center (HSIIAC)—formerly Crew System Ergonomics Information Analysis Center (CSEIAC)—provides Human Systems Integration (HSI) information and analysis services in support of research, design, development, test, and evaluation of human-operated systems (HSIIAC website, 2011). In a report published for the CSEIAC, Moroney references another system that is in development, the automated anthropometric data measurement system (AADMS). Both of these systems are examples of the automated anthropometric measuring tools currently in use or development and show the move from manual to automated measuring tools for anthropometric measurement purposes.

5.4.6 Anthropometric Design Aids and Data Sources

Anthropometric design aids can include data tables, templates, mannequins, two- and three-dimensional surface models, and computer-generated models. All of these aids rely on historic data on human body dimensions. These anthropometric data sources are available to serve as baseline information for comparison or to be used directly in design. The compatibility of the population of interest and the particular data source must be considered in selecting an appropriate database. Examples of anthropometric databases are provided in the following section; however, this is not an attempt to minimize the value or significance of other data sources. Each source is significant and appropriate in specific applications; however, no endorsement is made of any resource.

5.4.6.1 Civilian American and European Surface Anthropometry Resource

The Civilian American and European Surface Anthropometry Resource (CAESAR) began as a partnership between government and industry to collect an extensive sampling of consumer body measurements for comparison, contrast, and application. The project collected data on 2400 American and Canadian subjects and 2000 European civilians and a created a database to store this information (SAE International, 2010).

The CAESAR database contains anthropometric variability of men and women, ages 18–65. A broad range of representatives were solicited to ensure samples for various weights, ethnic groups, gender, geographic regions, and socioeconomic status. The study was conducted from April 1998 to early 2000 and includes three scans per person in a standing pose, full-coverage pose, and relaxed seating pose. Data collection methods were standardized and documented so that the database can be consistently expanded and updated (Ashdown et al., 2004).

The CAESAR product line was designed to provide reliable and current measurements of the human body for the current generations. This product line was developed as a result of a comprehensive research project that brought together representatives from numerous industries including apparel, aerospace, and automotive. The CAESAR product line is available to researchers, students, academics, and designers throughout the world.

5.4.6.2 U.S. Army Anthropometry Survey

The 1988 U.S. Army Anthropometry survey is one of the most widely used anthropometry databases because of the large number of measurements and the rigorous methodology used to collect the data. This data is most useful for analyzing relationships between anthropometric variables, since the sample population (U.S. Army as of 1988) is usually not representative of any particular target population. The data can be readily applied to groups of the population that tend to have characteristics similar to those of U.S. Army soldiers (i.e., comparable fitness levels, age, weight, etc.).

5.4.6.3 AnthroKids

Although many people believe that children are just little adults, this is not the case. Children have unique anthropometric characteristics and must be designed for accordingly. An example of the differences in anthropometrics for children compared to adults is the higher center of gravity due to the fact that the head is a larger proportion of total body weight with small children. The National Institute of Standards and Technology commissioned a collection of anthropometric data on children. The first study was performed in 1975 and followed up by another study in 1977. This study collected anthropometric data on children with an emphasis on measurements that could be used to support designers in the development of products for children, with a particular focus on safety concerns. (Ressler S., 2011).

5.4.6.4 International Anthropometric Resource

The global community of anthropometry has accessible resources to obtain anthropometric data. One such resource international ergonomists can access is the World Engineering Anthropometry Resource (WEAR). WEAR is an international collaborative effort to create a worldwide resource of anthropometric data for a wide variety of engineering applications (National Institute of Standards and Technology, 2007). Also, the U.S. National Aeronautics and Space Administration (NASA, 1978) published a reference publication with measures of 306 different body dimensions from 91 different populations around the world.

5.4.6.5 The International Journal of Clothing Science and Technology

The International Journal of Clothing Science and Technology boasts an article in the third issue in Volume 18 of a Croatian anthropometric system. This article includes information on the first systematic anthropometric measurement in all Croatian counties with an objective to determine a proposal of the new size system of

clothing and footwear (Dark
metric data from a variety o
ing firm. This firm has colle
from children to disabled, fo

5.4.7 Procedure for De

To obtain consistent and re
when designing an anthropo
list provides a guideline for

- Characterize the user
  - Identify the type
    the existing anthr
  - If reliable anthrop
    design decisions.
  - If there is no vali
    obtaining measure
    existing workforc
- Determine a sample s
  of interest.
- Determine the percen
  - If the workforce o
    it may be reasona
    gender, for examp
    95th percentile fe
  - It may be an issue
    der group and in t
    the 95th percentil
  - Determine popula
- Design workspaces a
  items and the largest
  - Determine reach
  - Determine clearai
- Identify relevant anth
- Collect anthropometr
- Obtain relevant statis
- Compare data to rele
- Determine applicable

Statistical analysis is vital
Measures of central tenden
sures of variability includin
and peakedness should be
tion coefficient and regressi

clothing and footwear (Darko et al., 2006). An organization that provides anthropometric data from a variety of countries is Humanics Ergonomics, a private consulting firm. This firm has collected a broad data set that includes anthropometric data from children to disabled, for many countries around the world (Humanics, 2010).

5.4.7 Procedure for Design Using Anthropometric Data

To obtain consistent and reliable measures, certain methods should be followed when designing an anthropometric study and in the collection of data. The following list provides a guideline for conducting anthropometric studies:

- Characterize the user population.
  - Identify the type of anthropometric data available, and whether or not the existing anthropometric data is valid for the present population.
  - If reliable anthropometric data exists, use the available data to support design decisions.
  - If there is no valid data, perform an analysis and create a database by obtaining measures of a sample population that is representative of the existing workforce.
- Determine a sample size to be used for collecting data from the population of interest.
- Determine the percentile range to be accommodated in the design.
  - If the workforce or environment is dominated by either men or women, it may be reasonable to give design consideration for the predominant gender, for example, by using the 5th to 95th percentile male or 5th to 95th percentile female measures.
  - It may be an issue of equality to provide accessibility for the other gender group and in these situations, design for the 5th percentile female to the 95th percentile male population.
  - Determine population size and characteristics.
- Design workspaces and tasks such that the smallest person can reach all items and the largest person can fit into all spaces.
  - Determine reach dimensions (5th percentile).
  - Determine clearance dimensions (95th percentile).
- Identify relevant anthropometric measures.
- Collect anthropometric data.
- Obtain relevant statistics.
- Compare data to relevant databases.
- Determine applicable ranges and measures to be used in the study outcomes.

Statistical analysis is vital in the analysis and use of anthropometric calculations. Measures of central tendency, such as the mean, median, and mode, as well as measures of variability including the range, standard deviation, standard error, skewness, and peakedness should be computed. Measures of relationship, such as the correlation coefficient and regression analysis, should be determined.

Confidence intervals (CIs) that show the varying degrees of confidence are significant in anthropometric studies. Generally, CIs are established that attempt to accommodate 90%–95% of the population. CIs are based on normal distributions and on the historic, statistical empirical rule. The empirical rule states that for a normally distributed data set, approximately

- 68.76% of the data set will be within 1 standard deviation.
- 95.65% of the data set will be within 2 standard deviations.
- 99.73% of the data set will be within 3 standard deviations.

These intervals can be used to construct approximate ranges for a population; however, to construct a CI, it is necessary to know the mean and standard deviation for a data set and define the level of desired confidence in the interval. Assuming normality a random sample and a data set containing at least thirty data points, the following applies:

$$95\%\ CI = \mu \pm 1.96\sigma \quad (5.1)$$

$$90\%\ CI = \mu \pm 1.65\sigma \quad (5.2)$$

Where
μ represents population mean
σ represents population standard deviation

For smaller samples, that are normally distributed the t-distribution may be used however, the CI's will have a larger range due to a reduced sample size. In this case, the CI formulas become

$$95\%\ CI = \mu \pm t\sigma \quad (5.3)$$

$$90\%\ CI = \mu \pm t\sigma \quad (5.4)$$

Where
μ represents population mean
σ represents population standard deviation
t –represents the value for the given sample size and the associated degrees of freedom

Statistical analysis should also examine the variability in a collected set of anthropometric data. Calculating values such as the coefficient of variation can reveal variability within a data set and provide insight regarding the normality of the distribution.

5.4.8 Anthropometrics and Biomechanics

Biomechanics is a field related to anthropometry that studies the human body in terms of a mechanical system. In order to understand how to model the human body,

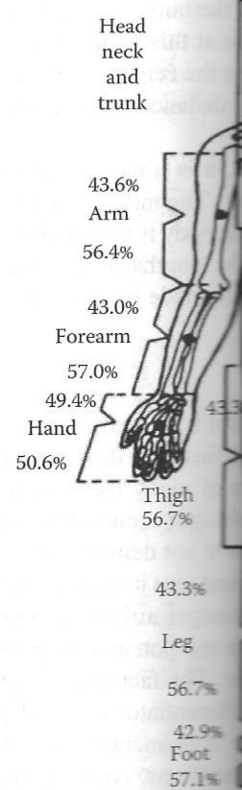


FIGURE 5.8 Locations of center of

a number of parameters must be
(lengths, widths, and circumference
and inertial property measurements
identifiable points or landmarks, it is
to measure the distances. Commonly
ment joints. Body segment link
angular measurement devices. This
center of gravity for humans.

A variety of anthropometric
information is used to identify the
The location of the center of
given percentage below the proxima
tion from which a segment can be
data has been used extensively to
approximate location of mass center
Generally, the subject lays horizonta
ity for a particular limb can be
determine the center of gravity. For

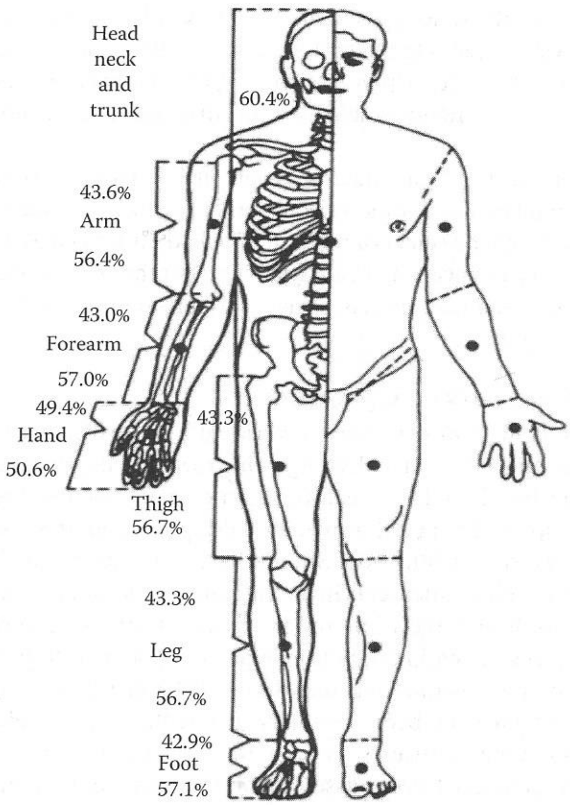


FIGURE 5.8 Locations of center of gravity.

a number of parameters must be understood including link length measurements (lengths, widths, and circumferences), volume and weight, mass center locations, and inertial property measurements. Assuming that the body is connected at easily identifiable points or landmarks, it is necessary to define these anatomical landmarks to measure the distances. Commonly used anatomical landmarks include the segment joints. Body segment link length measurements are obtained with linear or angular measurement devices. This is useful model to estimate the location of the center of gravity for humans.

A variety of anthropometric data is available on segment weights, and this information is used to identify the center of gravity locations for these segments. The location of the center of gravity is shown in Figure 5.8 and is located at the given percentage below the proximal end of the segment. Mass center is the location from which a segment can be suspended and have complete balance. Cadaver data has been used extensively to obtain mass center locations. Using this data, the approximate location of mass centers can be taken as a percentage of the link length. Generally, the subject lays horizontally on a force platform and the center of gravity for a particular limb can be calculated. Also, immersion methods are used to determine the center of gravity. For example, a limb is immersed into the water up to proximal end, where the water goes to overflow the tank. The limb is removed when one half of the water returns to the tank because at this point the water level should bisect the limb's mass center. Upon determining the center of gravity for a link, the location to the center of gravity is defined as the distance from the proximal to distal ends of the link.

To understand where to take measurements, it is important to know where the joint centers or rotations lie for the various joint. The measurements are then made from one joint to another's center of rotation. The body is treated as a system of links in order to perform a biomechanical analysis. The lengths are estimated or measured anthropometrically, and then the assessments are made in biomechanical modeling such as length analysis.

5.4.8.1 Anthropometry in Application

Anthropometric guidelines have played a critical role in different types of organizations including the airline and clothing industries. The degree of anthropometric study and application in a design is a function of many factors, including but not limited to, the impact of poor anthropometric design, economics, user expectations and in some cases, risk of litigation. Studies have not demonstrated a direct safety impact associated with smaller seats in aircraft and thus it appears that anthropometric principles have been largely ignored in passenger airline seating. Additionally, introducing changes in seating dimensions has the potential to have a substantial economic impact, thus making this undesirable. The fact that the smaller and less comfortable seating has not been a primary differentiator in travelers' selection of an airline is even more motivation to delay the implementation of these principles and designs that consider larger passenger dimensions. Anthropometric measurements that continue to be of interest in the airline industry include limb length, trunk dimensions, popliteal height, hip dimensions, and more. Devices such as seat belt extenders are used for larger passengers as well as the emerging requirement for larger passengers to purchase two seats. However, additional applications of anthropometric data are clearly needed in the commercial airline industry.

Anthropometric guidelines have been significant in the clothing industry. For example, how is it possible that a 5′8″, 150 lb woman, a 5′6″, 135 lb woman, and a 5′9″, 125 lb woman can all wear a size 8. These fitting anomalies are the reality today for the clothing industry, where a comprehensive analysis of body shapes and sizes has not been conducted for decades. The SizeUSA survey was an anthropometric research project designed to address this need in the U.S. clothing industry. Researchers gathered U.S. sizing data with the use of a three-dimensional measurement system and body scanner, which fed the data into measurement extraction software. The body measurement system consisted of four strategically placed cameras that used white light to register more than 200,000 data points on the body. These points were reduced to 40,000 and become a point cloud of the body. The results are 200 accurate body measurements in less than 1 min. This project scanned over 10,000 subjects who were grouped into gender, six age groups, and four ethnicities. The survey filled 48 statistical categories that could be utilized in a variety of ways to support the needs of clothing manufacturers. A detailed listing of anthropometric data sources is contained at the end of this chapter (Tables 5.3 and 5.4).

TABLE 5.3
Anthropometric Data (cm)[a]

Measurement	Males 50th Percentile	Males ±1 SD	Females 50th Percentile	Females ±1 SD	Population Percentiles, 50/50 Males/Females 5th	50th	95th
Standing							
1. Forward functional reach							
a. Includes body depth at shoulder	82.6 (79.3)	4.8 (5.6)	74.1 (71.3)	3.9 (4.4)	69.1 (65.5)	77.9 (74.8)	88.8 (86.5)
b. Acromial process to functional pinch	63.8 (62.1)	4.3 (8.9)	62.5 (60.4)	3.4 (6.7)	57.5 (48.5)	65.0 (61.1)	74.5 (74.5)
c. Abdominal extension to functional pinch[b]	23.1	2.0	20.9	2.1	18.1	22.0	25.8

TABLE 5.3
Anthropometric Data (cm)[a]

	Males		Females		Population Percentiles, 50/50 Males/Females		
Measurement	**50th Percentile**	**±1 SD**	**50th Percentile**	**±1 SD**	**5th**	**50th**	**95th**
Standing							
1. Forward functional reach							
a. Includes body depth at shoulder	82.6 (79.3)	4.8 (5.6)	74.1 (71.3)	3.9 (4.4)	69.1 (65.5)	77.9 (74.8)	88.8 (86.5)
b. Acromial process to functional pinch	63.8 (62.1)	4.3 (8.9)	62.5 (60.4)	3.4 (6.7)	57.5 (48.5)	65.0 (61.1)	74.5 (74.5)
c. Abdominal extension to functional pinch[b]	23.1	2.0	20.9	2.1	18.1	22.0	25.8
2. Abdominal extension depth							
3. Waist height	106.3 (104.8)	5.4 (6.3)	101.7 (98.5)	5.0 (5.5)	94.9 (91.0)	103.9 (101.4)	113.5 (113.0)
4. Tibial height	45.6	2.8	42.0	2.4	38.8	43.6	49.2
5. Knuckle height	75.5	4.1	71.0	4.0	65.7	73.2	80.9
6. Elbow height	110.5 (114.6)	4.5 (6.3)	102.6 (107.1)	4.8 (6.8)	96.4 (98.8)	106.7 (110.7)	116.3 (123.5)
7. Shoulder height	143.7 (146.4)	6.2 (7.8)	132.9 (135.3)	5.5 (6.6)	124.8 (126.6)	137.4 (140.4)	151.7 (156.4)
8. Eye height	164.4	6.1	151.4	5.6	144.2	157.7	172.3
9. Stature	174.5 (177.5)	6.6 (6.7)	162.1 (164.5)	6.0 (7.2)	154.4 (155.1)	168.0 (170.4)	183. 0 (188.7)
10. Functional overhead reach	209.6	8.5	199.2	8.6	188.0	204.5	220.8
Seated							
11. Thigh clearance height	14.7	1.4	12.4	1.2	10.8	13.5	16.5
12. Elbow rest height	24.1	3.2	23.1	3.0	18.4	23.6	28.9
13. Midshoulder height	62.4	3.2	58.0	2.7	54.5	60.0	66.5
14. Eye height	78.7	3.6	73.7	3.1	69.7	76.0	83.3
15. Sitting height normal	86.6	3.8	81.8	4.0	76.6	84.2	91.6
16. Functional overhead reach	128.4	8.5	119.8	6.6	110.6	123.6	139.3
17. Knee height	54.0	2.7	51.0	2.6	47.5	52.5	57.7

(continued)

TABLE 5.3 (continued)
Anthropometric Data (cm)[a]

Measurement	Males 50th Percentile	Males ±1 SD	Females 50th Percentile	Females ±1 SD	Population Percentiles, 50/50 Males/Females 5th	50th	95th
18. Popliteal height	44.6	2.5	41.0	1.9	38.6	42.6	47.8
19. Leg length	105.1	4.8	100.7	4.3	94.7	102.8	111.4
20. Upper-leg length	59.4	2.8	57.4	2.6	53.7	58.4	63.3
21. Buttocks-to-popliteal length	49.8	2.5	48.0	3.2	43.8	49.0	53.6
22. Elbow-to-fist length	38.5 (37.1)	2.1 (3.0)	34.8 (32.9)	2.3 (3.1)	31.9 (28.9)	36.7 (35.0)	41.1 (41.0)
23. Upper-arm length	36.9 (37.0)	1.9 (2.5)	34.1 (33.8)	2.5 (2.1)	31.0 (28.9)	35.7 (35.0)	39.4 (41.0)
24. Shoulder breadth	45.4	1.9	39.0	2.1	36.3	42.3	47.8
25. Hip breadth	35.6	2.3	38.0	2.6	32.4	36.8	41.5
Foot							
26. Foot length	26.8	1.3	24.1	1.1	22.6	25.3	28.4
27. Foot breadth	10.0	0.6	8.9	0.5	8.2	9.4	10.8
Hand							
28. Hand thickness, metacarpal III	3.3	0.2	2.8	0.2	2.7	3.0	3.6
29. Hand length	19.0	1.0	18.4	1.0	17.0	18.7	20.4
30. Digit two length	7.5	0.7	6.9	0.8	5.8	7.2	8.5
31. Hand breadth	8.7	0.5	7.7	0.5	7.0	8.2	9.3
32. Digit one length	12.7	1.1	11.0	1.0	9.7	11.8	14.2
33. Breadth of digit one interphalangeal joint	2.3	0.1	1.9	0.1	1.8	2.1	2.5
34. Breadth of digit three interphalangeal joint	1.8	0.1	1.5	0.1	1.4	1.7	2.0

35. Grip breadth, inside diameter	4.9	0.6	4.3	0.3	3.8	4.5	5.7
36. Hand spread, digit one to digit two, first phalangeal joint	12.4	2.4	9.9	1.7	7.5	10.9	15.5
37. Hand spread, digit one to digit two, second phalangeal joint	10.5	1.7	8.1	1.7	5.9	9.3	12.7
Head							
38. Head breadth	15.3	0.6	14.5	0.6	13.8	14.9	16.0
39. Interpupillary breadth	6.1	0.4	5.8	0.4	5.2	6.0	6.7
40. Biocular breadth	9.2	0.5	9.0	0.5	8.3	9.1	10.0
Other measurements							
41. Flexion-extension, range of motion of wrist radians (57°/rad)	2.33	0.33	2.46	0.26	1.92	2.4	2.8
42. Ulnar-radial range of motion of wrist radians (57°/rad)	1.05	0.23	1.17	0.24	0.81	1.15	1.49

35. Grip breadth, inside diameter	4.9	0.6	4.3	0.3	3.8	4.5	5.7
36. Hand spread, digit one to digit two, first phalangeal joint	12.4	2.4	9.9	1.7	7.5	10.9	15.5
37. Hand spread, digit one to digit two, second phalangeal joint	10.5	1.7	8.1	1.7	5.9	9.3	12.7
Head							
38. Head breadth	15.3	0.6	14.5	0.6	13.8	14.9	16.0
39. Interpupillary breadth	6.1	0.4	5.8	0.4	5.2	6.0	6.7
40. Biocular breadth	9.2	0.5	9.0	0.5	8.3	9.1	10.0
Other measurements							
41. Flexion-extension, range of motion of wrist radians (57°/rad)	2.33	0.33	2.46	0.26	1.92	2.4	2.8
42. Ulnar-radial range of motion of wrist radians (57°/rad)	1.05	0.23	1.17	0.24	0.81	1.15	1.49
43. Weight, in kilograms	83.2	15.1	66.4	13.9	47.7	74.4	102.9

Source: Adapted from Champney, P.C. (1979); Muller-Borer, B. (1981); Eastman Kodak Company, *Ergonomics Design for People at Work*, Vol. 1, Van Nostrand Reinhold, New York, 1983; NASA RP 1024, *Anthropometric Source Book: Volume 1: Anthropometry for Designers Anthropology Staff/Webb Associates*, NASA, Washington, DC, pp. 7–78, 1978.

Note: The mean, or 50th percentile, values, plus or minus one standard deviation (SD) of the mean, are shown for 43 anthropometric variables (column 1). Variables 1 through 10 are standing heights, clearances, or reaches, and variables 11 through 25 are measurements for the subject seated. Data on American men (columns 2 and 3) and women (columns 4 and 5) are statistically combined to derive the 5th, 50th, and 95th percentile values for a 50/50 mix of these populations (columns 6 through 8). The data are taken primarily from military studies, where several thousand people were studied. The entries shown in parentheses are from industrial studies, where 50–100 women and 100–150 men were studied. The data in the footnotes "a and b" are from a study on 50 women and 100 men in the industry.

[a] These values should be adjusted for clothing and posture.

[b] Add the following for bending forward from hips or waist—Male: waist, 25 ± 7; hips, 42 ± 8. Female: waist, 20 ± 5; hips, 36 ± 9.

TABLE 5.4
International Anthropometry: Adults, Height, and Weight Averages (with Standard Deviations)

	Sample Size	Stature (mm)	Weight (kg)
Algeria			
Females (1990)	666	1576 (56)	61 (1)
Australia			
Females, 77 (8) years old	138	1521 (70)	61 (13)
Males, 76 (7) years old (2000)	33	1658 (79)	72 (11)
Brazil			
Males (1988)	3076	1699 (67)	NDA
China			
Females (Hong Kong)	69	1607 (54)	NDA
Females (Taiwan) (1994)	300	1582 (49)	51 (7)
Females (Taiwan) (2000)	About 600	1572 (53)	52 (7)
Males (Hong Kong) (2000)	286	1737 (49)	NDA
Males (Canton) (1990)	41	1720 (63)	60 (6)
Males (Taiwan) (2002)	About 600	1705 (59)	67 (9)
Egypt			
Females (1987)	4960	1606 (72)	63 (4)
France			
Female soldiers	328	1620	58
Male soldiers (1997)	687	1747	70
Females	5510	1625 (71)	62 (12)
Males (IFTH and Goncalves, personal communication, 2006)	3986	1756 (77)	77 (13)
Germany (east)			
Females	123	1608 (59)	NDA
Males (1986)	30	1715 (66)	NDA
India			
Females	251	1523 (66)	50 (10)
Males (1997)	710	1650 (70)	57 (11)
East-Central India male farm workers (2002)	300	1638 (56)	57 (7)
Central India male farm workers (1989)	39	1620 (50)	49 (6)
South India male workers (1992)	128	1607 (60)	57 (5)
East India male farm workers (1997)	134	1621 (58)	54 (67)
Indonesia			
Females	468	1516 (54)	NDA
Males (1985)	949	1613 (56)	NDA
Iran			
Female students	74	1597 (58)	56 (10)
Male students (1997)	105	1725 (58)	66 (10)
Ireland			
Males (1991)	164	1731 (58)	74 (9)

TABLE 5.4 (continued)
International Anthropometry: ...
Standard Deviations)

Italy
Females (1991)
Females (2002)
Males (1991)
Males (2002)
Jamaica
Females
Males (1991)
Japan
Females
Males (1990)
Korea (South)
Female workers (1989)
Malaysia
Females (1988)
The Netherlands
Females, 20–30 years old (1998)
Females, 18–65 years old (2002)
Males, 20–30 years old (1998)
Males, 18–65 years old (2002)
Russia
Female herders (ethnic Asians)
Female students (ethnic Russians)
Female students (ethnic Uzbeks)
Female factory workers (ethnic R...
Female factory workers (ethnic U...
Male students (ethnic Russians)
Male students (ethnic Uzbeks)
Male factory workers (ethnic Russians)
Male factory workers (ethnic mix)
Male farm mechanics (ethnic Asians)
Male coal miners (ethnic Russians)
Male construction workers (ethnic R... (1999)
Saudi Arabia
Males (1985)
Singapore
Females (1988)
Males (pilot trainees) (1995)
Sri Lanka
Females
Males (1991)

TABLE 5.4 (continued)
International Anthropometry: Adults, Height, and Weight Averages (with Standard Deviations)

	Sample Size	Stature (mm)	Weight (kg)
Italy			
Females (1991)	753	1610 (64)	58 (8)
Females (2002)	386	1611 (62)	58 (9)
Males (1991)	913	1733 (71)	75 (10)
Males (2002)	410	1736 (67)	73 (11)
Jamaica			
Females	123	1648	61
Males (1991)	30	1749	68
Japan			
Females	240	1584 (50)	54 (6)
Males (1990)	248	1688 (55)	66 (8)
Korea (South)			
Female workers (1989)	101	1580 (57)	54 (7)
Malaysia			
Females (1988)	32	1559 (66)	NDA
The Netherlands			
Females, 20–30 years old (1998)	68	1686 (66)	67 (10)
Females, 18–65 years old (2002)	691	1679 (75)	73 (16)
Males, 20–30 years old (1998)	55	1848 (80)	81 (14)
Males, 18–65 years old (2002)	564	1813 (90)	84 (16)
Russia			
Female herders (ethnic Asians)	246	1588 (55)	NDA
Female students (ethnic Russians)	207	1637 (57)	61 (8)
Female students (ethnic Uzbeks)	164	1578 (49)	56 (7)
Female factory workers (ethnic Russians)	205	1606 (53)	61 (8)
Female factory workers (ethnic Uzbeks)	301	1580 (54)	58 (9)
Male students (ethnic Russians)	166	1757 (56)	71 (9)
Male students (ethnic Uzbeks)	150	1700 (52)	65 (7)
Male factory workers (ethnic Russians)	192	1736 (61)	72 (10)
Male factory workers (ethnic mix)	150	1700 (59)	68 (8)
Male farm mechanics (ethnic Asians)	520	1704 (58)	64 (8)
Male coal miners (ethnic Russians)	150	1801 (61)	NDA
Male construction workers (ethnic Russians) (1999)	150	1707 (69)	NDA
Saudi Arabia			
Males (1985)	1440	1675 (61)	NDA
Singapore			
Females (1988)	46	1598 (58)	NDA
Males (pilot trainees) (1995)	832	1685 (53)	NDA
Sri Lanka			
Females	287	1523 (59)	774 (22)
Males (1991)	435	1639 (63)	833 (27)

(continued)

TABLE 5.4 (continued)
International Anthropometry: Adults, Height, and Weight Averages (with Standard Deviations)

	Sample Size	Stature (mm)	Weight (kg)
Sudan			
Males			
Villagers (1981)	37	1687 (63)	NDA
City dwellers (1982)	16	1704 (72)	NDA
City dwellers (1982)	48	1668	NDA
Soldiers(1981)	21	1735 (71)	NDA
Soldiers (1982)	104	1728	NDA
Thailand			
Females	250	1512 (48)	NDA
Females	711	1540 (50)	817 (27)
Males	250	1607 (20)	NDA
Males (1991)	1478	1654 (59)	872 (32)
Turkey			
Females			
Villagers	47	1567 (52)	792 (38)
City dwellers	53	1563 (55)	786 (05)
Male soldiers (1991)	5108	1702 (60)	888 (34)
United States			
Females	About 3800	1625	NDA
Males (2004)	About 3800	1762	NDA
Midwest workers/with shoes and light clothes			
Females	125	1637 (62)	NDA
Males (1993)	384	1778 (73)	NDA
U.S. male miners (1993)	105	1803 (65)	NDA
U.S. Army soldiers			
Females	2208	1629 (64)	852 (35)
Males (1989)	1774	1756 (67)	914 (36)
North American (Canada and United States)			
Females,18–26 years old	1255	1640 (73)	NDA
Males, 18–65 years old (2002)	1120	1778 (79)	NDA
Vietnamese, living in the United States			
Females	30	1559 (61)	NDA
Males (1993)	41	1646(60)	NDA

Source: Kumar, S. (Ed.), *Biomechanics in Ergonomics*, 2nd edn., CRC Press, New York, 2008.

5.5 SUMMARY

Anthropometrics enables u
uct items, including system
height, weight, limb, and b
ranging from clothing, fur
shuttles and space stations.
pometric data will lead to
leisure settings, and produ
particularly those designed
with tragic consequences. T
is reinforced by product lia
numerous cultures and dev
of consumers.

OSHA Success with Erg

International Truck and E

State: Ohio

Company: International
Assembly Plant

Industry: Motor vehicle

Employees: 2500

Success Brief: The redesi
storage, and reevaluation
decrease in incident frequ
disorders.

The Problem

Four years before it launc
Plant, International Truck
nomic risks and other po
the same time increasing

The Solution

Before the launch of the
ees and safety and health
the workspaces. The em
cross-functional teams th

5.5 SUMMARY

Anthropometrics enables us to properly design equipment, processes, and product items, including system interfaces, to accommodate the user. Accurate data on height, weight, limb, and body segment sizes are needed to properly design items ranging from clothing, furniture, automobiles, buses, and subway cars to space shuttles and space stations. The collection, interpretation, and utilization of anthropometric data will lead to enhanced ergonomics in occupational environments, leisure settings, and product design. Safety issues related to consumer products, particularly those designed for use by children, continue to surface, sometimes with tragic consequences. The need for continual collection of anthropometric data is reinforced by product liability lawsuits, the continuing trend toward obesity in numerous cultures and development of products for an international cross-section of consumers.

Case Study

OSHA Success with Ergonomics

International Truck and Engine Corporation

State: Ohio

Company: International Truck and Engine Corporation, Springfield, Ohio Assembly Plant

Industry: Motor vehicle and passenger car bodies—SIC Code: 3711

Employees: 2500

Success Brief: The redesign of workstation layouts, improvement of racking and storage, and reevaluation and replacement of certain tools led to a significant decrease in incident frequencies and lost time cases caused by musculoskeletal disorders.

The Problem

Four years before it launched a new series of trucks at its Springfield Assembly Plant, International Truck and Engine set goals to decrease or eliminate ergonomic risks and other potential problems associated with production, while at the same time increasing the facility's productivity and efficiency.

The Solution

Before the launch of the new product line, management, production employees and safety and health representatives worked together in teams to redesign the workspaces. The employees raised concerns during workshops involving cross-functional teams that included skilled trades employees, line supervisors, maintenance supervisors, safety and ergonomics representatives, upper management representatives, and production line employees. During the workshops, the team members learned about ergonomic risk factors, the importance of workplace organization and set up, and various safety procedures to be used in their workplace. As part of the redesign, the company:

Installed lift and tilt tables so that employees could adjust the workstation height as needed, which reduced incidents of shoulder and back strains and sprains.

Hung and balanced all tools overhead, raised air hoses off the floor, and replaced pistol-grip tools with inline tools, which reduced wrist and elbow injuries and eliminated trip and fall hazards.

Redesigned flow-through racks to incorporate adjustable shelf heights so that employees of various heights could keep parts on racks within an employee's own personal "strike zone" for improved lifting.

Altered the radiator assembly line to improve the employees' access to the radiator under assembly by installing variable height running boards and a "kick lever" to allow rotation of the radiator as needed by the assembly line employees.

Standardized the containers, rack design, and stock positioning so that heavier items were carried the shortest distance and smaller parts were placed in standardized totes on rolling racks that allow for employee adjustment, depending on the employee's needs.

Source: Case Study reprinted as shown in OSHA website "Success Stories", accessed 2011; originally printed in *Occupational Health & Safety*, Volume 71, Issue 9, September 1, 2002. Updated, Subhash C. Vaidya, Navistar International Corporation, October 20.

EXERCISES

5.1 Explain the purpose for universal design and how this might impact the economics, dimensions, and processes of design from an anthropometric perspective.

5.2 In the absence of universal design, what ranges should the ergonomist promote design for?

5.3 In emergency situations, how should anthropometric data be used to guide design decisions?

5.4 Develop a process for collecting anthropometric data in an occupational ergonomic environment.

5.5 Contrast and compare the use of manual versus automatic anthropometric measurement tools.

5.6 Evaluate the use of goniometers for measuring body motions.

5.7 Describe how stature is measured and why it is relevant to occupational ergonomics.

5.8 Explain why the dimensi
design engineers.

5.9 Describe the effects of ag

5.10 Identify three anthropom
used, the population the
benefit from this data.

REFERENCES

Ashdown, S., Loker, S., Schoenfeld
fit analysis. *J. Textiles Appar*
Center for Universal Design at No
project/design-projects/udi/
Davis, J., Valentine, T., and Davis,
ses of full-face and profile fa
Defence Technical Information
(accessed September, 2011).
DOD-HDBK-743. (1980). *Anthrop*
Laboratories, DOD.
Eastman Kodak Company. (198
Nostrand Reinhold, New Yo
Ergonomics Technologies Webs
ERG02_08.asp
Ergonomic Technologies. (2010
from Ergonomic Technol
ERG02_08.asp
Garrett, J.W. and Kennedy, K.W.
AMRL TR-68-1, Aerospac
Force Base, OH.
Gordon, C.C., Churchill, T., Claus
Walker, R. (1989). 1988 and
tics interim report. United S
Center: Natick, MA.
Herzberg, F. (1968). Man and the
Hung, C.Y.P., Witana, C.P., and
from photographic images.
Conference on Work with C
Hung, P., Witana, C., and Goo
Photographic Images in W
Helander, and A.W. Yeo), D
Kroemer, K.H.E, Kroemer, H.J.,
Bases of Human Factors/Er
Kroemer, K.H.E. (1994). *Locatin*
Design, January Issue, 40 m
Kroemer, K.H.E., Kroemer, H.B.
Design for Ease and Efficie
Kroemer, K., Kroemer, H., and K
Ease and Efficiency, 2nd ed
Kroemer, K.H.E. (2006). *The Oc*
Raton, FL.

5.8 Explain why the dimensions of the "average user" should not be the goal of design engineers.

5.9 Describe the effects of age, gender, and size on anthropometrics.

5.10 Identify three anthropometric data sources and explain how they should be used, the population they are most applicable to, and an industry that will benefit from this data.

REFERENCES

Ashdown, S., Loker, S., Schoenfelder, K.A., and Lyman-Clarke, L. (2004). Using 3D scans for fit analysis. *J. Textiles Apparel Manage. Technol.*, 4(1).

Center for Universal Design at North Carolina State University. (2011). http://www.ncsu.edu/project/design-projects/udi/

Davis, J., Valentine, T., and Davis, R. (2010). Computer assisted photo-anthropometric analyses of full-face and profile facial images. *Forens. Sci. Int.*, 200(1), 165–176.

Defence Technical Information center (DTIC), http://www.dtic.mil/dticasd/anthro.html (accessed September, 2011).

DOD-HDBK-743. (1980). *Anthropometry of U.S. Military Personnel*, U.S. Army Natick R&D Laboratories, DOD.

Eastman Kodak Company. (1983). *Ergonomics Design for People at Work*, Vol. 1, Van Nostrand Reinhold, New York.

Ergonomics Technologies Website. (2011). http://www.armscordi.com/SubSites/ERGO/ERG02_08.asp

Ergonomic Technologies. (2010). Business activities. Retrieved November 8, 2010, from Ergonomic Technologies: http://www.armscorbusiness.com/SubSites/ERGO/ERG02_08.asp

Garrett, J.W. and Kennedy, K.W. (1971). A collation of anthropometry. Technical Report AMRL TR-68-1, Aerospace Medical Research Laboratories: Wright-Patterson Air Force Base, OH.

Gordon, C.C., Churchill, T., Clauser, C.C., Bradtmiller, B., McConville, J.T., Tebbets, I., and Walker, R. (1989). 1988 anthropometric survey of US army personnel: Summary statistics interim report. United States Army Natick Research, Development and Engineering Center: Natick, MA.

Herzberg, F. (1968). Man and the nature of work.

Hung, C.Y.P., Witana, C.P., and Goonetilleke, R.S. 2004. Anthropometric measurements from photographic images. Paper presented at *Proceedings of the 7th International Conference on Work with Computer Systems (WWCS)*, Kuala Lumpur, Malaysia.

Hung, P., Witana, C., and Goonetilleke, R. (2004). *Anthropometric Measurements from Photographic Images in Work with Computing Systems* (Eds. H.M. Khalid, M.G. Helander, and A.W. Yeo), Damai Sciences: Kuala Lumpur, Malaysia, pp. 104–109.

Kroemer, K.H.E, Kroemer, H.J., and Kroemer-Elbert, K.E. (1990). *Engineering Physiology: Bases of Human Factors/Ergonomics*, 2nd edn., Van Nostrand Reinhold: New York.

Kroemer, K.H.E. (1994). *Locating the Computer Screen: How High, How Far? Ergonomics in Design*, January Issue, 40 and October 1993 Issue, 7–8.

Kroemer, K.H.E., Kroemer, H.B., and Kroemer-Elbert, K.E. (1994). *Ergonomics: How to Design for Ease and Efficiency*, Prentice Hall: Englewood Cliffs, NJ.

Kroemer, K., Kroemer, H., and Kroemer-Elbert, K. (2003). *Ergonomics: How to Design for Ease and Efficiency*, 2nd ed. Prentice Hall: Upper Saddle River, NJ.

Kroemer, K.H.E. (2006). *The Occupational Ergonomics Handbook*, Taylor & Francis: Boca Raton, FL.