BUSINESS + INSTITUTIONAL FURNITURE MANUFACTURERS ASSOCIATION

BIFMA G1-2013

ERGONOMICS GUIDELINE FOR FURNITURE USED IN OFFICE WORK SPACES DESIGNED FOR COMPUTER USE

Preamble:

A message from the BIFMA G1 Subcommittee to the users of this Guideline.

The Ergonomics Subcommittee undertook revision of BIFMA G1 in 2009 as a result of the availability of new civilian anthropometric data. A number of G1 recommended dimensions and adjustment ranges changed as a result of adoption of this new data, which reflects changes in the size and shape of the North American working population. The Subcommittee understands that this may impart significant changes to products designed to meet BIFMA G1 recommendations. Therefore, the Subcommittee is suggesting that manufacturers understand and consider the following with respect to implications to products currently in the market, as well as the transitioning and timing relative to future products:

- Products designed for office work previously sold and currently in use as well as those being manufactured at the time of publication of the BIFMA G1-2013 document that are designed to meet BIFMA G1-2002 recommendations are considered acceptable even though they may not meet BIFMA G1-2013 recommendations.

- Manufacturers are encouraged to design products to meet the recommendations in BIFMA G1-2013 as soon as possible. It is understood that due to design and development cycles, tooling, and other considerations, design transitions to BIFMA G1-2013 may take some time. Some manufacturers may choose not to update existing products to the 2013 Guideline revision; therefore, any manufacturer's reference to BIFMA G1 for its product's dimensions must indicate the proper edition (2002 vs. 2013).

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1. Foreword

The *Ergonomics Guideline for Furniture used in Office Work Spaces Designed for Computer Use* referred to throughout this document as the "Guideline", quotes the terminology, measurable ergonomics guiding principles and design requirements of the international standards published by the International Organization for Standardization ISO 9241-302:2008 *Ergonomics of human-system interaction-Part 302: Terminology for electronic visual displays;* ISO 9241-303:2008 *Ergonomics of human-system interaction-Part 303: Requirements for electronic visual displays;* and ISO 9241–5: 1998 *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 5: Workstation layout and postural requirements.*

ISO 9241-303 and 9241-5 represent accepted principles for office ergonomics. They also provide guidance for evaluating workstation furniture that conforms to the body sizes of the working population. Because body sizes vary widely in different parts of the world, ISO 9241-303 and ISO 9241-5 do not provide specific dimensions for workstation components such as chairs and work surfaces.

Since the publication of the G1-2002 Guideline, a comprehensive civilian anthropometric database, Civilian American and European Surface Anthropometry Resource (CAESAR), has become available that is more representative of the North American office worker population than the previously used military database, Anthropometric Survey of U.S. Army Personnel (ANSUR or NATICK). This revised Guideline uses the civilian database (CAESAR) as a basis for the recommendations given.

This Guideline also considered the information, dimensions and adjustment ranges as they appear in ANSI/HFES 100-2007 and CAN/CSA Z412-00 (R2005). Where reference information is incomplete, conflicting or impractical, this Guideline suggests commonly used industry practices.

The application of the concept of **Fit**, as defined by ISO 9241-5, 4.3, is the primary consideration of this Guideline:

> *"Selection and design of furniture and equipment requires a fit to be achieved between a range of task requirements and the needs of users. The concept of fit concerns the extent to which furniture and equipment (work chairs, work surfaces, visual display units, input devices, etc.) can accommodate individual users' needs.*
>
> *Good fit is needed for the intended user population including users sharing workstations and users with special needs, e.g. handicapped persons. Fit can be accomplished by furniture built for a specified use (or user), or be provided in a range of sizes and forms or by adjustability and combinations thereof.*
>
> *Since, except under special circumstances, workstations cannot be custom-made for individual users, some alternative forms of ensuring a good fit are*

required. The extent to which the workstation provides a good fit between the requirements of users and their work should be of primary consideration."

2 Scope

The purpose of this Guideline is to provide guidance to designers and specifiers in developing, designing and specifying ergonomic solutions for computer workspaces in North America. The relevant measurable ergonomic principles and design requirements are found in ISO 9241-303 and 9241-5. The dimensions and adjustment ranges of components are based on the anthropometric data provided in CAESAR (June 2002), weighted to the United States population demographics from the National Health and Nutrition Examination Survey (NHANES) 2007-2008 and 2009-2010 datasets. Other tasks may require considerations not addressed in this Guideline.

Proper application of ISO's principles will enhance the performance and comfort of computer users. The more intensive the computer usage, the more important adherence to these principles becomes.

This Guideline is intended for use by:

- BIFMA Members and other Furniture Manufacturers
- Interior Designers/Architects/Specifiers/Industrial Designers
- Facility and Purchasing Managers
- Ergonomists, Industrial Hygienists, Occupational Therapists, Health Care Providers
- Testing Laboratories
- Furniture Dealers and their clients
- Other professionals involved in the design, manufacturing, specifying, qualifying and purchasing of office furniture for computer work spaces

Note: G1 is a Guideline not a Standard; the dimensions given within the G1 document are recommendations not requirements. The committee intends this document to be primarily used to give design guidance to manufacturers of furniture to be used in office workspaces. It is expected that specifiers/customers will want to use this document to determine their purchasing specifications. It should be noted that this document does not make specific recommendations for some product dimensions. This is due to the complexities inherent in some of these areas; they are presented in the G1's discussion sections. In some cases, a manufacturer will provide information pertaining to the percentile of the user population their product(s) will accommodate.

3 Product Evaluation Statements

Designing products to fit the 5th percentile female body dimensions to the 95th percentile male (or in some cases, female, whichever is more extreme) body dimensions to accommodate a large number of users. This Guideline attempts to achieve that objective.

It is important, however, to realize that designing/purchasing furniture for the above range will not accommodate at least 5 percent of the users for any particular dimension. In order to accommodate users outside the 5th to 95th percentile ranges, it may be necessary to design/purchase products/components that are not within that range. The practice of ergonomics requires fitting the work environment to the user. A furniture component that fits a particular user (follows a given "ultimate test for fit") meets ISO and the recommendations in this Guideline, even if it does not meet the given dimensional recommendations.

It is acknowledged that a number of individuals are outside of the anthropometric dimensions used in the development of this Guideline. Because of the many complexities and variation in human anthropometry, some of the people that are outside of the limits considered in this guideline will still be able to comfortably use products designed to these recommendations; others, however will not be able to comfortably/correctly use the products designed to this Guideline. Alternate products should be sourced for these individuals.

Any manufacturer's reference to BIFMA G1 for its product's dimensions must indicate the proper edition (2002 vs. 2013).

4 Limitations

The work space dimensions recommended in this document are based on the following anthropometric databases: CAESAR database (North American) weighted to represent the population demographics of the NHANES 2007-2008 and 2009-2010 population surveys. The data set was analyzed for outliers as well as incorrect representation of any particular demographics. The data set was modified to correct for these conditions. See Appendix A for further information.

The work space dimensions are based on meeting the requirements of the relevant 5th percentile female through 95th percentile male (or in some cases, female) body dimensions in an upright seated posture. Other postures or configurations, such as the use of stools in the workstation, may result in different dimensional requirements. Some of the recommendations in this guideline may be applicable to stools, however, they were not specifically developed for the design of stools.

The application of ergonomic principles is broader than anthropometry and workstation design should consider other aspects such as lighting, acoustics, heating & ventilation, and psychosocial aspects.

The application of ISO principles to specific user/work space combinations may result in dimensional conflicts. The final criteria for determining whether an individual user has been accommodated are the parameters given in the Ultimate Test for Fit, found after each Recommendation. Multiple product solutions may be required in order to accommodate the entire user population.

5 Definitions

Note: Refer to BIFMA PD-1 Mechanical Test Definitions for related terms not included in this Guideline. Otherwise, the common dictionary definition shall be used for terms not defined in this section or in BIFMA PD-1. In case of a conflict between the definitions in this Guideline and PD-1, the definitions in this Guideline shall apply.

Abduct: To draw away from the middle axis of the body.

Accommodation: "*adjustment of the optics of an eye to keep an object in focus on the retina as its distance from the eye varies.*
NOTE: Accommodation can also be a process of adjusting the focal length of a lens." (ISO 9241-302, 3.5.1).

Acromion: The outer end of the spine of the scapula that forms the outer angle of the shoulder.

Armrests: ***"****Support for the lower arms"* (ISO 9241-5, 3.3). For the purpose of this Guideline, armrests are attached to the chair.

Armcaps: The top of an armrest.

Backrest: "*part of a work chair that provides support of the [user's] back*" (ISO 9241-5, 3.4). Also referred to in ISO 9241 as "*back rest*" or "*back support*".

BIFMA: Business and Institutional Furniture Manufacturer's Association, a not-for-profit trade association of furniture manufacturers and suppliers.

CGSB: Canadian General Standards Board, a Canadian government agency that produces voluntary standards in a wide range of subject areas through standards committees and the consensus process.

Clothing Allowance: A dimensional consideration added to ergonomic recommendations for material thicknesses of clothing.

CMD: Chair Measuring Device. A device used for the measurement of seating products.

Computer: For the purposes of this Guideline, a computer may include a central processor unit, display, and/or input devices. This includes the category of portable computers typically referred to as "laptop" or "notebook" computers with the display and input device integral to the same unit.

Computer Work Space: The portion of a workstation dedicated to computer use. Typically, these work spaces are comprised of seating, computer support surfaces, input device support surfaces, etc.

Convergence: Turning inward of the lines of sight toward each other as the object of fixation moves toward the observer.

CSA: Canadian Standards Association, also known as CSA International, a voluntary membership association engaged in standards development and certification activities.

Design Viewing Distance: **"***distance, or range of distances, between the screen and the operator's eyes for which the display is designed to be viewed*." (ISO 9241-302, 3.3.24).
Note: The distance or range of distances (specified by the screen supplier) between the screen and the operator's eyes for which the images on the display meet the requirements of this part of ISO 9241, such as character size, raster modulation, fill factor, spatial instability (jitter) and temporal instability (flicker).

Extracted Measurements: Measures taken by manipulating a 3D object in software and extracting XYZ coordinates to measure dimensions.

Frankfort Plane: **"***imaginary plane through the head established by the lateral extensions of a line between the triagion and the lowest point of the orbit…***.**
NOTE: *Alternatively, it is the horizontal plane at the level of the upper edge of the opening of the external ear opening and the lower border of the lower edge of the eye socket, when the median plane of the head is held vertically*." (ISO 9241-302, 3.3.29).

Gaze Angle: **"***angle from the Frankfort plane to the plane formed by the pupils and the visual target*." (ISO 9241-302, 3.3.31). Also referred to as "line-of-sight angle".

Head Tilt Angle: **"***angle from the Frankfort plane to the horizontal plane and due to tilt of the head…*
NOTE: When the head is erect, the head tilt angle is about 4°." (ISO 9241-302, 3.3.32).

HFES: Human Factors and Ergonomics Society, the principal association of ergonomists in the United States.

Input Device: *"User controlled device that transmits information to a system"* (ISO 9241-9). Input devices include items such as keyboards, computer mouse, trackballs, light pens, and touch screens.

Intensive: For the purposes of this Guideline, intensive use of a computer/computer workstation means that most or all of the day (more than 5 hours) is dedicated to computer work**.** Intensive computer use may include tasks such as CAD design, programming, word processing, graphic design, data entry and telemarketing.

ISO: International Organization for Standardization, a worldwide federation of national standards bodies.

Line-of-Sight: **"***line connecting the point of fixation and the centre of the pupil*

NOTE: The line-of-sight with two eyes is the line connecting the point of fixation and the midpoint between the two pupils." (ISO 9241-302, 3.3.36).

Line-of-Sight Angle: See gaze angle.

Lumbar: Lower region of the spinal column (the L1 – L5 vertebrae).

Monitor: Electronic visual display for computers (sometimes called "visual display unit"). A monitor may be a flat panel display or a Cathode Ray Tube (CRT). For the purposes of this Guideline, a monitor is not a television.

Movement Allowance: A dimensional consideration added to ergonomic recommendations for motion.

Neutral Postures: The positions of body elements (wrist, neck, head, etc.) that lead to the minimal amount of musculoskeletal tension. These positions may be referred to as "design reference postures".

Percentiles: Each of 100 equal groups into which a population can be divided according to the distribution of values of a particular body dimension. For example, the 20th percentile is the value below which 20% of the observations/population may be found.

Pose A: CAESAR standing pose where "the subject placed his or her feet on foot outlines positioned ten centimeters apart at the inside of the heel. The subject's heel was lined up with the back of the foot outline and the second toe lined up with the line drawn through the long axis of the foot on the foot outlines. The footprints were positioned on the scanner platform at a 30° angle…. The investigator instructed the subject to stand up straight and look straight ahead. The investigator then used a dowel (20 centimeters in length) to adjust the subject's arm position so the hands were 20 centimeters away from the lateral-most point of the hip/thigh area. For individuals with "hips," the dowel was placed at the widest protrusion of the hips (as viewed from the front). For individuals without a pronounced hip (more commonly males than females), the dowel was placed at the wrist. The arms and wrists were kept straight and the palms of the hands faced the body, with the fingers spread." (CAESAR Final Report, V1).

Pose B: CAESAR seated comfort working posture. "The goal of the seated comfortable working posture was to capture the natural, comfortable, seated working position. The subject sat on the modified stool and the investigator adjusted the seat to a height that provided a comfortable working position as indicated by the subject. The subject was allowed to sit anywhere on the seat; however, both feet had to be flat on the platform. The investigator asked the subject to sit up straight, look straight ahead, and place the hands on the thighs. Next, the investigator asked the subject to keep the hands on the thighs and relax the postural rigidity until the subject had assumed a comfortable working position. The hands were placed at mid-thigh to prevent the medial and lateral femoral epicondyles from being blocked by the hands and fingers in the scan. The investigator placed a small block, marked with a reference landmark, behind the subject on the flat seat surface (at the surface level), in contact with the center of the subject's buttocks." (CAESAR Final Report, V1).

Pose C: CAESAR seated coverage posture. "The seated coverage posture was designed to expose hard-to-see areas underneath the arms, between the thighs, and under the chin…. The subject placed his or her feet on foot outlines positioned on the scanner platform for this seated posture. The investigator instructed the subject to sit up straight and look straight ahead. The subject sat on a modified stool that had a flat surface and a pneumatic height adjustment. The investigator adjusted the seat to a height at which the knee angle was slightly greater than 90° with the calf almost perpendicular to the scanner platform. Keeping the feet on the foot outlines, the legs were spread slightly to allow coverage between the thighs. The subject held his or her hands over the head in the coronal plane and the subject's shoulders and elbows formed right angles. The subject closed his or her right hand around a one-inch diameter dowel and spread the fingers of the left hand. The left hand was in line with the arm, with the hand flat and palm facing forward (away from the body). The head was tilted backward slightly so that the chin/neck angle was greater than 90° to expose the shaded area under the chin. The investigator placed a butt block, marked with a reference landmark, behind the subject on the flat seat surface (at the surface level), in contact with the center of the subject's buttocks." (CAESAR Final Report, V1).

Seating Reference Point (SRP): Used to define the point where the CAESAR subject's buttocks were in contact with the butt block reference and the seat on which they were sitting. There are X-, Y-, and Z-axes for the seating reference point, referring to width (hip to hip), height (floor to leg), and depth directions (buttocks to knee).

Screen: The part of a monitor designed to display electronic information.

Support Surface: Surfaces typically provide support for displays and input devices. See also work surface.

Thoracic: Middle area of the spinal column (the T1 - T12 vertebrae).

Ultimate Test for Fit: The method for determining if a given parameter fits an individual user without requiring physical measurements.

Viewing Direction: "*direction from which the display is viewed as measured from the normal (perpendicular) using spherical-polar coordinates*." (ISO 9241-302, 3.3.44).

Viewing Distance: The distance between the screen and the viewer's eyes. (See also design viewing distance).

Workstation: A group of furniture items and components where a person performs work.

Work Chair: Another term for "Task Chair".

Work Surface: Surface on which equipment and task materials are used. (Defined in ISO 9241-5 as "*worksurface*").

6 General Considerations

6.1 Guideline Layout

The sections of this Guideline pertaining to the ergonomic recommendations are presented in the following format:

- Section Title
- ISO Related Quote and Reference*
- Relevant Body Dimension**
  - What is it and how is it measured/calculated***
  - Data Table (CAESAR data and applicable allowances)
- Why is Parameter "x" (for example, Seat Height) Important?
- Discussion
- Recommendation for Parameter (Dimensions/Ranges)
- Ultimate Test for Fit for the Individual User

* All ISO 9241 text quoted throughout this Guideline is *italicized* and in quotation marks.
** All CAESAR text quoted throughout this Guideline is in quotation marks only.
*** Calculated dimensions are those that utilized two different anthropometric measurements to derive the dimension.

6.2 Anthropometric Data Source

The CAESAR data was chosen for this Guideline because it is the most up-to-date and comprehensive civilian data available.

Data relating to body sizes of the user population are taken from the traditional and derived (scanned or extracted) measurements in the CAESAR database. Some dimensions used in this document were derived by adding and/or subtracting anthropometric dimensions within subjects. That procedure adds and/or subtracts anthropometric dimensions for each subject contained within the CAESAR database, and then calculates a mean for the new dimension. Percentiles are calculated using the means and standard deviations for the derived dimensions. The within subjects method produces more accurate dimensions than simply adding and/or subtracting percentile dimensions in the published summary CAESAR data tables.

All CAESAR data, quoted text and relevant body dimensions (measurements and diagrams) used throughout this Guideline, unless otherwise noted, are from the following sources:

Robinette, K. M., Blackwell, S., Hoeferlin, D., Fleming, S., Kelly, S., Burnsides, D., Boehmer, M., Brill, T., & Daanen, H. A. M. (2002). *Civilian American and European Surface Anthropometry Resource (CAESAR) Final Report Volume I: Summary* (Technical). Wright-Patterson AFB, Ohio: Human Effectiveness Directorate Crew Systems Interface Division.

Robinette, K. M., Blackwell, S., Hoeferlin, D., Fleming, S., Kelly, S., Burnsides, D., Boehmer, M., Brill, T., & Daanen, H. A. M. (2002). *Civilian American and European Surface Anthropometry Resource (CAESAR) Final Report Volume II: Demographic and Measurement Descriptions* (Technical). Wright-Patterson AFB Ohio: Human Effectiveness Directorate Crew System Interface Division.

Society of Automotive Engineers, SAE International, Warren, Pennsylvania, www.sae.org/caesar

The posture and measurement diagrams used throughout this document are to illustrate where anthropometric measurements were taken. They are not necessarily meant to represent preferred or recommended postures.

If another database is available, or has been developed for a particular population, the user of this Guideline is encouraged to apply such information.

6.3 Chair Measurement

The chair parameters provided in this Guideline are measured using the BIFMA Chair Measuring Device and the CMD-1-2013 *UNIVERSAL MEASUREMENT PROCEDURE FOR THE USE OF BIFMA CHAIR MEASURING DEVICE® (CMD)* (see Figure 1). The definitions used in the CMD-1-2013 procedure relating to product dimensions and adjustment ranges are applicable throughout this Guideline.

The CMD-1-2013 procedure defines measurement variability (uncertainty of measurement) for each chair measurement. This variability is based on many factors such as manufacturing/material variation, operator-to-operator measurement variation, timing of measurements, construction details such as textiles and support materials used, etc. Compliance evaluations by manufacturers and independent laboratories must apply these uncertainties to extend the acceptance range when determining whether a product meets the recommendations of the Guideline.

NOTE: The initial set-up position in the CMD procedure, especially for seat pan angle, will affect many of the measurements made with the BIFMA CMD. It is common for a chair to have a forward seat angle adjustment position of 2 or 3 degrees, while the "design" or "typical" seat pan angle may be 3 or 4 degrees rearward. In this case, the forward seat slope of 2 or 3 degrees would be the most horizontal position, and measurements would be taken with the chair from this set-up condition. However, many if not most of the anthropometric measurements used in determining ergonomic standards were not taken with subjects in a forward posture (forward seat slope), and measurements taken with a chair in such a position may not be appropriate for use in evaluation of a product against, and determining compliance to, this Guideline. It is acceptable to use other “design” or “typical” (rearward seat slope) conditions in the initial set-up as long as the alternate position is noted in any and all test reports and compliance claims/documents.

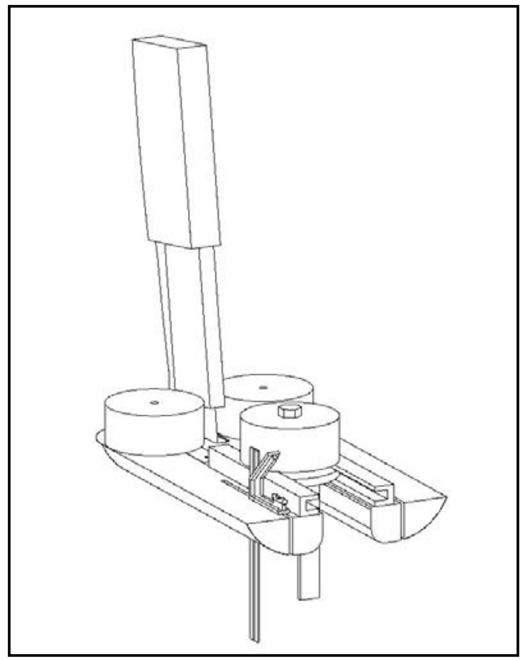

Figure 1 – CMD (BIFMA - Chair Measuring Device)

There are similar devices used to determine chair measurements. These devices may differ in terms of weight, dimensions, and measurement protocol, which may yield different results. The ISO Chair Measuring Device per ISO/TR 24496:2012 “Office furniture – Office work chairs – Methods for the determination of dimensions” has been determined to provide acceptable results and may be used to measure a chair according to this Guideline. Other devices should not be used to determine if a product meets the dimensional and adjustment ranges in this Guideline.

6.4 Measurement Tolerance

For chair measurements the uncertainties given in the appropriate CMD procedure shall be considered the tolerances.

For work surface(s) the tolerance, unless otherwise specified, shall be:

- Linear measurements, ±1.5 mm (1/16 in.).

6.5 Working Postures

Some typical working postures include:

- Rearward/Reclined
- Upright
- Forward Tilt
- Standing

All of these working postures are acceptable as long as the concept of fit is given proper consideration. ISO principles suggest that movement within and among these and other postures is encouraged.

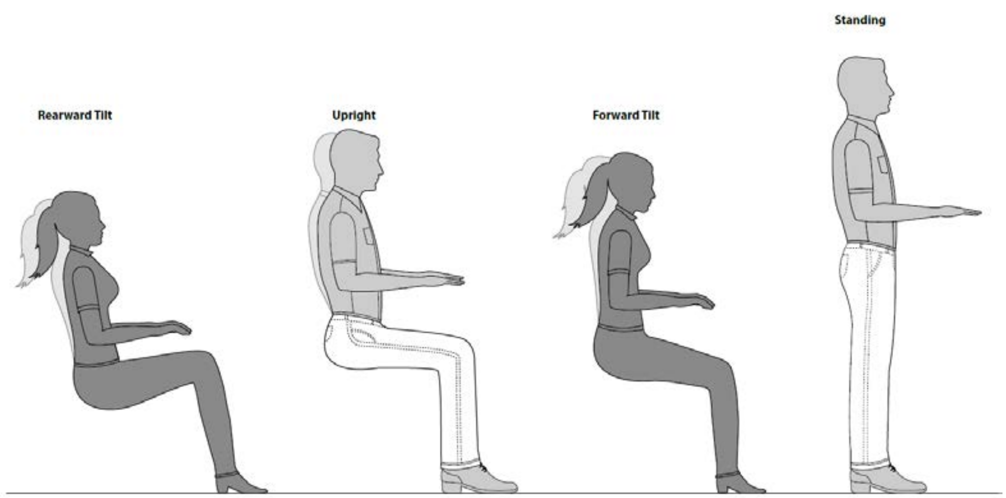

Figure 2 – Typical Working Postures

While the CAESAR body dimensions are generally taken from both seated upright and standing postures, there is no uniquely correct working posture that would fit any user for an extended period of time and/or accommodate every personal working habit. The dimensions given in this Guideline generally consider upright postures only. Other dimensions may be acceptable if other postures are assumed.

7 The Work Chair

Sitting Postures (ISO 9241-5, 5.2.2)

> *"The purpose of well-designed seating is to provide stable support which allows movement, comfort, and task accomplishment."*

General Considerations (ISO 9241-5, 5.5.1)

> *"The purpose of good seating is to provide stable body support in a dynamic posture which is comfortable over a period of time, physiologically satisfactory and appropriate to the task or activity which is to be performed."*

7.1 Seat

7.1.1 Seat Height

Seat Height (ISO 9241-5, 5.5.2.2)

> *"The appropriate seat height for a user for sitting in the upright position is the popliteal height plus the thickness of footwear. Work chairs designed to accommodate a specified user population shall achieve fit for the range suitable for the intended user population. This range can be covered by applying the concept of fit."*
>
> *"Within a selected range of adjustability, the seat height shall be user adjustable."*

Relevant Body Dimension:

Popliteal Height, [CAESAR Pose C (Popliteal)[1]]

What is Popliteal Height and How is it Measured?

> "The Popliteal Height is the distance from the back of the knee (popliteal landmark) to the floor. The popliteal landmark was identified in the Sitting Coverage Pose (Pose C) as the most anterior, most superior point behind the knee, as viewed from the side. For the measurements for Pose C, the seat was positioned to cause the tops of the thighs to slant slightly downward to improve coverage of the upper thighs."

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[1] See Table A1 for additional information as to the origin of the measurement; some measurements were taken using "traditional" methodologies (such as calipers) others were extracted from body scans in the CAESAR database. Those measurements that were extracted are noted accordingly in Table A1.

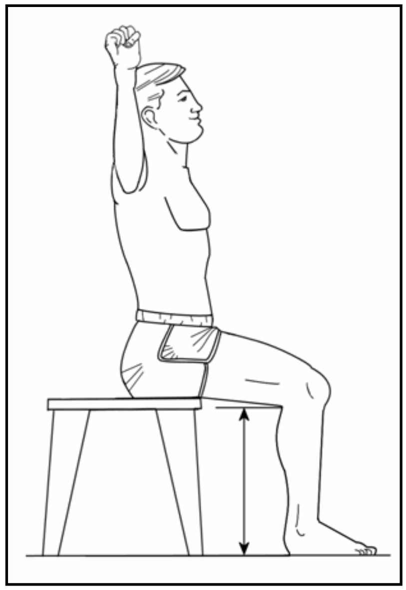

Figure 3 – Popliteal Height

Data Table (CAESAR Data and Applicable Allowances):

Table 1 Seat Height

	Female		Male	
	mm	inches	mm	inches
5th Percentile Popliteal Height	346	13.6	392	15.4
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Seat Height	376	14.8	422	16.6
95th Percentile Popliteal Height	430	16.9	482	19.0
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Seat Height	460	18.1	512	20.2

*No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

Why is Seat Height Important?

Proper seat height ensures the comfort of the lower limbs by distributing pressure on the underside of the thighs and helping to maintain proper torso-to-thigh angle. Seat height is also important in proper positioning of the upper body in relation to the work surface.

Discussion

If a seat pan is too high it can lead to increased pressure on the underside of the thighs; seat pans that are too low may lead to decreased torso-to-thigh angle and increased pressure under the sitting bones (ischial tuberosities). Either of these conditions can lead to compression of blood vessels causing decreased blood flow and discomfort.

Proper positioning of the upper body leads to correct hand position relative to the work surface and, given that it dictates sitting eye height, is a critical factor in determining the line-of-sight.

Table 1 indicates that an adjustment range of 376 mm (14.8 in.) to 512 mm (20.2 in.) [travel of 136 mm (5.4 in.)] accommodates the 5th percentile female to the 95th percentile male popliteal height.

Mechanical restrictions in the design of height adjustment mechanisms often make the 136 mm (5.4 in.) range difficult to achieve. When attempting to fit a large group of users, it may be necessary to consider multiple chairs (or height adjustment mechanisms), thereby providing more than one range of height adjustability.

- For example: One chair with a 76 mm (3.0 in.) seat height adjustment range from 376 mm (14.8 in.) to 452 mm (17.8 in.) accommodates the 5th through the 91st percentile female and up to the 28th percentile male popliteal heights.

- A second chair (or cylinder) with a range of 102 mm (4.0 in.) from 410 mm (16.2 in.) to 512 mm (20.2 in.) accommodates the 20th percentile through the 100th percentile female popliteal height and from the 2nd percentile through the 95th male popliteal height.

- When combined, these two chair height adjustment ranges accommodate the 5th percentile female popliteal height to the 95th percentile male popliteal height.

The range of seat height adjustment needs to cater to the intended user population. Allowances should be made for footwear and variations in sitting postures. "*A footrest is necessary in cases where the work chair height is to be set in a position which does not allow a computer user's feet to rest flat on the floor.*" (ISO 9241-5, 5.6.2) The use of a footrest may restrict postural changes.

For workstations with fixed standing height work surfaces, a stool may be used to allow the user to occasionally sit to relieve pressure on the legs and feet and promote postural changes. The user should be able to support their feet with a footrest/footring, and the seat height of the stool should allow the user to attain neutral postures and adequate back support (see Section 8.1 Clearances Under Work Surfaces). Special consideration should be given to foot support; footrests should not restrict the user's foot placement in a manner that requires them to maintain a knee angle (thigh to lower leg angle) of less than 90 degrees. Footrest/footrings that adjust in height accommodate a larger range of users. Some stools, especially those that do not tilt or recline, may inhibit postural changes.

For sit-to-stand worksurfaces, stools are not recommended as they may restrict the user's movement. Sit-to-stand surfaces encourage postural changes by allowing the user to occasionally stand as an alternate posture. Such workstations should not contain stools, which may encourage users to sit at the surface in the standing position; doing so may inhibit postural changes.

Recommendation for Seat Height

A chair, or chair with a combination of height adjustment mechanisms, should have a minimum seat height range from 376 mm (14.8 in.) to 512 mm (20.2 in.).

Ultimate Test for Fit for the Individual User

Users should be able to sit with their feet comfortably on the floor or footrest without undue pressure on the underside of the thighs. The torso-to-thigh angle should not be less than 90°.

7.1.2 Seat Depth

Seat Depth (ISO 9241-5, 5.5.2.3)

"The fit for seat depth is achieved if the depth is less than the buttock-popliteal length of the user. Work chairs designed to accommodate a specified user population can achieve fit by either adjustability or by using different sizes of the seat pan for the range suitable for the intended user population."

"Adjustable seat depth can be achieved either by adjusting the back rest in relation to the seat or by moving the seat pan in relation to the back rest. If the seat depth is fixed, priority should be given to proper back support since proper back support is more important than the support of the whole length of the thighs."

Relevant Body Dimension:

Buttock-Popliteal Length [CAESAR Popliteal Fossa Pose C - SRP Z Pose C (Extracted)]

What is Buttock-Popliteal Length and How is it Calculated?

Buttock-Popliteal Length is the horizontal distance between the Seating Reference Point Z (most rearward position of the buttocks) and the Popliteal Fossa landmark placed on the back of the knee. It is calculated from extracted Pose C measurements of the whole-body scan in the Z-direction.

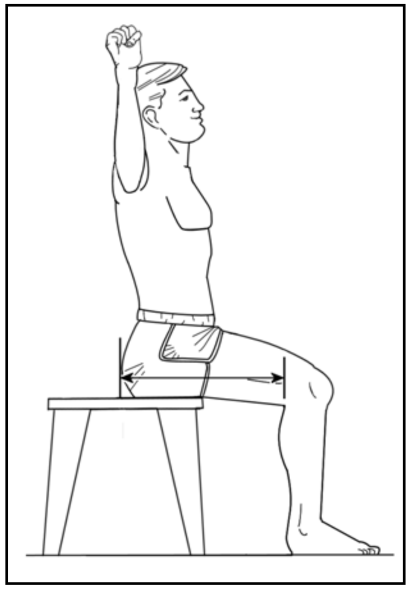

Figure 4 – Buttock-Popliteal Length

Data Table (CAESAR Data and Applicable Allowances):

Table 2 Seat Depth

	Female		Male	
	mm	inches	mm	inches
5th Percentile Buttock-Popliteal Length	425	16.7	438	17.2
Minus Clearance Allowance*	-10	-0.4	-10	-0.4
Resulting Seat Depth	415	16.3	428	16.8
95th Percentile Buttock-Popliteal Length	526	20.7	542	21.3
Minus Clearance Allowance*	-10	-0.4	-10	-0.4
Resulting Seat Depth	516	20.3	532	20.9

* No ISO guidance for a clearance allowance is available; therefore an industry practice of 10 mm (0.4 in.) is recommended.

Why is Seat Depth Important?

Adequate seat depth supports the thighs and allows the user to sit back far enough to use the lower portion of the backrest without creating pressure on the back of the knees.

Discussion

Table 2 indicates that after applying a clearance allowance of 10 mm (0.4 in.) to prevent the back of the knees from contacting the seat, a seat no deeper than 415 mm (16.3 in.) will fit the 5th percentile female and all users with a longer buttock-popliteal length. While a depth of 415 mm (16.3 in.) will provide full thigh support for smaller users while allowing them to properly use the back support, users with long thighs may prefer a deeper seat. It is important to note that if the seat is deeper than 415 mm (16.3 in.), only users with longer thighs will be able to properly utilize the back support. One should keep in mind that *"back support is more important than the support of the whole length of the thighs" (ISO 5.5.2.3).* A seat cushion with a waterfall or declining front edge may reduce contact/pressure at the back of the knees.

Recommendation for Seat Depth

For chairs with fixed seat depth, the depth should not be deeper than 415 mm (16.3 in.) to accommodate the 5th percentile female buttock-popliteal length.

For chairs with adjustable seat depth, the adjustment range should include a seat depth of 415 mm (16.3 in.) or less.

Ultimate Test for Fit for the Individual User

Users should be able to sit in the chair without undue pressure at the back of the knees, their back properly supported by the backrest and with adequate buttock and thigh support.

7.1.3 Seat Width

Seat Width (ISO 9241-5, 5.5.2.4)

"For seat width, fit is achieved when the seat width is wider than the width of the hips."

Relevant Body Dimension:

Hip Breadth, Sitting

What is Hip Breadth, Sitting and How is it Measured?

Hip breath, sitting, is the “breadth of the body measured across the widest portion of the hips”. “Subject sits erect on a flat surface, looking straight ahead. Knees are bent at right angles and the feet are supported. Thighs, knees, and feet are kept together (touching). Knees are bent 90º. Measurement is taken without pressing into the flesh of the hips.”

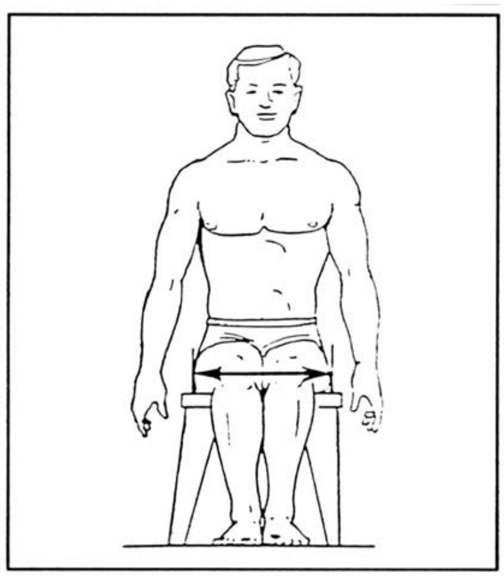

Figure 5 – Hip Breadth, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 3 Hip Breadth, Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Hip Breadth, Sitting	352	13.9	333	13.1
90th Percentile Hip Breadth, Sitting	489	19.2	431	17.0
95th Percentile Hip Breadth, Sitting	517	20.4	447	17.6

Why is Seat Width Important?

Adequate seat width allows users to maintain comfortable pressure distribution across the seat and adjust their posture.

Discussion

Ergonomic guidelines/standards for office chairs typically use the 95th percentile of female, seated hip breadth as a target for chair seat surface breadth, under the assumption that a sitter requires a seat as wide as his or her hips. Female hip breadth is traditionally used since it is wider than the male hip breadth. However, the standard hip breadth measure is taken at the widest point on the hips, which is often wider than the sitter's buttocks at the seat contact. Typically, hip breadth is taken from direct measurements, however, other techniques such as pressure mapping or derivation from 3-D scanned data can give approximations of true contact area. While large-scale studies are not available, preliminary investigations from scanned data suggest the contact area on a flat surface may be at least 25 mm (1.0 in.) less than seated hip breadth. (Therefore in the recommendation the 90^{th} percentile female, seated hip breadth is used to account for the 25 mm (1.0 in.) difference).

Seat shape and contour also play an important role in user comfort. The CMD measurement for seat width is taken based on the minimum seat width within a prescribed zone. Extreme seat shapes may give measures that suggest seat widths that are larger or smaller than the apparent (user perceived) width. Similarly, the seat width dimension is not affected by the seat contour (or seating surface – foam, mesh, gel, etc.), yet such contours/surfaces will have a significant effect on the user's comfort.

In the previous BIFMA G1-2002 Guideline, the seat width dimension included a 25.4 mm (1.0 in) allowance for clothing, resulting in dimensions of 457 mm (18.0 in.) that accommodated up to the 95^{th} percentile female and the 99^{th} percentile male. In this current Guideline, a clothing allowance was not added to the Hip Breadth, Sitting dimension because it is not necessary for the clothing to be supported by the seat cushion. Based on the CAESAR data, seat widths of 457 mm (18.0 in.) that met BIFMA G1-2002 will now only accommodate up to the 75^{th} percentile female and 97^{th} percentile male hip breadths.

Seat surfaces that are wide enough to accommodate the 90^{th} percentile hip breadth may not adequately accommodate smaller users and/or result in inadequate arm support.

Conversely, seat surfaces that accommodate a smaller percentile of the population may cause undue pressure to the hips/thighs, which can restrict blood flow and cause discomfort for larger users.

Seat width will often affect the armrest position. Depending on the seat width, this can impact ingress/egress (for larger users) or arm support (for smaller users). See armrest section 7.4.

Recommendation for Seat Width

The seat width should be at least 489 mm (19.2 in.). This seat width will accommodate at least* the 90th percentile female hip breadth and the 97th percentile male hip breadth.

If a larger seat width is provided, the percentile of users supported should be stated.

For example, a seat width of 517 mm (20.4 in.) will accommodate at least* the 95th percentile female hip breadth and greater than the 99th percentile male hip breadth.

To determine the percentile of users supported by a given seat width, see Appendix B for the hip breath, sitting dimensions.

*Reference Discussion regarding hip breadth width versus seat contact area.

Ultimate Test for Fit for the Individual User

The seat should be wide enough to accommodate the seated contact area of the user. The seat width should not limit the ability to comfortably use the armrests (see Section 7.4.3 Inside Distance Between Armrests).

7.1.4 Seat Pan Angle

Seat Angle (ISO 9241-5, 5.5.3.2)

“The seat angle should allow users to vary their posture forward and backward.”

“Seats may be designed with a fixed or adjustable seat angle. Adjustable seat pans may incorporate a forward as well as a rearward tilt.”

Relevant Body Dimension:

Not applicable

CAESAR Supporting Information:

None available

Why is Seat Pan Angle Important?

Appropriate seat pan angles provide the user with adequate support in various seated working postures.

Discussion

Increasing the torso-to-thigh angles to greater than 90 degrees has been shown to promote healthy curvature in the lumbar area of the spine. Adjustable seat pan angles, when used properly, may promote movement from one posture to another.

Inappropriate seat pan angles may result in the user assuming non-neutral postures (e.g., less than 90 degrees at the hips) when performing their tasks. Excessive forward seat pan angle may cause users to slide out of the seat, or shift too much weight to their feet resulting in prolonged static loading of leg muscles. Excessive rearward angle, if accompanied by an upright backrest, will compromise the lumbar curvature and will lead to torso-to-thigh angles of less than 90 degrees, which may lead to discomfort.

Rearward seat pan angle, if accompanied by an excessive rise in its front edge of the seat, may not allow users to keep their feet firmly on the floor or footrest. This may result in compression under the thighs, decreased blood flow and discomfort.

Research does not agree on the exact limits of either forward or rearward seat pan angles, or the appropriate amount of adjustment. The recommendation, therefore, is based on industry practice.

Recommendation for Seat Pan Angle

Industry practice suggests that the seat pan angle, if fixed, should fall within a range from 0° (horizontal) to 4° rearward.

If adjustable rearward, forward or both, the seat pan angle adjustment should include some part of the range between 0° (horizontal) to 4° rearward.

Ultimate Test for Fit for the Individual User

The angle of the seat pan should allow the user to support their feet on the floor or footrest. Seat pan angles should not cause the user's torso-to-thigh angle to be less than 90°. Forward seat pan angles should not cause users to shift excessive weight to their feet or experience the sensation of sliding out of the chair.

7.2 Backrest

Back Support (ISO 9241-5, 5.5.4)

"The back rest should be capable of providing support to the back of the user in all sitting positions. Back rests can be designed to give support for different parts of the back."

7.2.1 Backrest Height

Back Support (ISO 9241-5, 5.5.4)

"For some types of work where reclining posture is essential, higher back rests which also provide support for the shoulder blades are recommended."

Relevant Body Dimension:

Tenth Rib Midspine, Sitting and Acromial Height, Sitting

What is Tenth Rib Midspine, Sitting and How is it Measured?

Tenth Rib Midspine, Sitting is the "level of the right tenth rib (landmark), marked on the spine" from the seated surface. "The anthropometer is used to mark the height of the landmark at midspine (on the spine in the midsagittal plane)."

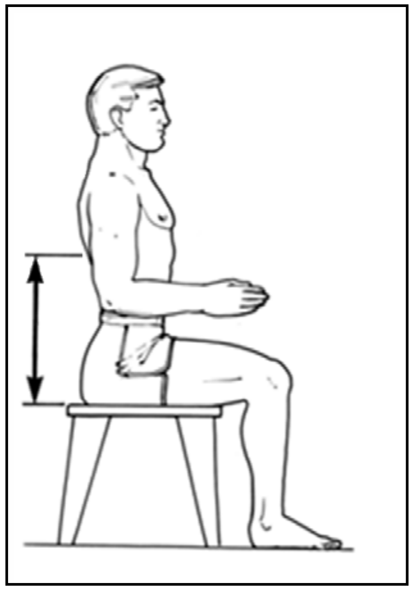

Figure 6 – Tenth Rib Midspine, Sitting

What is Acromial Height, Sitting and How is it Measured?

The Acromion is the top of the shoulder. The Acromial Height, Sitting is the "vertical distance from a horizontal sitting surface to acromion."

"Subject sits erect on a flat surface, looking straight ahead. Knees are bent at right angles and the feet are supported. Thighs are parallel to each other, the feet are in line with the thighs, and the knees are bent 90º. Upper arms hang freely downwards and forearms are horizontal."

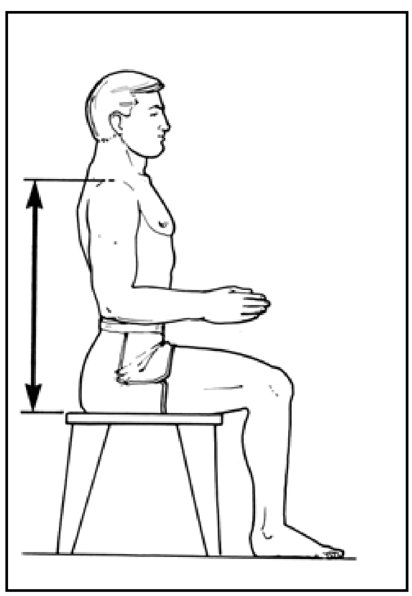

Figure 7 – Acromial Height, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 4 Tenth Rib Midspine, Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Tenth Rib Midspine, Sitting	244	9.6	250	9.8
95th Percentile Tenth Rib Midspine, Sitting	354	13.9	346	13.6

CAESAR Supporting Information:

Table 5 Acromial Height, Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Acromial Height, Sitting	515	20.3	537	21.1
95th Percentile Acromial Height, Sitting	613	24.1	651	25.6

Why is Backrest Height Important?

A proper backrest height allows both adequate support for the back in various postures and an acceptable curvature in the spine, thereby minimizing musculoskeletal loading and reducing the likelihood of back pain. Higher backrests help support the upper back in reclined postures.

Discussion

Many variables affect the proper height of the backrest including task type, tilt/recline angle, flexibility and contour of the backrest. Backrests should provide adequate back/lumbar support and accommodate the protuberances of the buttocks. Backrest height and shape may affect arm and shoulder movement. Higher backrests are desirable for chairs that recline. Higher backrests should be slightly concave in the area immediately above the lumbar region.

No research has shown sufficient evidence to support a recommendation for minimum backrest height, but it should at least support the lumbar region. Because of several variables that make it hard to repeat lumbar height measurements, lumbar height anthropometric values are not found in anthropometric databases. CAESAR has a measurement for the Tenth Rib Midspine, which is near or above the upper lumbar region. The recommendation, therefore, is to use this value for a minimum backrest height. Table 4 may be used to specify this minimum height that will support the lower back region.

Higher backrests are common and generally preferred for chairs that recline in order to support the thoracic area. In the absence of research to support a specific landmark for thoracic support, acromial height is used. The dimensions provided in Table 5 may be used to determine the height of a backrest that also supports the thoracic area (upper back and shoulders).

Recommendation for Backrest Height

The minimum backrest height should be 354 mm (13.9 in.).

Ultimate Test for Fit for the Individual User

The Ultimate Test for Fit is highly posture-dependent. The lower back (lumbar area) should be supported. For tasks requiring upper body mobility the backrest should provide adequate back support but not interfere with the user's movement. For users who prefer reclining postures, the back height should provide support for the upper back and shoulders.

7.2.2 Backrest Width

Back Support (ISO 9241-5, 5.5.4)

"The back rest should be capable of providing support to the back of the user in all sitting positions."

Relevant Body Dimension:

Bi-Cristale Breadth

What is Bi-Cristale Breadth and How is it Measured?

The scan extracted point-to-point distance from left iliocristale to right iliocristale landmarks. The data was collected using a whole-body scanner.

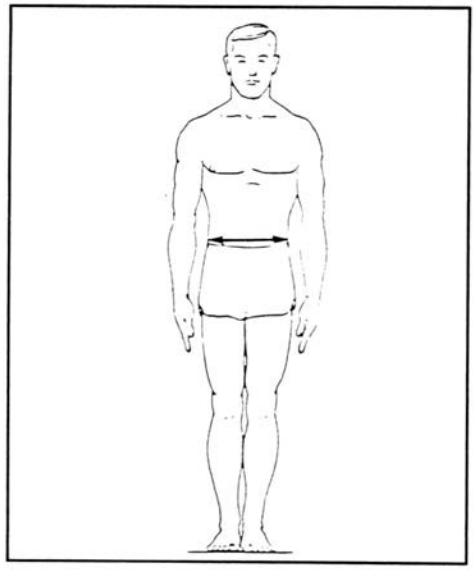

Figure 8 – Bi-Cristale Breadth, Standing

Data Table (CAESAR Data and Applicable Allowances):

Table 6 Bi-Cristale Breadth, Standing

	Female		Male	
	mm	inches	mm	inches
5th Percentile Bi-Cristale Breadth	271	10.7	288	11.3
95th Percentile Bi-Cristale Breadth	404	15.9	424	16.7

Why is Backrest Width Important?

Adequate backrest width provides proper support for the back in a variety of postures.

Discussion

The backrest should be wide enough to support the back in the lumbar region. In the absence of an anthropometric measurement representative of the lumbar width, the CAESAR bi-cristale breadth, standing, is an acceptable indicator of this dimension when in the seated position. The CMD defines the backrest width as the minimum width within the lumbar support zone. There is no research that clearly shows how much width of the lower back must be supported to provide comfortable support in the lumbar area.

While there are several anthropometric measures that provide guidance regarding backrest width in the thoracic region, there is no clear evidence regarding the appropriate amount of support required. Narrower backrests allow greater movement of the upper body but may not provide adequate support for the shoulder blades, especially when reclining. Wider backrests provide support for the shoulder blades, but depending on their torsional flexibility, may limit the overall movement of the upper body. No specific recommendation is made for backrest width above or below the lumbar region.

Recommendation for Backrest Width in Lumbar Region

In the absence of an anthropometric measurement representative of the lumbar width, previous NATICK data, and industry practice is that minimum width of the backrest in the lumbar region should be at least 360 mm (14.2 in.).

Due to the complexity and interdependency of the many variables for backrest width above or within the lumbar region, the Ultimate Test for Fit is the most important criteria for acceptability.

Ultimate Test for Fit for the Individual User

The backrest should be wide enough to provide adequate support for the users back without causing localized pressure points.

7.2.3 Lumbar Support

Back Support (ISO 9241-5, 5.5.4)

"Back rests should be designed to give support particularly for the lumbar region of the body."

"[Back rests should] have a maximum prominence in the mid-lumbar region (to aid lordosis and to prevent kyphosis)…"

Relevant Body Dimension:

Not applicable

CAESAR Supporting Information:

None available.

Why is Lumbar Support Important?

Adequate lumbar support helps maintain the natural curvature of the spine at the small of the back, encourages postures that evenly distribute pressure within the intervertebral discs and minimizes back strain.

Discussion

The preferred lumbar height and a protrusion will vary depending on the individual's anthropometry, posture and personal preference. Lumbar support areas that are too prominent or inappropriate in either size or location may encourage undesirable postures or localized pressure points. Adequate lumbar support is highly dependent on the shape, location and firmness of the support material.

Research does not support any specific lumbar depth (protrusion); therefore, no depth recommendation is given.

Gender, age, and the trend towards obesity, all affect the characteristics of the lumbar support a user prefers. Females tend to have more pronounced lordosis (lumbar curvature) than males, which suggest they may need additional lumbar depth adjustment. Lordosis tends to decrease as workers age, suggesting older users are more sensitive to lumbar placement and, therefore, are more likely to make adjustments to lumbar position.

A combination of a reclined backrest and appropriate lumbar support shape (one that mimics the person's lumbar curvature) enhances comfort and reduces potential compression on the spine.

There is inconsistency in the anthropometric landmark used to measure lumbar height. In some cases, lumbar height is based on a specific boney feature of a chosen lumbar vertebra; in other cases lumbar height is based on the point of maximum curvature in the lumbar area. Furthermore, lumbar height is difficult to measure because 1) palpation of the lumbar vertebral discs and/or spinous processes can be difficult and painful and 2) height to maximum lumbar curvature is highly dependent on seated posture and seat/seat cushion characteristics making standardization difficult and application theoretical.

Research has shown a relationship between a user's BMI and preferred lumbar height; those with greater BMI's prefer a higher lumbar support. The increasing girth in the mid-torso area evidenced by the increasing user weight in the CEASAR data may affect the lumbar support area. Increased prominence of soft tissues on the torso of obese individuals may affect the preferred height and protrusion of the lumbar support.

Studies indicate a wide range of user preferred lumbar height. The recommendation for lumbar height is based on industry practice, and falls within the range of user preferences. Because no widely accepted research is available for lumbar depth or its adjustment no recommendation is given.

With the increase in an obese North American population, the lumbar height maximum may be higher than industry practice has suggested. The increase in adipose tissue under the buttocks and thighs raises the user's seat height and shifts the lumbar range higher than if the individual were not obese. As stated previously, at the time of publication, there was no database available that measured lumbar height and range in a consistent and repeatable manner.

Recommendation for Lumbar Support

The height of the most forward point of the lumbar support based on industry practice should be within the range of 150 mm to 250 mm (5.9 in. to 9.8 in.).

If adjustable, the height of the lumbar support should include at least part of the recommended range given above.

The lumbar support should follow the shape of the spine, however, due to the wide variety of shapes, and the inconsistencies and difficulty in measuring this characteristic, the Ultimate Test for Fit is the most important criteria for acceptability.

Ultimate Test for Fit for the Individual User

The height and shape of the chair's lumbar support area should support the user's lower back. The support should not cause localized pressure points.

7.3 Movements of the Seat Pan and Backrest

Relevant Design Parameter (ISO 9241-5, 5.5.3.1)

"Together with job content and the design of other furniture elements, seating design plays an important role in encouraging movement. Thus, seat design should allow frequent posture adjustments by the user."

Movements of the Seat Pan and Back Support (ISO 9241-5, 5.5.3.3)

"The movements of the seat pan and the back support should allow users to vary their posture to suit user comfort and changes to task requirements. The movements of the seat pan and the back rest can occur independently from each other with one of the two elements fixed, or the angle can open up by simultaneous movement of the seat pan and the back rest in a preset ratio greater than one.

The design should take into account that users should be able to set and change positions at any time."

Relevant Body Dimension:

Not applicable

CAESAR Supporting Information:

None available

Why is Movement of the Seat Pan and Back Support Important?

Movements of the seat pan and back support allow users to vary their posture for comfort and to accommodate changes in task requirements. Postural changes promote fluid movement within the spine and circulatory system, which aids in nourishment of the vertebral discs and the user's extremities. Appropriate seat-to-back angles also reduce spinal compression and muscle activity in the back.

Discussion

Neither ISO nor CAESAR provides measurable seat-to-back angle principles. To best allow for changes in postures this angle should be variable.

The backrest should achieve a position at or rearward of vertical. (See Section 7.1.4 for Seat pan angle considerations). Seat pan movement should not inhibit lower leg and ankle movement or force the user's feet to remain off the floor or footrest. The back support should stay in contact with the user's back, especially in the lumbar area, as it reclines.

Disc pressure and muscle activity in the lumbar region decreases as the user reclines, resulting in improved lumbar curvature and comfort.

Research suggests the seat-to-back angle should be from 90° to 135° for upright or reclined postures. Users in forward-tilt postures may prefer other seat-to-back angles. The seat-to-back angle should not cause the user to adopt a torso-to-thigh angle of less than 90°.

For chairs that allow movement of the back relative to the seat (movement of the seat-to-back angle), a range of motion of up to 30° between 90°and 120° will reduce spinal compression, decrease muscle tension and increase comfort.

Recommendation for Movements of the Seat Pan and Back Support

If fixed, the angle between the seat and back should allow the user to achieve a torso-to-thigh angle of at least 90°. If adjustable, industry practice suggests that the backrest should have an adjustment range of 15° or greater, of which at least 15° should fall within the range of 90° (vertical) to 120°.

Ultimate Test for Fit for the Individual User

The chair should allow the user to sit in a position where the torso-to-thigh angle is equal to or greater than 90°. The back support should stay in contact with the user's back, especially in the lumbar area, as it reclines. The seat and backrest angles should adjust to accommodate the varying postures assumed by the user throughout the day.

7.4 Armrests

Arm Support (ISO 9241-5, 5.5.5)

"…Armrests can support the muscular system of neck and shoulders and can be an aid to standing up and sitting down. For armrests with height and width adjustability, the range should cover the range from 5th percentile female to 95th percentile male of the intended user population."

"Armrests should not restrict the VDT user's preferred working posture. If armrests obstruct the user, they should be adjustable, or detachable, so that they do not interfere with task performance… ."

Proper support of the arms while maintaining proximity to the work surface is affected by a number of chair dimensions and adjustments, including seat width, distance between armrests, armrest width, length, and height, and dimensions and movement of the armcaps. It is important to consider these factors because armrest geometry and position should accommodate various user postures and body dimensions. Although armrests are typically part of the chair, alternate methods may provide adequate support.

7.4.1 Armrest Height

Armrest Height (ISO 9241-5, A2.5[2])

"This dimension is defined best (though not absolutely correctly) by the height of the elbow above the seat and is described technically as ELBOW HEIGHT, sitting."

"The armrest height is related to the operator's elbow position, thickness of work surface top in conjunction with thigh height, and armrest separation. The armrest height interacts with the width of the seat and the separation of the armrest because a small user will have to raise the upper arm to the side to reach the armrest, or lean over to one side. This complex relationship needs more detail to be resolved than can be provided by simple linear anthropometric data."

[2] Quotations with an "A" in the section number are derived from ISO 9241-5 "*Annex A (informative) Anthropometric data needed for workstation design and selection".*

Relevant Body Dimension:

Elbow Height, Sitting

What is Elbow Height, Sitting and How is it Measured?

Elbow Height, Sitting is the "vertical distance from a horizontal sitting surface to the lowest bony point of the elbow bent at a right angle with the forearm horizontal". It is measured by having the subject sit "erect on a flat surface, looking straight ahead. Knees are bent at right angles and feet are supported. Thighs are parallel to each other, feet are in line with the thighs, and knees are bent 90º. Upper arms hang freely downwards and forearms are horizontal".

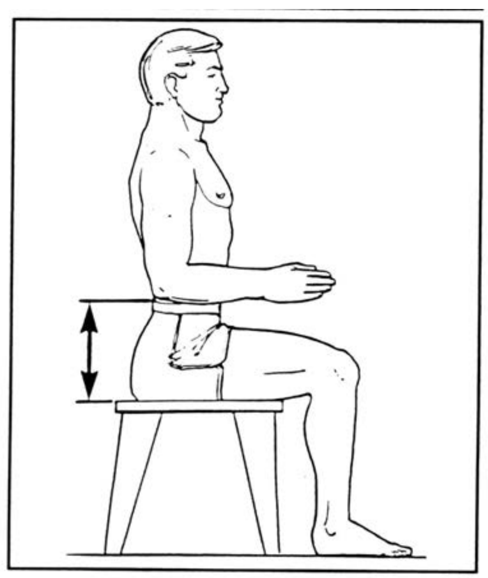

Figure 9 – Elbow Height, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 7 Elbow Height, Sitting

	Female		Male	
	mm	inches	mm	inches
5^{th} Percentile Elbow Height, Sitting	195	7.7	196	7.7
95^{th} Percentile Elbow Height, Sitting	281	11.1	289	11.4

Why is Armrest Height Important?

Proper armrest height supports the muscular system of the neck and shoulders.

Discussion

The height of the armrest should not cause the user to lift and/or abduct their shoulders or hold their arms significantly forward from the body.

Notwithstanding the complexity of this measurement as noted in the ISO 9241 reference, the recommendation given below uses only the Elbow Height dimension as the primary factor in armrest height determination.

Given the CAESAR data, armrest height should be adjustable from 195 mm (7.7 in.) to 289 mm (11.4 in.) to accommodate the 5th percentile female to 95th percentile male elbow heights.

It is common industry practice to utilize armrests that cover smaller adjustment ranges of approximately 200 mm (7.9 in.) to 250 mm (9.8 in.). This range accommodates the 10^{th} to the 70^{th} percentile female elbow heights and the 10^{th} to the 65^{th} percentile male elbow heights.

Fixed height armrests are not recommended for computer-intensive tasks.

Recommendation for Armrest Height

For adjustable height armrests, the height should adjust to include the range of 195 mm to 289 mm (7.7 in. to 11.4 in.). This may be accomplished either through a single set of armrests covering the recommended adjustment range, or multiple sets of armrests each covering a portion of the recommended adjustment range.

Ultimate Test for Fit for the Individual User

The height of the armrest should allow users to sit in a variety of postures while supporting their forearms and/or elbows in a manner that avoids lifting the shoulders (armrests too high) or leaning to the side/dropping the shoulders to reach the armrest (armrests too low). The armrest height should allow the performance of tasks.

7.4.2 Armrest Length and Position

Armrest Length (ISO 9241-5, A2.6)

"This dimension is important in maintaining the ability of the user to get as close as possible to the work surface while maintaining the effective use of the back rest."

"The armrest length determines how close to the work surface the seat back rest can be for a small seated user. In designing armrests, their maximum length if they are higher above the seat than the thigh thickness of the small user (and therefore will not go into the kneehole), is determined by the body thickness of the small operator. If the armrest is too long, the small user is unable to sit close to the work surface and gain support from the back rest of the seat."

Relevant Body Dimension:

Abdominal Extension Depth

What is Abdominal Extension Depth and How is it Calculated?

Abdominal Extension Depth is the calculated horizontal distance between the Anterior Abdomen Z, Sitting landmark (forward-most point of the abdomen) and the Posterior Abdomen Z, Sitting landmark (landmark on the back of the individual) with the subject seated in the Coverage Pose C.

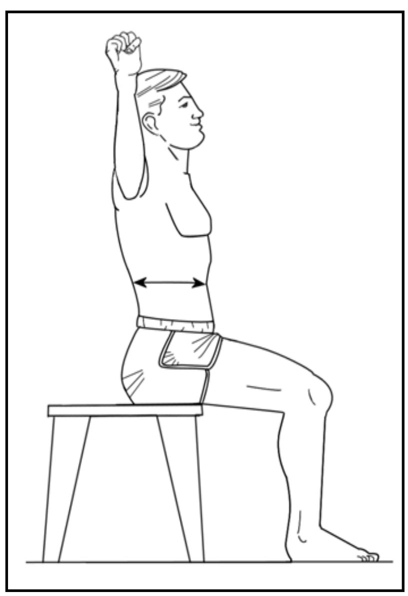

Figure 10 – Abdominal Extension Depth

Data Table (CAESAR Data and Applicable Allowances):

Table 8 Abdominal Extension Depth

	Female		Male	
	mm	inches	mm	inches
5th Percentile Abdominal Extension Depth	208	8.2	228	9.0
95th Percentile Abdominal Extension Depth	418	16.5	406	16.0

Why is Armrest Length and Position Important?

Armrest length and position is important to provide a distributed interface for the user's forearm when resting or working in a task chair. According to ISO, the armrest length is the distance from the front of the backrest to the most forward point on the armrest. The length and position (ability to pivot and/or fore-aft movement) of the armrest is important because it affects the user's proximity to the work surface, the ability to properly support the user's forearm, and to properly utilize the backrest for support.

Discussion

Abdominal Extension Depth (torso thickness) can be used to estimate the relative length and position of a chair armrest. This dimension alone suggests that the position of the front of the armrest relative to the front of the backrest should be no less than 208 mm (8.2 in.). However, other anatomical variations, such as the shape and curvature of the users back will also influence the length and position of the armrest.

In general, armrests that are too long will interfere with the smaller user's ability to get close to the work surface, inhibit wrist movement and affect the median nerve. Armrests that are too long may also cause interference with the larger user's elbow, potentially affecting the ulnar nerve.

Additionally, the height and depth of work surface/input device support may impact the distance that the user will sit from the work surface. These variations may require the armrest position to be adjustable to properly accommodate users.

It may not be necessary that the user's entire forearm be supported by the armrest, but the armrest should provide even pressure distribution over the contact area.

Recommendation for Armrest Length and Position

No specific recommendation for armrest length or position is made.

Ultimate Test for Fit for the Individual User

The length and position of the armrest should allow users to properly support their forearms while sitting close enough to the work surface to perform their tasks and maintaining contact with the backrest. The position of the armrests should provide adequate support for the forearm without affecting wrist movement or causing excessive pressure on the elbow.

7.4.3 Inside Distance Between Armrests (Pads/Caps) -- Sitting

Inside Distance Between Armrests (ISO 9241-5, A2.7)

"It is relevant in ensuring that the armrest does offer a comfortable resting position for the arms without being too cramped. It is also important in ensuring that the hips clear the armrests when getting into and out of the work chair. Bearing in mind these two factors, the choice should always be towards the maximum dimension. As mentioned in A.2.5, this dimension should always be considered in conjunction with armrest height, as the two interact significantly."

Relevant Body Dimension:

Hip Breadth, Sitting

What is Hip Breadth, Sitting and How is it Measured?

Hip breadth, sitting is the breadth of the body measured across the widest portion of the hips.

The measurement is taken with the subject sitting erect on a flat surface, looking straight ahead. Knees are bent at right angles and the feet are supported. Thighs, knees, and feet are kept together (touching). Knees are bent 90º. Measurement is taken without pressing into the flesh of the hips.

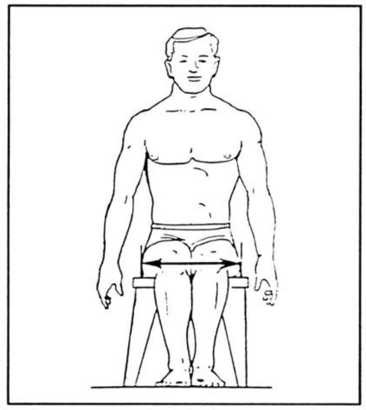

Figure 11 – Hip Breadth, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 9 Hip Breadth, Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Hip Breadth, Sitting	352	13.9	333	13.1
Plus Clothing Allowance*	4	0.2	4	0.2
Resulting Inside Distance Between Armrests	356	14.1	337	13.3
90th Percentile Hip Breadth, Sitting	489	19.2	431	17.0
Plus Clothing Allowance*	4	0.2	4	0.2
Resulting Inside Distance Between Armrests	493	19.4	435	17.2
95th Percentile Hip Breadth, Sitting	517	20.4	447	17.6
Plus Clothing Allowance*	4	0.2	4	0.2
Resulting Inside Distance Between Armrests	521	20.6	451	17.8

* McCullough, E.A. & Jones, B.W. (1984, December). A Comprehensive Data Base for Estimating Clothing Insulation, ASHRAE RP-411.

Why is Inside Distance Between Armrests (Pads / Caps) Important?

Appropriate inside distance between the armrests allows for easy entry/exit of the chair while providing proper support of the forearm as noted in section 7.4.1. and 7.4.2.

Discussion

Armrests should allow adequate clearance for the hips/thighs for the purpose of ingress/egress, and armrest support structures should provide adequate clearance for the user's hips/thighs when in a seated position.

The width of the user's hips/thighs is narrower in a standing position than when seated. The CAESAR anthropometric data does not have a measurement of standing hip breadth available. Humanscale 1/2/3 (1974) shows that the width of the 95th percentile female hip breadth is 25 mm (1.0 inch) narrower in the standing position as compared to seated, such that the clearance required at the armrest position when entering/exiting the chair is narrower than when seated Additionally, the setback of the arms relative to the angle of approach when entering or exiting the chair will affect the clearance required for this dimension. These variables imply the clearance required between armrests for ingress/egress is less than that for the armrest support structures.

When a clothing allowance is added to the Hip Breadth measurement, an inside distance between armrests of 493 mm (19.4 in.) will fit all users to the 90th percentile female hip breadth (which is wider than the 90th percentile male hip breadth). It should be noted that fixed width armrests that accommodate the 90th percentile female hip breadth will not address the needs of a large specific subset of the population.

For users with narrow shoulder breadths, an inside distance between armrests of 493 mm (19.4 in.) may force the elbows away from the body to reach the armrests. This position might create an uncomfortable upper arm-to-torso angle if the armrests are not adjustable. This issue may be addressed by the use of armrests that adjust towards the body (e.g., lateral and/or pivoting movement).

When considering adjustable armrests, an adjustment range from the 90th percentile female (493 mm [19.4 in.]) to the 5th percentile male (337 mm [13.3 in.]) would require at least 78 mm (3.1 in.) per arm of lateral (horizontal) movement. This adjustment range is difficult to achieve due to mechanical restrictions and aesthetic considerations in the design of armrests. Optional seat widths may be considered as an alternative means to provide a method of getting the armrests closer to the body, which will then allow for adequate arm support.

Anthropometric diversity and the need for fit of a given user population leads to the requirement for armrest adjustability, optional seat widths or a combination of the two.

For chairs with arms, adjustable width armrests that fit the user are preferred for computer-intensive tasks.

Recommendation for Inside Distance Between Armrests (Pads / Caps)

For adjustable width armrests, the inside distance between armrest adjustment range should include a distance of at least 493 mm (19.4 in.) to accommodate the 90^{th} percentile female hip breadth and the 98^{th} percentile male hip breadth.

The percentile of users supported should be stated.

> For example, an armrest adjustment range from 337 mm (13.3 in.) to 523 mm (20.6 in.) will accommodate the 5^{th} percentile male hip breadth, sitting up to the 95th percentile female hip breadth, sitting and greater than the 99th percentile male hip breadth, sitting. A combination of armrest designs and/or multiple seat widths may be used to meet this recommendation.
>
> To determine the percentile of users supported by a given inside distance between armrests, see Appendix B for the hip breadth, sitting dimensions.

For fixed armrests the inside distance between armrests should be at least 493 mm (19.4 in.) to accommodate the 90^{th} percentile female hip breadth and the 98^{th} percentile male hip breadth.

Ultimate Test for Fit for the Individual User

Armrests should allow users to sit in a variety of postures while supporting their forearms in a manner that avoids lifting the shoulders and/or forcing the elbows away from the body. Armrests should allow for performance of tasks. The inside distance between the armrests should allow the user to easily enter and exit the chair. The hips should comfortably fit between the armrests.

8 Work Surfaces

Worksurfaces -- General (ISO 9241-5, 5.1)

"The main factors in determining appropriate workstation arrangements are seat and worksurface, line-of-sight angle, worksurface and keyboard height, knee clearance, forearm inclination and elbow height."

"Furniture, equipment and work environment may be designed for use in the seated or standing position and where sitting and standing alternate. Workstations need to be capable of supporting several tasks (screen viewing, keyboard input, non-keyboard input device usage, writing, etc.) and should therefore be designed with such functions in mind."

Standing and sit/stand postures (ISO 9241-5, 5.2.3)

"The standing posture is recommended if it can alternate with a sitting position. This can be achieved if the workplace comprises either workstations or worksurfaces for sitting and standing postures or an adjustable workstation that can accommodate the same person in the seated and standing position."[3]

General recommendations (ISO 9241-5, 5.4.1)

"Support surfaces for displays and input devices and associated equipment and materials should allow adequate clearance for the user's anthropometric characteristics and postural changes."

Clearance under worksurfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

---

[3] Sit to stand height adjustment range may be derived from the requirements for the 5th percentile female seated dimensions and the 95th percentile male standing dimensions. The 5th percentile female dimensions establish the minimum of the height adjustment range and the 95th percentile male dimensions establish the maximum.

8.1 Clearances Under Work Surfaces for Seated Work

8.1.1 Height Clearance for Legs - Sitting

Support surfaces (ISO 9241-5, 7.1)

> *"Compliance with 5.4.2 [Clearances under worksurfaces] at a workstation is given if the height of the legroom is greater than thigh clearance height, sitting + popliteal height, sitting + allowance for footwear…For furniture with fixed height, use thigh clearance height and popliteal height, sitting for the 95th percentile male of the intended user population."*

Relevant Body Dimensions:

Thigh Height, Popliteal Height and Knee Height

What is Thigh Height and How is it Calculated?

Thigh Height is the calculated vertical distance between the Seating Reference Point Y (sitting surface) and the Superior Thigh Y landmark (highest point top of the thigh) taken from Pose C.

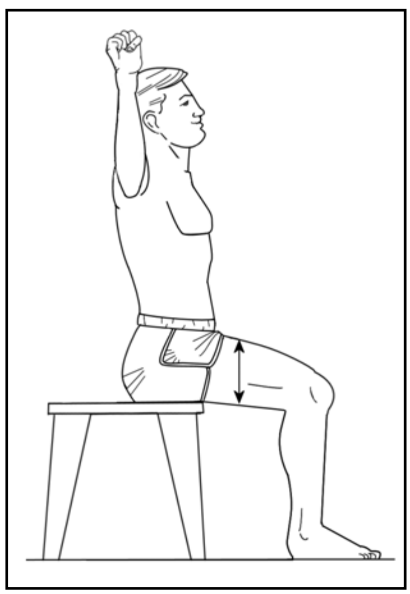

Figure 12 – Thigh Height

What is Popliteal Height and How is it Calculated?

"The Popliteal height is the distance from the back of the knee (popliteal landmark) to the floor. The popliteal landmark was identified in the Sitting Coverage Pose (Pose C) as the most anterior, most superior point behind the knee, as viewed from the side. For the measurements for Pose C, the seat was positioned to cause the tops of the thighs to slant slightly downward to improve coverage of the upper thighs."

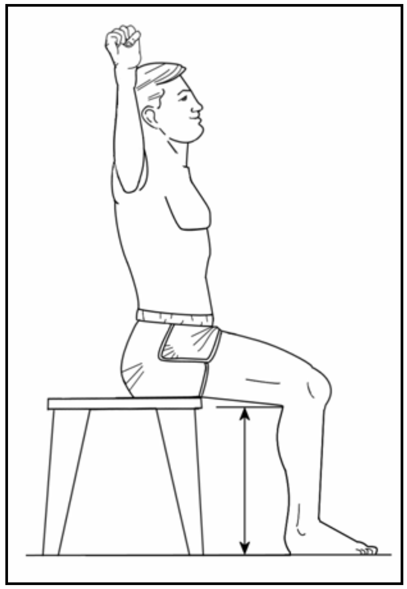

Figure 13 – Popliteal Height

What is Knee Height and How is it Measured?

Knee height is "the vertical distance from the foot support surface to the highest point of the border of the patella."

"Subject sits erect on a flat surface with knees bent at right angles and the feet supported."

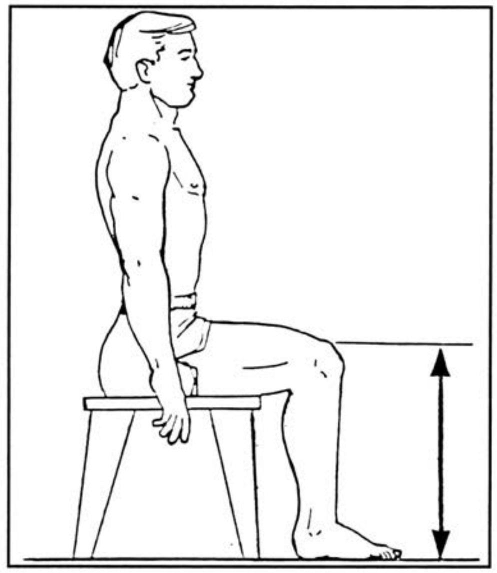

Figure 14 – Knee Height

Data Table (CAESAR Data and Applicable Allowances):

Table 10 Height Clearance for Legs at the Front Edge of the Work Surface – Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Thigh Height Plus Popliteal Height*	485	19.1	542	21.3
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Height Clearance for Legs at the Front Edge of the Work Surface	515	20.3	572	22.5
95th Percentile Thigh Height Plus Popliteal Height*	587	23.1	668	26.3
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Height Clearance for Legs at the Front Edge of the Work Surface	617	24.3	698	27.5

Table 11 Height Clearance for Knees – Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Knee Height, Sitting	465	18.3	508	20.0
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Height Clearance for Knees	495	19.5	538	21.2
95th Percentile Knee Height, Sitting	557	21.9	613	24.1
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Height Clearance for Knees	587	23.1	643	25.3

*Derived from within subject measurements.
**No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

Why is Height Clearance for Legs Important?

Adequate height clearance allows users to sit in close proximity to their work surface and permits space for postural changes.

Discussion

The height clearance for legs derived from CAESAR data is based on a 90° angle between the lower legs and the thighs, therefore may not provide enough space for postural changes or alternate sitting postures. Height clearance for legs accounts for the natural sloping of the thighs towards the floor between the hips and the knees when the user is sitting in an upright posture. The slope of the thighs determines the clearances required under the front edge of the work surface (region that is closest to the user's abdomen and thighs) and at the knee (region furthest away from the user under the work surface).

The CAESAR data for knee height plus consideration for the thickening of the thigh as it approaches the torso was used to calculate the recommended clearance dimensions.

If the work surface is a fixed height, it should accommodate the 95th percentile male's height clearance for thighs and lower legs (See Table 10). Smaller individuals may need to raise their chair and use a footrest.

Recommendation for Height Clearance for Legs - Sitting

If the work surface height is not adjustable, the height clearance for legs should be no less than 698 mm (27.5 in.) at the front edge of the work surface and 643 mm (25.3 in.) at 434 mm (17.1 in.) rearward from the front edge of the work surface.

If the work surface height is adjustable, it should include a height clearance of 698 mm (27.5 in.) at the front edge (indicator “A”) of the work surface and 643 mm (25.3 in.) (indicator “B”) at 434 mm at (17.1 in.) from the front edge (indicator “A”) as part of the range. See Table 16 and Figure 22 at the end of Section 8.1 for the recommended clearance envelope for seated work.

Ultimate Test for Fit for the Individual User

When centered on their task, users should be able to fit their legs in the space provided under the work surface without contacting the support structure. The space should be adequate to permit users to get close to their work surface while allowing freedom of movement.

8.1.2 Depth Clearance for Knees - Sitting

Clearance under worksurfaces (ISO 9241-5, 5.4.2)

“For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed.”

“The main considerations are for clearance for thighs, knees, lower legs and feet.”

Relevant Body Dimensions:

Buttock-Knee Length and Abdominal Extension Depth

What is Buttock-Knee Length and How is it Measured?

Buttock-knee length is “horizontal distance from the foremost point of the kneecap to the rearmost point of the buttock.”

“Subject sits erect on a flat surface, looking straight ahead. Knees are bent at right angles and the feet are supported. Thighs are parallel to each other, the feet are in line with the thighs, and knees are bent 90°. Upper arms hang freely downwards and forearms are horizontal.”

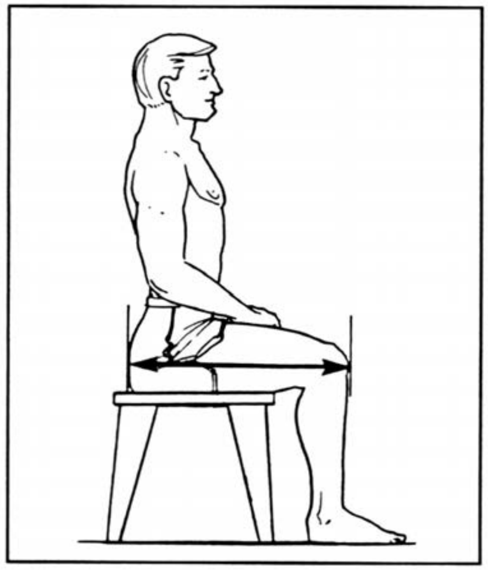

Figure 15 – Buttock-Knee Length

What is Abdominal Extension Depth and How is it Calculated?

Abdominal extension depth is the calculated horizontal distance between the Anterior Abdomen Z, Sitting landmark (forward-most point of the abdomen) and the Posterior Abdomen Z, Sitting landmark (landmark on the back of the individual) with the subject seated in the Coverage Pose C.

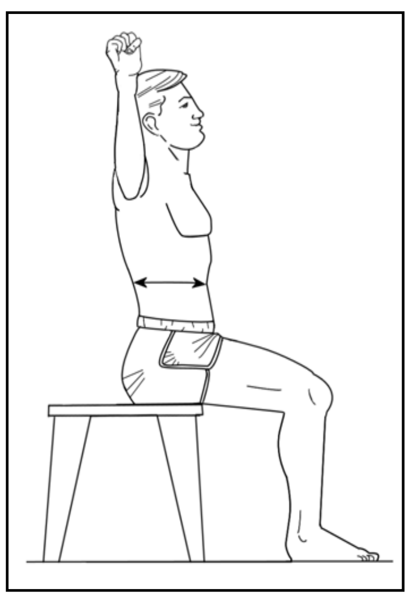

Figure 16 – Abdominal Extension Depth

Data Table (CAESAR Data and Applicable Allowances):

Depth clearance for knees is derived from Buttock-Knee Length minus Abdominal Extension Depth within subjects.

Table 12 Depth Clearance for Knees - Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Buttock-Knee Length minus Abdominal Extension Depth*	205	8.1	236	9.3
Movement Allowance**	45	1.8	45	1.8
Resulting Depth Clearance for Knees - Sitting	250	9.9	281	11.1
95th Percentile Buttock-Knee Length minus Abdominal Extension Depth*	376	14.8	389	15.3
Movement Allowance**	45	1.8	45	1.8
Resulting Depth Clearance for Knees - Sitting	421	16.6	434	17.1

*Derived from within subject measurements.
**As agreed upon by BIFMA Ergonomic subcommittee.

Why is Depth Clearance for Knees Important?

Adequate knee depth allows users to sit close to their work surface without contacting the support structure and provides space for postural changes.

Discussion

The CAESAR data given in Table 12 omits an allowance for lumbar concavity. The recommendation below acknowledges this omission, but uses the space to allow for additional clearance for multiple postures. The data also assumes that the user is positioned nearly flush to the front edge of the input device support surface and in an upright posture, although this may not be a typical position. The recommendation is based on the anthropometric data alone. When a user is in a more typical working posture, i.e., away from the front edge of the input device support surface, additional clearance is available.

Recommendation for Depth Clearance for Knees - Sitting

The depth clearance for knees should be no less than 434 mm (17.1 in.) as measured from the front edge of the input device support surface. This dimension applies to the envelope under the computer support surface and input device support surfaces. See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

Users should be able to fit their knees in the space provided under the work surface without obstruction. There should be enough space to allow users to get close to their work surface while allowing some freedom of movement.

8.1.3 Width Clearance for Legs - Sitting

Clearance under work surfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimension:

Bi-lateral Femoral Epicondyle Breadth, Sitting

What is Bi-lateral Femoral Epicondyle Breadth, Sitting and How is it Calculated?

Bi-lateral femoral epicondyle breadth, sitting is "the distance from left lateral femoral epicondyle to right lateral femoral epicondyle landmarks." It is a calculated point-to-point distance using landmarks from a whole-body scanner.

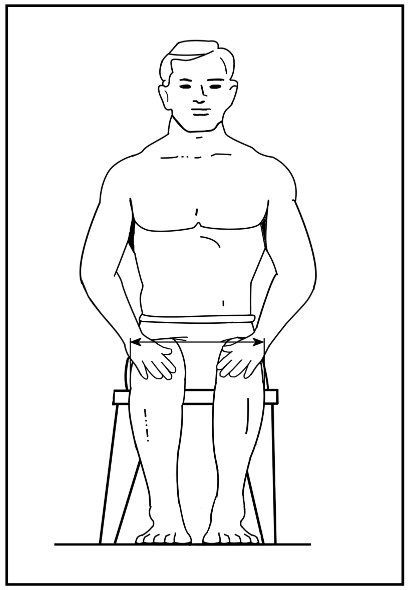

Figure 17 – Bi-lateral Femoral Epicondyle Breadth, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 13 Width Clearance for Legs

	Female		Male	
	mm	inches	mm	inches
5th Percentile Bi-lateral Femoral Epicondyle Breadth, Sitting	269	10.6	383	15.1
Plus Movement Allowance	45	1.8	45	1.8
Resulting Width Clearance for Legs	314	12.4	428	16.9
95th Percentile Bi-lateral Femoral Epicondyle Breadth, Sitting	488	19.2	574	22.6
Plus Movement Allowance	45	1.8	45	1.8
Resulting Width Clearance for Legs	533	21.0	619	24.4

Why is Width Clearance for Legs Important?

Appropriate width clearance allows the 95th percentile male leg clearance (width at the knees) to fit between the support structures of the work surface and permits postural changes.

Discussion

The previous Guideline (G1-2002) used Hip Breadth, Sitting for the knee width clearance. Because CAESAR subjects seated in Pose B position were sitting in a more relaxed leg posture, the width of the outside of the knees would be a better representation of width clearance for the legs.

The Pose B position does not account for space needed to move through a variety of postures, so a movement allowance of 45 mm (1.8 in.) was added.

Recommendation for Width Clearance for Legs - Sitting

The width clearance for legs under work surfaces should be no less than 619 mm (24.4 in.). See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

Users should be able to fit their knees/legs in the space provided under the work surface without obstruction. The space should be adequate to allow some freedom of movement.

8.1.4 Height Clearance at Foot Level - Sitting

Clearances under work surfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimension:

Lateral Malleolus Height (Ankle Height)

What is Lateral Malleolus Height and How is it Calculated?

Lateral malleolus height is “the vertical distance from the standing surface to a point picked on the right lateral malleolus landmark”. It is a calculated point-surface distance using landmarks from a whole-body scanner.

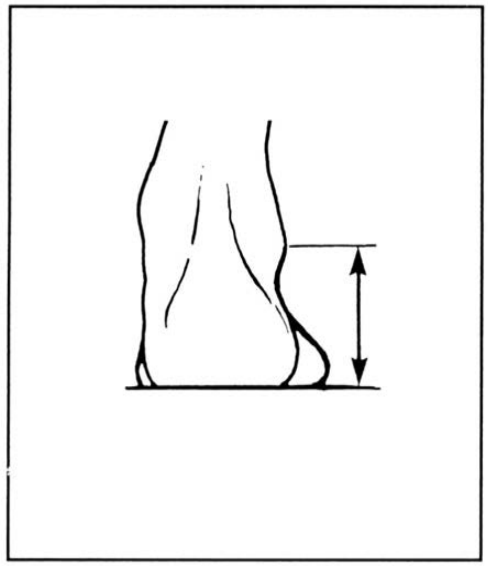

Figure 18 – Lateral Malleolus Height

Data Table (CAESAR Data and Applicable Allowances):

Table 14 Height Clearance at Foot Level

	Female		Male	
	mm	inches	mm	inches
5th Percentile Lateral Malleolus Height	54	2.1	62	2.4
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Height Clearance at Foot Level	84	3.3	92	3.6
95th Percentile Lateral Malleolus Height	76	3.0	84	3.3
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Height Clearance at Foot Level	106	4.2	114	4.5

*No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

Why is Height Clearance at Foot Level Important?

Adequate height clearance at foot level allows users to sit in close proximity to their work surface without obstruction at foot level, providing space for postural changes.

Discussion

Since no data for foot height is available in CAESAR, the Lateral Malleolus Height dimension was chosen to give guidance for the height clearance at foot level. This same dimension was used for Foot Level Clearance in BIFMA G1-2002.

An allowance of 30 mm (1.2 in.) for shoe height was added to the CAESAR data. If a footrest is used, the clearance is measured from the top of the footrest.

Recommendation for Height Clearance at Foot Level - Sitting

The height clearance at foot level should be no less than 114 mm (4.5 in.). See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

When centered on their task, users should be able sit close to the work surface in an upright posture without obstruction at foot level.

8.1.5 Depth Clearance at Foot Level - Sitting

Clearance under work surfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimensions:

Buttock-Popliteal Length, Foot Length and Abdominal Extension Depth

What is Buttock-Popliteal Length and How is it Calculated?

Buttock-Popliteal Length is the horizontal distance between the Seating Reference Point Z (most rearward position of the buttocks) and the Popliteal Fossa landmark placed on the back of the knee. It is calculated from extracted Pose C measurements of the whole-body scan in the Z-direction.

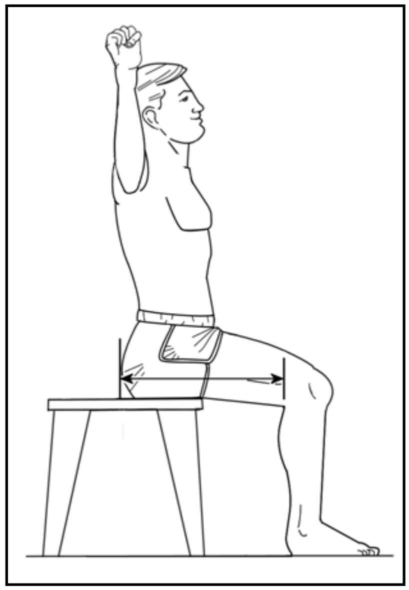

Figure 19 – Buttock-Popliteal Length

What is Foot Length and How is it Measured?

Foot length is the “maximum distance from the rear of the heel to the tip [of] the longest (first or second) toe, measured parallel to the longitudinal axis of the foot.” Measurements were taken using an anthropometer while “the subject stands with weight equally distributed on both feet.”

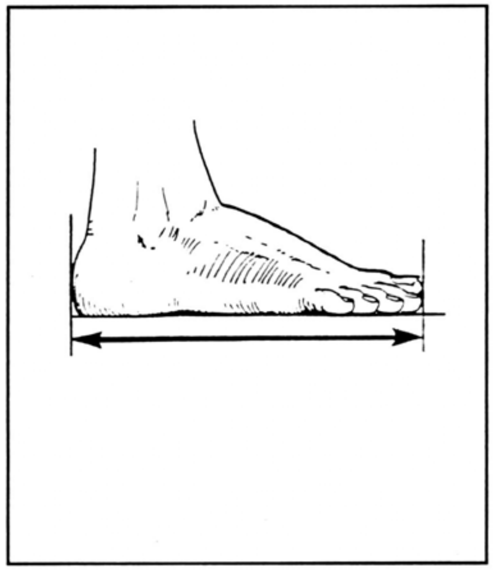

Figure 20 – Foot Length

What is Abdominal Extension Depth and How is it Calculated?

Abdominal extension depth is the calculated horizontal distance between the Anterior Abdomen Z, Sitting landmark (forward-most point of the abdomen) and the Posterior Abdomen Z, Sitting landmark (landmark on the back of the individual) with the subject seated in the Coverage Pose C.

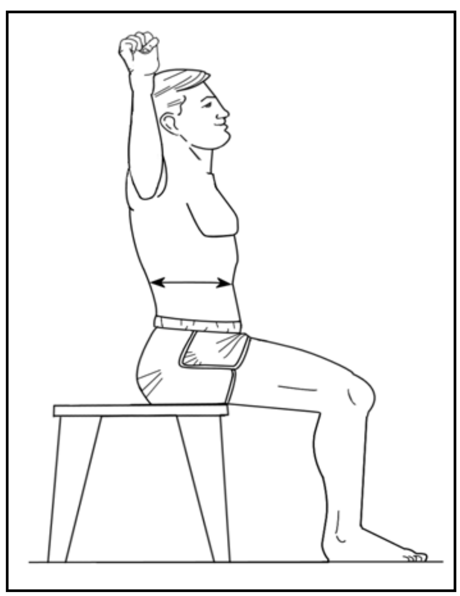

Figure 21 – Abdominal Extension Depth

Data Table (CAESAR Data and Applicable Allowances):

The depth clearance at foot level when seated is derived from Buttock-Popliteal Length plus Foot Length, minus Abdominal Extension Depth within subjects.

Table 15 Depth Clearance at Foot Level

	Female		Male	
	mm	inches	mm	inches
5th Percentile Depth Clearance at Foot Level*	297	11.7	356	14.0
Movement Allowance	45	1.8	45	1.8
Resulting Depth Clearance at Foot Level	342	13.5	401	15.8
95th Percentile Depth Clearance at Foot Level*	515	20.3	544	21.4
Movement Allowance	45	1.8	45	1.8
Resulting Depth Clearance at Foot Level	560	22.1	589	23.2

*Derived from within subject measurements.

Why is Depth Clearance at Foot Level Important?

Adequate depth clearance at foot level allows users to sit in close proximity to their work surface without obstruction at foot level as they perform their work tasks and providing space for postural changes.

Discussion

The depth clearance at foot level is measured from the front edge of the input device surface extending horizontally towards the back edge of the computer support surface, throughout the 639 mm (25.2 in.) width specified in section 8.1.3.

The clearances in Table 15 are based on a 90° angle between the lower leg and the thigh. This does not allow for the clearance required for the extension of the leg or postural changes for long-legged users. For example, the 95th percentile male popliteal length, with a 30° leg extension requires an additional 278 mm (10.9 in.) of clearance. This additional clearance can be achieved in a variety of ways, including additional work surface depth, additional foot clearance space and/or the use of either fixed or adjustable input device support surfaces.

Depth clearance at foot level is also affected by the proximity of the user to the edge of the input device support surface or the computer display and the length of the shoe beyond the toe. The design of the workstation should consider all of these factors to achieve appropriate clearance.

The recommendation assumes that the user is positioned nearly flush to the front edge of the input device support surface and in an upright posture, although this may not be a typical position. If the user is in a more typical working posture, i.e., away from the front edge of the input device support surface, additional depth clearance at foot level becomes available.

Previously (per BIFMA G1-2002), a depth clearance at foot level of 598 mm (23.5) was necessary to accommodate up the 95th percentile male buttock-knee length. CAESAR data indicates that the depth clearance has decreased to 589 mm (23.2 in). This change may be attributed to increased abdominal extension depth, which reduces the amount of horizontal distance below the work surface required to accommodate the legs. In addition, 45 mm (1.8 in.) for movement allowance was added to this dimension.

Recommendation for Depth Clearance at Foot Level - Sitting

The depth clearance at foot level when seated should be no less than 589 mm (23.2 in.), but it is important that the discussion above be considered. See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

Users should be able to fit their legs in the space provided under the work surface without obstruction. There should be adequate space to permit users to get close to their work surface while allowing freedom of foot movement and/or postural changes.

8.1.6 Summary of Clearances Under Work Surfaces for Seated Work

Table 16 Clearance Envelope for Seated Work

Section	Dimension		Recommendation*	
8.1.1	Height Clearance for Legs at the Front Edge of the Work Surface - Sitting	A	698 mm	27.5 in.
	Height Clearance for Knees - Sitting	B	643 mm	25.3 in.
8.1.2	Depth Clearance for Knees - Sitting	C	434 mm	17.1 in.
8.1.3	Width Clearance for Legs - Sitting	D	619 mm	24.4 in.
8.1.4	Height Clearance at Foot Level – Sitting	E	114 mm	4.5 in.
8.1.5	Depth Clearance at Foot Level – Sitting	F	589 mm	23.2 in.

* All dimension tolerances to be ± 1.5 mm (1/16 in.)

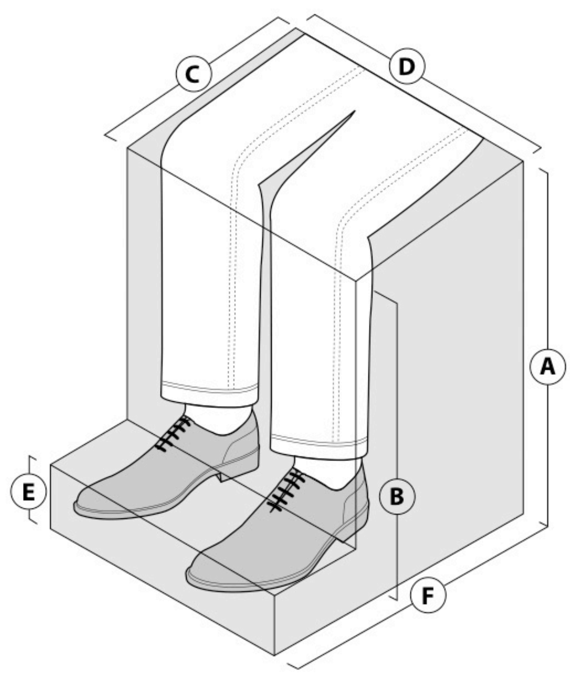

Figure 22 – Seated Clearance Envelope Based on 95th Percentile Male Dimensions

8.2 Clearances Under Work Surfaces for Standing Work

8.2.1 Height Clearance for Feet - Standing

Clearances under worksurfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimension:

Lateral Malleolus Height

What is Lateral Malleolus Height and How is it Calculated?

Lateral malleolus height is "the vertical distance from the standing surface to a point picked on the right lateral malleolus landmark". It is a calculated point-surface distance using landmarks from a whole-body scanner.

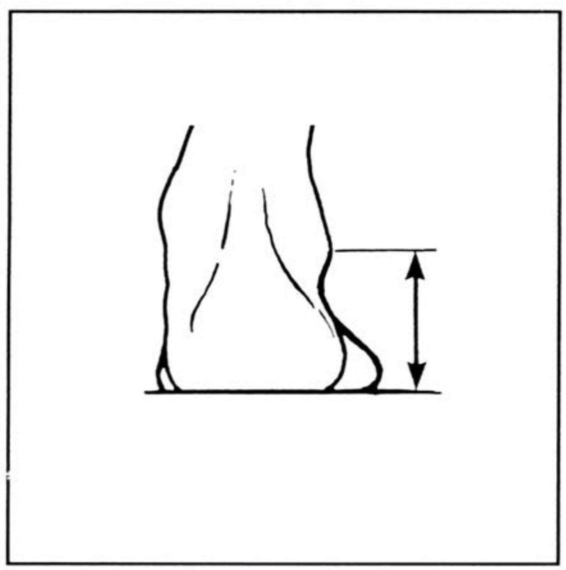

Figure 23 – Lateral Malleolus Height

Data Table (CAESAR Data and Applicable Allowances):

Table 17 Height Clearance for Feet

	Female		Male	
	mm	inches	mm	inches
5^{th} Percentile Lateral Malleolus Height	54	2.1	62	2.4
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Height Clearance for Feet	84	3.3	92	3.6
95^{th} Percentile Lateral Malleolus Height	76	3.0	84	3.3
Plus Shoe Allowance*	30	1.2	30	1.2
Resulting Height Clearance for Feet	106	4.2	114	4.5

*No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

Why is Height Clearance for Feet Important?

Appropriate height clearance permits the user's feet to fit under the work surface, thereby allowing the user to stand close to the task.

Discussion

Since no clear data is available, the CAESAR Lateral Malleolus Height dimension was chosen to give guidance for the height clearance at foot level. An allowance of 30 mm (1.2 in.) for shoe height was added to the CAESAR data. If a footrest is used, the clearance is measured from the top of the support.

Recommendation for Height Clearance for Feet - Standing

The height clearance at foot level should be no less than 114 mm (4.5 in.). See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

When centered on their task, users should be able to stand close to the work surface in an upright posture without obstruction at foot level.

8.2.2 Depth Clearance for Feet - Standing

Clearances under worksurfaces (ISO 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimensions:

None available

CEASAR Supporting Information:

None available

Why is Depth Clearance at Foot Level Important?

Adequate depth clearance at foot level allows users to stand in close proximity to their work surface.

Discussion

CAESAR does not provide anthropometric data for the length of the foot extending forward of the ankle. Given the lack of specific data, the recommended dimension is based on the seated depth clearance shown in Figure 22 (depth clearance for feet minus depth clearance for knees).
This guideline has chosen the 152 mm (6.0 in.) dimension for foot (toe) depth clearance given in the 2010 ADA Standards for Accessible Design.

This dimension is measured from the front edge of the work surface extending horizontally towards the back edge of the work surface, throughout the 566 mm (22.4 in.) width specified in section 8.2.3. The clearance dimension should be maintained at floor level vertically through a plane 114 mm (4.5 in.) above and parallel to floor level. **Note:** prior recommendation (BIFMA G1 – 2002) was based on hip breadth, this new recommendation is based on clearance for knees (width).

Recommendation for Depth Clearance for Feet (Toes) - Standing

The depth clearance for the foot in front of the ankle (toe clearance) should be no less than 152 mm (6.0 in.). See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

When centered on their task, users should be able to stand close to the work surface in an upright posture without obstruction at foot level.

8.2.3 Width Clearance for Feet - Standing

Clearances under worksurfaces (ISO 9241-5, 5.4.2)

"For seated and standing work, sufficient vertical, horizontal and lateral clearance between the torso and lower limbs of users…and workstation components…is needed."

"The main considerations are for clearance for thighs, knees, lower legs and feet."

Relevant Body Dimensions:

Hip Breadth, Sitting

What is Hip Breadth, Sitting and How is it Measured?

Hip breadth, sitting is the "Breadth of the body measured across the widest portion of the hips".

"Subject sits erect on a flat surface, looking straight ahead. Knees are bent at right angles and the feet are supported. Thighs, knees, and feet are kept together (touching). Knees are bent 90º. Measurement is taken without pressing into the flesh of the hips."

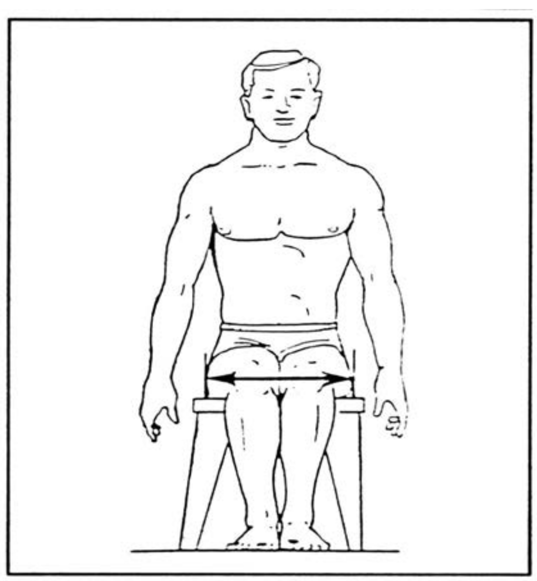

Figure 24 – Hip Breadth, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 18 Hip Breadth, Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Hip Breadth, Sitting	352	13.9	333	13.1
Plus Movement Allowance	45	1.8	45	1.8
Plus Clothing Allowance*	4	0.2	4	0.2
Resulting Breadth	401	15.9	382	15.1
95th Percentile Hip Breadth, Sitting	517	20.4	447	17.6
Plus Movement Allowance	45	1.8	45	1.8
Plus Clothing Allowance*	4	0.2	4	0.2
Resulting Breadth	566	22.4	496	19.6

* McCullough, E.A. & Jones, B.W. (1984, December). A Comprehensive Data Base for Estimating Clothing Insulation, ASHRAE RP-411.

Why is Width Clearance for Feet Important?

Appropriate width clearance permits the user's feet to fit under the work surface.

Discussion

Since no clear data is available for width clearance at foot level, the CAESAR Hip Breadth, Sitting dimension was chosen as an approximation for the width clearance at foot level (Hip Breadth, Standing data is available in the CAESAR survey, but is narrower than the Hip Breadth, Sitting dimension). The Hip Breadth, Sitting dimension was also chosen based on the assumption that users of computer workstations may alternate between a full sitting posture and a standing posture at the same workstation. The clearance is based on the 95th percentile female hip breadth, which is wider than the 95th percentile male hip breadth.

An allowance of 49 mm (2.0 in.) for movement and clothing was added to the Hip Breadth, Sitting data to arrive at the recommended dimension.

Recommendation for Width Clearance for Feet - Standing

The width clearance for feet to fit under the work surface should be no less than 566 mm (22.4 in.). See Figure 22 for recommended clearance envelope dimensions.

Ultimate Test for Fit for the Individual User

When centered on their task, users should be able to stand close to the work surface in an upright posture without obstruction and with room for movement.

8.2.4 Summary of Clearances Under Work Surfaces for Standing Work

Table 19 - Clearance Envelope for Standing Work

Section	Dimension		Recommendation	
8.2.1	Height Clearance for Feet, Standing	A	114 mm	4.5 in.
8.2.2	Depth Clearance for Feet, Standing	B	152 mm	6.0 in.
8.2.3	Width Clearance for Feet, Standing	C	566 mm	22.4 in.

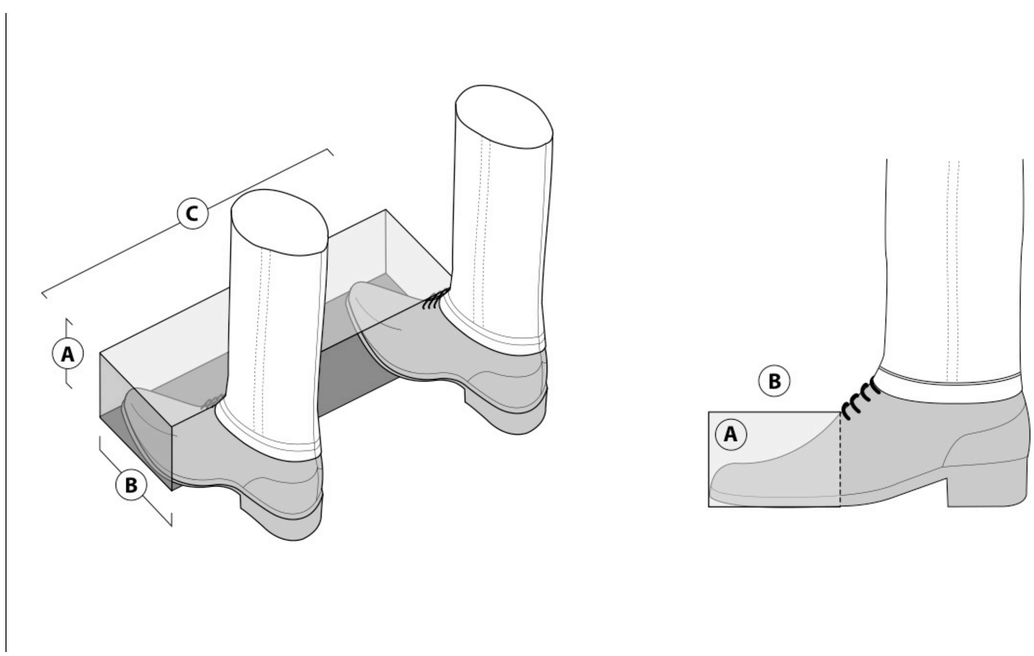

Figure 25 – Clearance at Feet Envelope, Standing

8.3 Support Surface Heights for Input Devices for Seated and Standing Work

General recommendations (ISO 9241-5, 5.4.1)

"The worksurface should provide support for the display and input devices and associated equipment and material, as well as for the hands and arms of the user."

Recommended support surface heights are determined by a number of variables, including under work surface clearance requirements, input device geometry and location, monitor size and location, and whether the support surfaces are to be used in a seated or standing posture. When support surfaces are used in a seated posture, the seat height is also a factor. Some of these variables are potentially conflicting, especially the height requirements for the input device and the monitor. For example, if a single surface is used to support both of these elements it is likely that when the height is appropriate for the input device it may be too high for the monitor, causing inappropriate viewing angles. Conversely, heights that allow an appropriate viewing angle for the monitor may cause the input device to be too low, causing inappropriate arm or wrist angles. It is typical to provide multiple support surface heights to remedy this conflict. Single surfaces may be acceptable if the height of the support surface satisfies both the input device and monitor support surface recommendations.

8.3.1 Support Surface Height for Input Devices - Sitting

General recommendations (ISO 9241-5, 5.4.1)

"For input device use, the height of the support surface should allow comfortable and efficient posture of the upper arms, forearms and hands…The worksurface should be height adjustable, and when required by task, also tiltable."

Relevant Body Dimensions:

Popliteal Height and Elbow Height, Sitting

What is Popliteal Height and How is it Measured?

"The Popliteal Height is the distance from the back of the knee (popliteal landmark) to the floor. The popliteal landmark was identified in the Sitting Coverage Pose (Pose C) as the most anterior, most superior point behind the knee, as viewed from the side. For the measurements for Pose C, the seat was positioned to cause the tops of the thighs to slant slightly downward to improve coverage of the upper thighs."

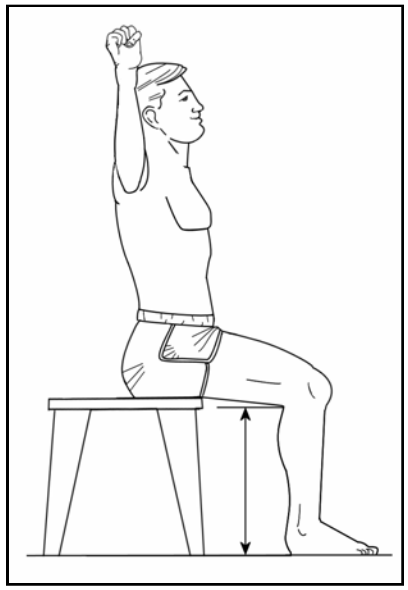

Figure 26 – Popliteal Height

What is Elbow Height, Sitting and How is it Measured?

Elbow Height, Sitting is the "vertical distance from a horizontal sitting surface to the lowest bony point of the elbow bent at a right angle with the forearm horizontal." It is measured by having the subject sit "erect on a flat surface, looking straight ahead. Knees are bent at right angles and feet are supported. Thighs are parallel to each other, feet are in line with the thighs, and knees are bent 90º. Upper arms hang freely downwards and forearms are horizontal."

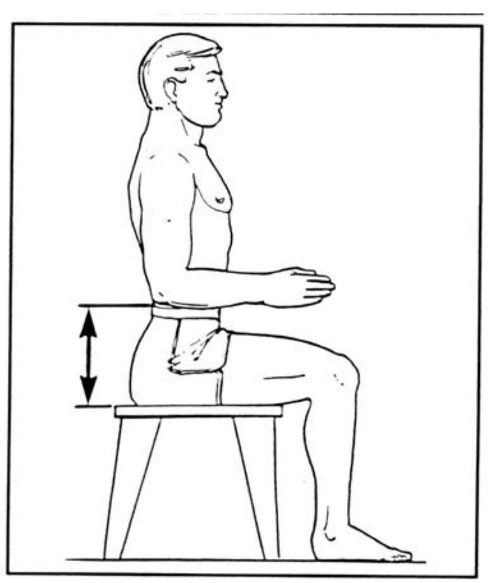

Figure 27 – Elbow Height, Sitting

Data Table (CAESAR Data and Applicable Allowances):

Table 20 Input Devices Support Surface Height for Seated Work

	Female		Male	
	mm	inches	mm	inches
5th Percentile Popliteal Height plus Elbow Height, Sitting*	570	22.4	618	24.3
Plus Shoe Allowance**	30	1.2	30	1.2
Minus Input Device Thickness***	-25	-1.0	-25	-1.0
Resulting Input Devices Support Surface Height for Seated Work	575	22.6	623	24.5
95th Percentile Popliteal Height plus Elbow Height, Sitting*	685	27.0	742	29.2
Plus Shoe Allowance**	30	1.2	30	1.2
Minus Input Device Thickness***	-25	-1.0	-25	-1.0
Resulting Input Devices Support Surface Height for Seated Work	690	27.2	747	29.4

* Derived from within subject measurements.
** No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).
*** Input device thickness is based on industry average of 25 mm (1 in.)

Why is Support Surface Height for Input Device - Sitting Important?

Proper support surface height allows comfortable and efficient positioning of the upper arms, forearms and hands, while providing adequate height clearance for the legs with their feet comfortably in contact with the floor.

Discussion

Two different methods may be used to determine appropriate input device support surface height. One is based on leg clearance (shoe allowance, plus popliteal height, plus thigh clearance, plus input device support surface thickness). The other method is based on elbow height (shoe allowance, plus popliteal height, plus elbow height, sitting, minus input device thickness). This Guideline has chosen to use the latter method (see Table 20) as the Elbow Height, Sitting dimension relates more directly to input device height.

The input device support surface should not interfere with leg clearance. The location of the top of the input device (in particular, the home row of the keyboard) should allow the user to maintain neutral shoulder, elbow and wrist postures. Several other factors must also be considered when determining support surface height, including the thickness of the input device and its support surface[4], the under-support surface height clearance, and any adjustable input device support mechanisms.

With the forearms in a horizontal position the input device support surface should be located in the space between the top of the thigh and the underside of the forearm. See Figure 28.

For many users, however, this space will not accommodate the thickness of the input device. The issue is compounded when the thickness of the support surface is added. Thinner support surfaces and/or input devices accommodate a larger percentage of users. While the absolute adjustment range will not change, it will start at a lower height for thinner support surfaces and higher for thicker support surfaces.

Tilt adjustment of the support surface will also influence the height of the support surface and will be dependent on the user's seated position. Care should be taken to maintain neutral wrist postures and ensure elbow angles are between 70 and 135 degrees. Depending on the seated posture, the user may need to use positive or negative support surface tilt to achieve neutral postures.

Most users assume postures that allow them to comfortably perform their tasks with products that fit in the space referenced above. There are circumstances, however, when individual users will not be able to adequately adjust their postures. In these cases, compromises in posture and/or furniture will be required. Figure 28 shows examples of variability in the space between forearms and thighs.

If an input device support surface is fixed in height, there may not be sufficient leg space for taller users. Shorter users may require the use of a footrest to provide adequate leg support, but this may inhibit movement, especially of the lower body.

[4] For the purpose of this discussion, these thickness dimensions are considered to be 25 mm (1.0 in.) for the input device and 38 mm (1.5 in.) for the support surface.

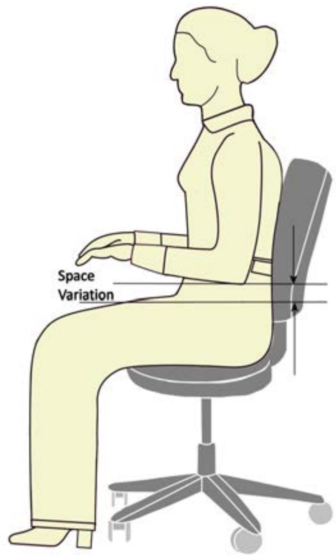

Figure 28 – Forearm to Thigh Space

Recommendation for Support Surface Height for Input Device - Sitting

Height adjustable input device support surfaces that are horizontal should include an adjustment range from 575 mm (22.6 in.) to 747 mm (29.4 in.) as measured to the top of the surface. If the support surface is tilt adjustable additional height adjustment range will be required.

If the support surface height is fixed, the height should be no less than 747 mm (29.4 in.) as measured to the top of the surface. A fixed height support surface, however, will only accommodate a subset of the population. Footrests may be required when a higher seat height is used for shorter individuals so they can sit at the support surface for input devices.

Ultimate Test for Fit for the Individual User

Users should be able to sit in a variety of positions at the support surface with adequate clearance for the legs with their feet comfortably supported on the floor or footrest. Their shoulders, elbows and wrists should be in neutral postures. In some cases, however, even height adjustable support surfaces will not accommodate the user because there is little or no space between the top of their thigh and the underside of their forearm in which to fit the keyboard and support surface. In these instances, compromises in posture will be necessary.

8.3.2 Support Surface Height for Input Devices - Standing

General recommendations (ISO 9241-5, 5.4.1)

"For input device use, the height of the support surface should allow comfortable and efficient posture of the upper arms, forearms and hands…The work surface should be height adjustable, and, when required by task, also tiltable."

Elbow height, standing (ISO 9241-5, A.3.2)

"This dimension is important in determining worksurface heights for office tasks carried out in standing position. It is defined as the vertical distance from the floor to the lowest bony point of the bent elbow with the subject standing fully erect, the upper arm hanging freely and the forearm bent at right angles…"

Relevant Body Dimension:

Elbow Height, Standing

What is Elbow Height, Standing and How is it Calculated?

Elbow Height, Standing is "the vertical distance from the standing surface to the olecranon [elbow] landmark". This is calculated based on point-to-surface distance as taken by a whole-body scanner.

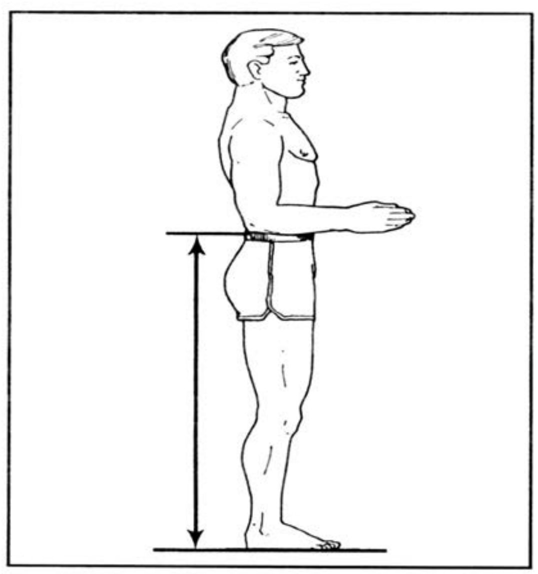

Figure 29 – Elbow Height, Standing

Data Table (CAESAR Data and Applicable Allowances):

Table 21 Input Devices Support Surface Height for Standing Work

	Female		Male	
	mm	inches	mm	inches
5th Percentile Elbow Height, Standing	968	38.1	1042	41.0
Plus Shoe Allowance*	30	1.2	30	1.2
Minus Input Device Thickness**	-25	-1.0	-25	-1.0
Resulting Input Devices Support Surface Height for Standing Work	973	38.3	1047	41.2
95th Percentile Elbow Height, Standing	1140	44.9	1232	48.5
Plus Shoe Allowance*	30	1.2	30	1.2
Minus Input Device Thickness**	-25	-1.0	-25	-1.0
Resulting Input Devices Support Surface Height for Standing Work	1145	45.1	1237	48.7

*No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

**Input device thickness is based on industry average of 25 mm (1 in.)

Why is Support Surface Height for Input Device – Standing Important?

Proper input device support surface height allows comfortable and efficient positioning of the upper arms, forearms and hands.

Discussion

The height of the input device support surface should allow the user to maintain neutral shoulder, elbow and wrist postures relative to the top surface of the input device (e.g., home row of keys). Appropriate input device support surface height depends on the thickness of the input device[5]. Tilt adjustment of the support surface will also influence the height of the support surface. When using surfaces with adjustable tilt angles care should be taken to maintain neutral wrist postures and ensure elbow angles are between 70 and 135 degrees.

[5] For the purpose of this discussion, the input device thickness dimension is considered to be 25 mm (1.0 in.).

If the input device support surface is tilt adjustable, additional height adjustment range will be required.

Adjustable height surfaces are preferred. Fixed height surfaces will disaccomodate a certain percentage of the user population.

Adopting alternate positions while standing may alleviate pressure on the legs/feet and promote blood flow. Foot rests/foot rails encourage alternate positions and may be beneficial in standing workstations.

Recommendation for Support Surface Height for Input Device – Standing

Height adjustable input device support surfaces that are horizontal should include an adjustment range from 973 mm (38.3 in.) to 1237 mm (48.7 in.) as measured to the top of the surface.

If the support surface height is fixed, its height should fall within the range given above.

Ultimate Test for Fit for the Individual User

Users should be able to stand erect at the input device support surface, with adequate clearance for their feet. The shoulders, elbows and wrists should be in neutral postures.

8.4 Monitor Placement

General recommendations (ISO 9241-5, 5.4.1)

"The worksurface should provide support for the display and input devices and associated equipment and material, as well as for the hands and arms of the user."

Viewing distances and angles of view (ISO 9241-5, 5.4.3)

"The user should be able to angle, tilt, or swivel the display unit in such a way that she or he maintains a relaxed working posture regardless of the eye height, minimizes accommodative effort, and avoids disturbing reflections and glare."

Viewing conditions - General (ISO 9241-303 5.1.1)

"A number of viewing conditions that are necessary, though not sufficient of themselves, can be specified for achieving fast, error-free and near-effortless viewing. These pertain to the design viewing distance and direction and to the needed gaze and head tilt angles of the viewer.

It is known that viewing distance and line-of-sight angle (gaze angle) need to be compatible with the user's vergence and accommodation capability and his or her capability to focus on short distances."

8.4.1 Distance to Monitor – Sitting or Standing

Viewing distance and its variation (ISO 9241-5, A.2.12)

"If a workstation comprises visual displays of different technologies, the viewing distances under which optimum visual conditions can be achieved should be determined before organizing and dimensioning the workstation."

Design viewing distance (ISO 9241-303, 5.1.2)

"The design viewing distance is dependent on the task and the electronic visual display and shall not be less than 300 mm, being the typical minimum comfortable viewing distance, or near point, for normal [emmetropic] eyes of adults. There is a physiologically determined relationship between the near point and the age of the user… and between the near point and luminance level; however, there is a large variance in this relation."

"For larger visual displays, such as those in office tasks, the preferred viewing distance is longer – typically 400 mm to 750 mm."

Relevant Body Dimensions:

Not applicable

CAESAR Supporting Information:

None available

Why is Distance to the Monitor Important?

Appropriate distance to the monitor permits the user to view the monitor while maintaining neutral neck postures with a minimal amount of eyestrain.

Discussion

The distance to the monitor is influenced by monitor size, character and object size, screen resolution and presbyopia (loss of near-focusing ability) in an aging population.

According to ISO, the preferred viewing distance to the monitor is between 400 mm (15.7 in.) and 750 mm (29.5 in.). This is for prolonged text-oriented operations for normal sighted (or corrected to normal sighted) adults. Many adults over the age of 40 are unable to accommodate viewing distances of 400 mm (15.7 in.) without corrective lenses. Research suggests a typical user's resting focus is 670 mm (26.4 in.), which implies the preferred viewing distance will be greater than 400 mm (15.7 in.). Greater viewing distances tend to reduce the potential for eyestrain. Longer viewing distances are only limited by the ability to read the screen.

A support surface should have sufficient depth to place the monitor at the minimum recommended distance from the eye while supporting the monitor in a stable manner. Greater support surface depths are acceptable.

If monitors are supported by a monitor arm, it is preferable that the arm has a horizontal movement of 350 mm (13.8 in.) to accommodate a preferred viewing distance of 400 mm (15.7 in.) to 750 mm (29.5 in.).

Smaller monitors may allow for higher placement, however, the accompanying decrease in screen size may result in the need for decreased viewing distances.

At typical monitor viewing distances, the visual system functions better when the user has a downward viewing angle. For a typical working environment with an approximately vertical position of the upper body, the work surface and the visual display should permit the user to view the screen with a gaze angle from 0° to 45° and a head-tilt angle of from 0° to 20°. These angle values can require the tilt and/or height of the visual display to be adjustable so that a perpendicular view (line of sight is perpendicular to the surface of the monitor) can be obtained.

Recommendation for Distance to Monitor - Sitting or Standing

The distance to the monitor should be a minimum of 400 mm (15.7 in.).

For monitors supported by a surface, the surface depth should be at a minimum 400 mm (15.7 in.) plus the depth of the monitor (including base, if applicable).

- For example, if the monitor is a CRT with a depth of 500 mm (19.7 in.) the support surface should be at least 900 mm (35.4 in.) deep. If the monitor is a flat panel display with a support base that is 200 mm (7.9 in.) the support surface should be at least 600 mm (23.6 in.) deep.

For monitors supported by monitor arms, the arm should allow the monitor to be positioned to achieve a minimum 400 mm (15.7 in.) viewing distance.

Ultimate Test for Fit for the Individual User

With the user seated (or standing, as appropriate) with their head in an upright (neutral) posture, the distance from the user's eyes to the monitor should be approximately an arm's length away from the front of the body. This allows the user to focus on the screen images such that they are legible, readable and comfortable to use.

8.4.2 Monitor Height Range – Sitting and Standing

Design reference posture (ISO 9241-5, 5.2.1)

“The line-of-sight in the relaxed seated position is inclined approximately by 35° below the horizontal.”

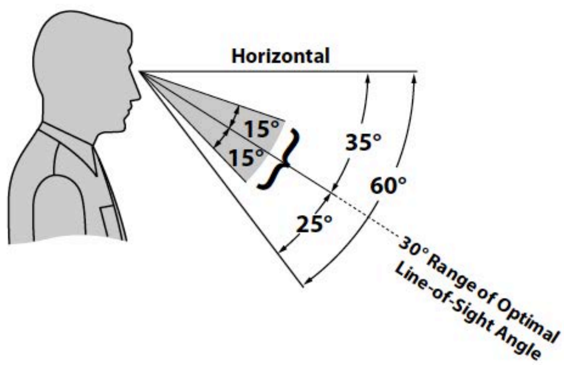

Figure 30 – Optimum Vertical Position of Monitor Sitting (from line-of-sight)

“The optimum position for the most important visual display is within +/- 15° in the vertical and horizontal direction from the line-of-sight.”

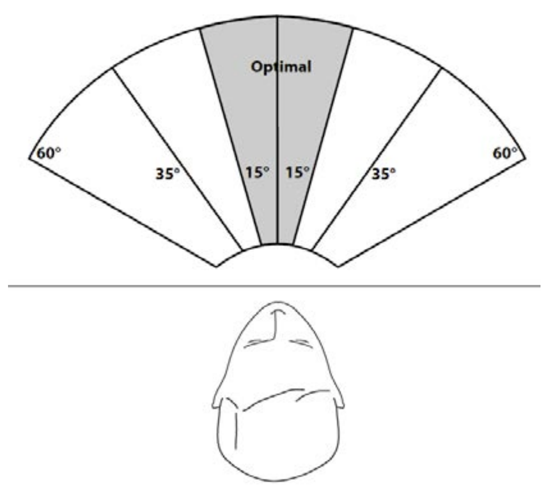

Figure 31 – Optimum Horizontal Position of Monitor Sitting and Standing (from line-of-sight)

"In the standing position, the inclination of the line-of-sight is about 30°."

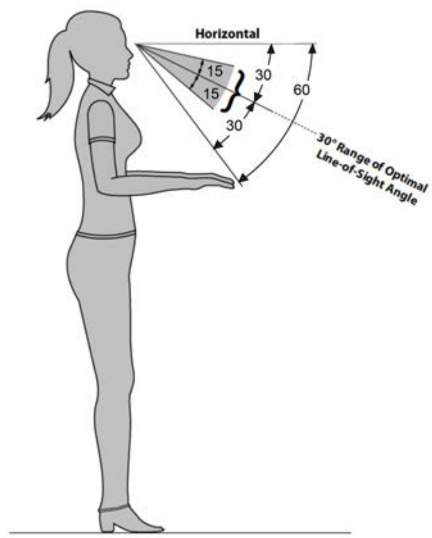

Figure 32 – Optimum Vertical Position of Monitor Standing (from line-of-sight)

Eye height, sitting (ISO 9241-5, A.2.4)

"The eye height is important to ensure that the visual elements of the task can be accommodated without undue load on the neck, shoulder and upper spine."

Eye height, standing (ISO 9241-5 A.3.1)

"This dimension is usually defined as the vertical distance from the floor to the inner corner of the eye and is described technically as eye height, standing …For comfortable viewing of visual display terminals and related visual material, it should be remembered that, in the relaxed seated position, the head is tilted forward."

"This dimension is important in determining that the visual elements of the task can be accommodated without undue load on the neck, shoulder and upper spine and lower limbs."

Relevant Body Dimensions for Seated Postures:

Eye Height, Sitting and Popliteal Height

What is Eye Height, Sitting and How is it Measured?

Eye height, sitting is “the vertical distance from a horizontal sitting surface outer corner of the eye,” measured with an anthropometer. The “subject sits erect on a hard surface, looking straight ahead. Knees are bent at right angles and feet are supported. Thighs are parallel to each other, feet are in line with the thighs, and knees are bent 90°. Upper arms hang freely downwards and forearms are horizontal.”

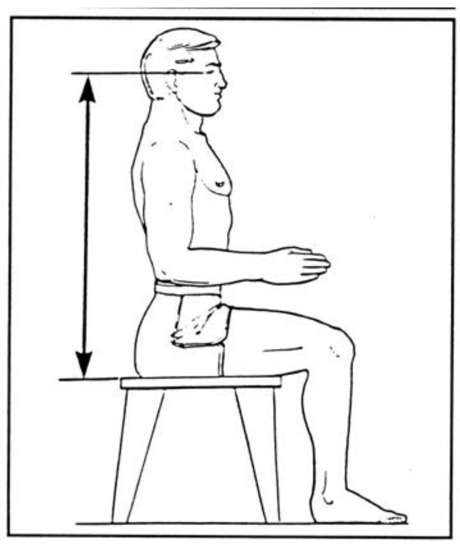

Figure 33 – Eye Height, Sitting

What is Popliteal Height and How is it Measured?

“The Popliteal Height is the distance from the back of the knee (popliteal landmark) to the floor. The popliteal landmark was identified in the Sitting Coverage Pose (Pose C) as the most anterior, most superior point behind the knee, as viewed from the side. For the measurements for Pose C, the seat was positioned to cause the tops of the thighs to slant slightly downward to improve coverage of the upper thighs.”

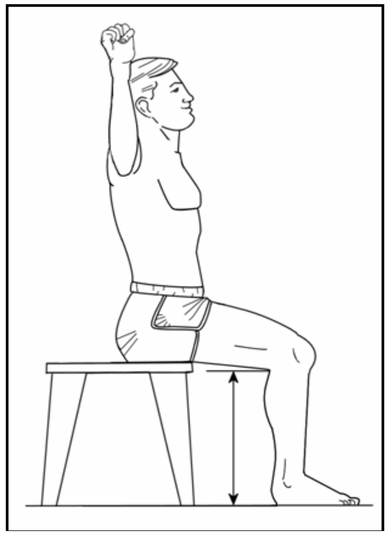

Figure 34 – Popliteal Height

Data Table (CAESAR Data and Applicable Allowances):

The Eye Height (from floor), Sitting is derived by adding Eye Height, Sitting plus Popliteal Height, within subjects.

Table 22 Monitor Height (from Floor), Sitting

	Female		Male	
	mm	inches	mm	inches
5th Percentile Eye Height Sitting plus Popliteal Height*	1061	41.8	1146	45.1
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Monitor Height	1091	43.0	1176	46.3
95th Percentile Eye Height Sitting plus Popliteal Height*	1230	48.4	1341	52.8
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Monitor Height	1260	49.6	1371	54.0

*Derived from within subject measurements.
**No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

What is Eye Height, Standing and How is it Calculated?

Eye height, standing is a derived measurement based on the vertical distance between a floor surface and the corner of the eye of a subject standing erect.

CAESAR does not have a calculated Eye Height, Standing, therefore this dimension was derived using within subject calculations by first subtracting the Eye Height, Sitting from Sitting Height to get the distance from the top of the head to the eye. This value was then subtracted from Stature to yield Eye Height, Standing.

Table 23 Monitor Height (from floor), Standing

	Female		Male	
	mm	inches	mm	inches
5th Percentile Height, Standing*	1412	55.6	1519	59.8
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Monitor Height	1442	56.8	1549	61.0
95th Percentile Eye Height, Standing*	1652	65.0	1783	70.2
Plus Shoe Allowance**	30	1.2	30	1.2
Resulting Monitor Height	1682	66.2	1813	71.4

*Derived from within subject measurements.

**No CAESAR guidance is available for shoe allowance. ISO 9241-5, Table A1 suggests 30 mm (1.2 in.).

Why is Monitor Height Important?

Monitor height influences both posture and visual comfort. If the monitor is too high, users will likely tilt their head backward, which may lead to non-neutral neck postures and increased muscle tension. This is especially true if users wearing multifocal lenses use the lowest part of the lense- to view the monitor. Downward gaze angles are beneficial at close distances such as found in computer work spaces. However, a monitor that is too low may cause users to tilt their head too far forward, which may lead to increased muscle activity and possibly neck pain and/or headaches.

Discussion

Monitor height is influenced by eye height above the floor, monitor tilt, viewing distance and gaze angle. Its height may also be influenced by the leg clearance envelope, especially if the monitor is supported on a surface. When the monitor is at an appropriate height, the user will be able to view the monitor screen without visual or postural discomfort, or increased risk of musculoskeletal disorders.

Regardless of the size of the monitor or how it is supported, the top of the screen should be at or below the user's horizontal line of sight when the head is in an upright position (eye height). If a user moves into a reclined posture, the height of the monitor may need to increase to keep the top of the screen at or below the user's line of sight. If the user tilts their head forward of perpendicular, the height of the monitor may need to be lowered.

The screen should be at or slightly rearward from perpendicular relative to the user's line of sight. As a general rule, the top of the screen should not be closer to the eyes than the bottom of the screen. For CRT type monitors, tilting the monitor rearward may require it to be lowered to maintain the screen at or below the horizontal line of sight. For flat screen displays, tilting the monitor rearward may require it to be raised.

Users that wear multifocal lenses or those who prefer the top line of the screen to be lower than the horizontal line of sight (looking down the bridge of their nose with head remaining upright) will require lower monitor placement to keep the screen within their preferred gaze angle.

For some user-monitor combinations it will be impossible to satisfy both the leg clearance envelope and the monitor location recommendations. In such cases, compromises will be necessary. To preserve the recommended knee clearance space, limitations of the viewing angle, viewing distance, and/or monitor size will be necessary.

Due to the many variations in the size of monitors, users' preferred viewing angles, viewing distances and knee clearance recommendations, many support heights and/or adjustment ranges are acceptable. Given the complexity and interdependencies of these many variables a recommendation based only on the horizontal line of sight with the user in an upright seated posture with the head erect is provided (variables such as monitor tilt, as well as parameters such as gaze angle, head tilt angle, etc., are not considered in the recommendation).

Recommendation for Monitor Height – Sitting and Standing

For upright-seated postures, the top line of the screen should be adjustable by a minimum of 280 mm (11.0 in.) from 1091 mm (43.0 in.) to 1371 mm (54.0 in.) above floor level.

For upright standing postures, the top line of the screen should be adjustable by a minimum of 371 mm (14.6 in.) from 1442 mm (56.8 in.) to 1813 mm (71.4 in.) above floor level.

Ultimate Test for Fit for Individual the User

The monitor should be positioned at a height that permits the user, when seated or standing in an upright posture with the head erect, to comfortably view the entire monitor display quickly and with little effort. The top of the screen should not be closer to the eyes than the bottom of the screen.

9 Other Related Topics

9.1 Laptops

General recommendations (ISO 9241-5, 5.4.1)

"The worksurface should provide support for the display and input devices and associated equipment and material, as well as for the hands and arms of the user."

Viewing distances and angles of view (ISO 9241-5, 5.4.3)

"The user should be able to angle, tilt, or swivel the display unit in such a way that she or he maintains a relaxed working posture regardless of the eye height, minimizes accommodative effort, and avoids disturbing reflections and glare."

General (Viewing conditions) (ISO 9241-303 5.1.1)

"A number of viewing conditions that are necessary, though not sufficient of themselves, can be specified for achieving fast, error-free and near-effortless viewing. These pertain to the design viewing distance and direction and to the needed gaze and head tilt angles of the viewer.

It is known that viewing distance and line-of-sight angle (gaze angle) need to be compatible with the user's vergence and accommodation capability and his or her capability to focus on short distances."

Design viewing direction* (ISO 9241-303, *5.1.3)

"For normal use in which the user moves his or her head, a display shall be legible from any angle of inclination up to at least 40° from the normal to the surface of the display, measured in any plane."

Design viewing distance (ISO 9241-303, 5.1.2)

"The design viewing distance is dependent on the task and the electronic visual display and shall not be less than 300 mm, being the typical minimum comfortable viewing distance, or near point, for normal [emmetropic] eyes of adults. There is a physiologically determined relationship between the near point and the age of the user… and between the near point and luminance level; however, there is a large variance in this relation."

"For larger visual displays, such as those in office tasks, the preferred viewing distance is longer – typically 400 mm to 750 mm."

Gaze and head tilt angles (ISO 9241-303, 5.1.4)

"For a typical working environment, with an approximately vertical position of the upper body, the work place and the visual display should permit the user to view the screen with a gaze angle from 0 degrees to 40 degrees and a head-tilt angle of from 0 degrees to 25 degrees. Note: these angle values can require the tilt of the display to be adjustable, so that perpendicular view can be obtained. In addition, the height [above floor level] of the display might have to be adjustable."

Relevant Body Dimensions and how are they Measured/Calculated:

Thigh Clearance; Popliteal Height; Elbow Height, Sitting: See Section 8.3.1
Elbow Height, Standing: See Section 8.3.2
Eye Height, Sitting; Popliteal Height: See Section 8.4.2.1
Eye Height, Sitting; Sitting Height, Stature: See Section 8.4.2.1

CAESAR Supporting Information:
See Sections 8.3.1 (Support Surface Height for Input Devices - Sitting), 8.3.2 (Support Surface Height for Input Devices - Standing), and 8.4 (Monitor Placement)

Why is Proper Positioning of the Laptop Important?

Laptop computers are prevalent in the office environment. Proper positioning of the laptop is important to enhance comfort, maintain productivity and to minimize the risk of injury. The fact that the display, keyboard, and input device are all connected in one unit compromises the concept of "fit" (ISO 9241-5, 4.3).

Discussion

Working solely on a laptop puts users in awkward postures. If the keyboard is correctly positioned for the user, the screen is not (See Figure 35). If the screen is correctly positioned, the keyboard is not. Compounding the problem, keyboards on laptops can be smaller than standard-size keyboards further contributing to awkward hand and wrist postures.

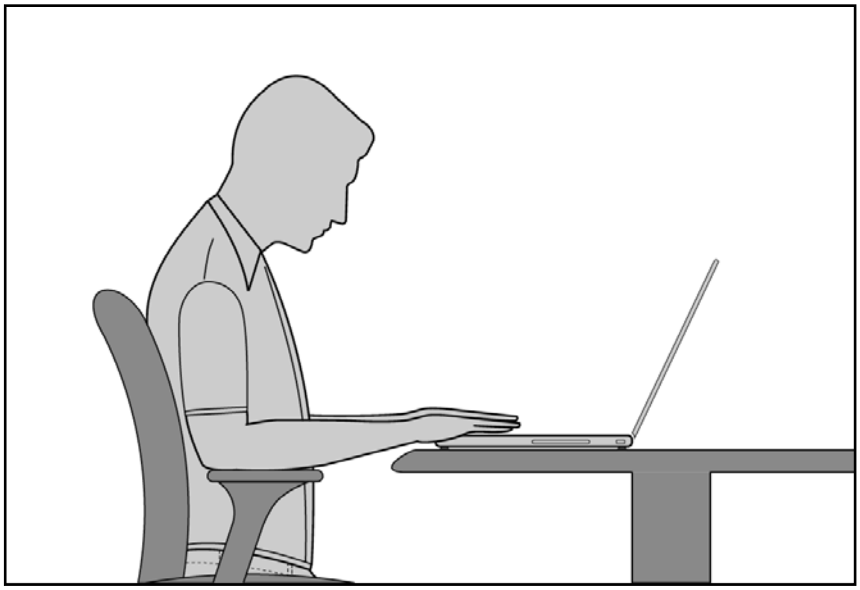

Figure 35 – Non-recommended Laptop Positioning

The same ergonomic principles for independent monitor and input device positioning apply to the use of laptops. This generally requires separation of the monitor and keyboard. This is often accomplished through the use of docking stations that allow for separate monitor and input device connections with the laptop functioning as the processor and hard drive. Laptops may also be positioned to be used as the visual display with external input devices connected to the laptop (See Figure 36).

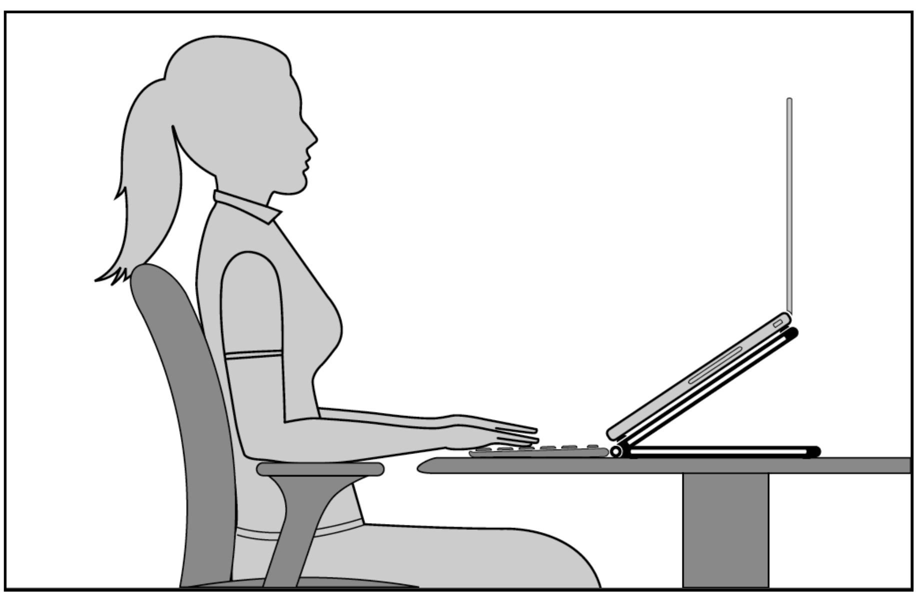

Figure 36 – Recommended Laptop Positioning

The monitor or laptop screen should be positioned at a height that permits the user, when seated or standing in an upright posture with the head erect, to comfortably view the entire monitor display. The top of the screen should not be closer to the eyes than the bottom of the screen.

Recommendation for Laptops

Due to the interdependencies of the many variables (laptop size, usage, number and type of external devices) the Ultimate Test for Fit is the most important criteria for the proper positioning of laptops.

Ultimate Test for Fit for Individual the User

Users should be able to comfortably work with the laptop and any external input devices in a variety of positions with the head, shoulders, elbows and wrists in neutral postures and adequate clearance for the lower body.

9.2 Multiple Monitors

Design Reference Posture (ISO 9241-5, 5.2.1)

“The line-of-sight in the relaxed seated position is inclined approximately by 35° below the horizontal.”

“The optimum position for the most important visual display is within +/- 15° in the vertical and horizontal direction from the line-of-sight.”

“In the standing position, the inclination of the line-of-sight is about 30º.”

Design viewing direction (ISO 9241-303, 5.1.3)

For normal use in which the user moves his or her head, a display shall be legible from any angle of inclination up to at least 40° from the normal to the surface of the display, measured in any plane.

Viewing distances and angles of view (ISO 9241-5, 5.4.3)

“The user should be able to angle, tilt, or swivel the display unit in such a way that she or he maintains a relaxed working posture regardless of the eye height, minimizes accommodative effort, and avoids disturbing reflections and glare.”

Viewing distance and its variation (ISO 9241-5, A.2.12)

> *"If a workstation comprises visual displays of different technologies, the viewing distances under which optimum visual conditions can be achieved should be determined before organizing and dimensioning the workstation."*

Design viewing distance (ISO 9241-303, 5.1.2)

> *"The design viewing distance is dependent on the task and the electronic visual display and shall not be less than 300 mm, being the typical minimum comfortable viewing distance, or near point, for normal [emmetropic] eyes of adults. There is a physiologically determined relationship between the near point and the age of the user… and between the near point and luminance level; however, there is a large variance in this relation."*

> *"For larger visual displays, such as those in office tasks, the preferred viewing distance is longer – typically 400 mm to 750 mm."*

General recommendations (ISO 9241-5, 5.4.1)

> *"For input device use, the height of the support surface should allow comfortable and efficient posture of the upper arms, forearms and hands…The worksurface should be height adjustable, and when required by task, also tiltable."*

Relevant Body Dimensions and how are they Measured/Calculated:

Eye Height, Sitting; Popliteal Height: See Section 8.4.2
Eye Height, Sitting; Sitting Height; Stature: See Section 8.4.2

CAESAR Supporting Information:
See section 8.4 (Monitor Placement)

Why is Proper Positioning of the Multiple Monitors Important?

Multiple monitors are becoming prevalent in the office environment. Proper positioning of multiple monitors is important to enhance comfort, maintain productivity and to minimize the risk of injury. If not positioned appropriately, the use of multiple monitors has the potential to compromise the concept of "fit" (ISO 9241-5, 4.3).

Discussion

The use of multiple monitors, whether vertically or horizontally positioned, may increase the visual and postural demands on the user. Where multiple monitors are used for occasional reference only, the primary monitor should be positioned according to the Guidelines in Section 8.4. Where multiple monitors are used equally, monitor placement should also adhere to the recommendations in Section 8.4.

ISO gives a variety of recommendations regarding the vertical placement of monitors. The optimal position of the most important part of the visual display is ± 15 degrees in both the horizontal and vertical plane from the user's predominant line of sight while gazing straight ahead. Multiple monitors should be positioned in the vertical plane such that their entire viewing areas are within a line-of-sight from horizontal to 35 degrees downward for seated positions and 30 degrees downward for standing positions. ISO does not provide clear recommendations regarding the horizontal placement of monitors; however, they do suggest that in the horizontal plane their entire viewing areas should be within a line-of-sight of ± 40 degrees.

Recommendation for Multiple Monitors

Due to the complexities and interdependencies of the many variables (monitor size, monitor usage, monitor support, number of monitors, etc.) the Ultimate Test for Fit is the most important criteria for the proper positioning of multiple monitors.

Ultimate Test for Fit for Individual the User

The monitors should be positioned at a height that permits the user, when seated or standing in an upright posture with the head erect, to comfortably view all of the screens. The top of the screens should not be closer to the eyes than the bottom of the screens.

The distance from the user's eyes to the screens should be approximately an arm's length away from the front of the body. This allows the user to focus on the screen images such that they are legible, readable and comfortable to use.

10 Summary of Guideline - Dimensions and Adjustment Ranges

Parameter	Section No.	Dimension/Range
The Work Chair	7	
Seat Height	7.1.1	Minimum seat height range for a chair or combination of chairs should include heights from 376 mm (14.8 in.) to 512 mm (20.2 in.)
Seat Depth: - if fixed - if adjustable	7.1.2	 Not be deeper than 415 mm (16.3 in.) The adjustment range should include a seat depth of 415 mm (16.3 in.) or less.
Seat Width:	7.1.3	The seat width should be at least 489 mm (19.2 in.).
Seat Pan Angle: -if fixed - if adjustable	7.1.4	 Within the range from 0° (horizontal) to 4° rearward Should include some part of the range from 0° (horizontal) to 4° rearward
Backrest Height:	7.2.1	Greater than 354 mm (13.9 in.)
Backrest Width in Lumbar Region:	7.2.2	At least 360 mm (14.2 in.)
Lumbar Support - If fixed - if adjustable	7.2.3	 The vertical height of the most forward point of the lumbar support to the seat pan should fall within the range of 150 mm to 250 mm (5.9 in. to 9.8 in.) Should include at least part of the recommended range given above.
Movements of the Seat Pan and Back Support	7.3	
- if fixed		The angle between the seat and back should allow the user to achieve a torso-to-thigh angle of at least 90°.
- if adjustable		The backrest should have an adjustment range of 15° or greater, of which at least 15° should fall within the range of 90° (vertical) to 120°.
Armrest Height	7.4.1	Should adjust to include the range of 195 mm to 289 mm (7.7 in. to 11.4 in.). May be achieved with single or multiple sets of armrests.
Armrest Length and Position	7.4.2	No specific armrest length or position recommendation, see Discussion and Ultimate Test For Fit.
Inside Distance Between Armrests (Pads / Caps) - if fixed -if adjustable	7.4.3	 No less than 493 mm (19.4 in.) Range should include 493 mm (19.4 in.)

Summary of Guideline -- Continued		
Parameter	**Section No.**	**Range**
Work Surfaces		
Clearances Under Work Surfaces for Seated Work	8.1	
Height Clearance for Legs - Sitting - if fixed - if adjustable	8.1.1	No less than 698 mm (27.5 in.) at the front edge of the work surface and 643 mm (25.3 in.) at 434 mm (17.1 in.) rearward from the front edge of the work surface It should include a height clearance of 698 mm cm (27.5 in.) as part of the adjustment range
Depth Clearance for Knees - Sitting	8.1.2	No less than 434 mm (17.1 in.)
Width Clearance for Legs - Sitting	8.1.3	No less than 619 mm (24.4 in.)
Height Clearance at Foot Level - Sitting	8.1.4	No less than 114 mm (4.5 in.)
Depth Clearance at Foot Level - Sitting	8.1.5	No less than 589 mm (23.2 in.)
Clearances Under Work Surfaces for Standing Work	8.2	
Height Clearance for Feet - Standing	8.2.1	No less than 114 mm (4.5 in.)
Depth Clearance for Feet - Standing	8.2.2	No less than 152 mm (6.0 in.)
Width Clearance for Feet - Standing	8.2.3	No less than 566 mm (22.4 in.)
Support Surface Heights for Input Devices and Computers	8.3	
Support Surface Height for Input Devices -- Sitting - if fixed - if adjustable	8.3.1	No less than 747 mm (29.4 in.) as measured to the top of the surface Minimum adjustment range from 575 mm (22.6 in.) to 747 mm (29.4 in.) as measured to the top of the surface
Support Surface Height for Input Devices -- Standing - if fixed - if adjustable	8.3.2	If the support surface height is not adjustable, its height should fall within the range given below. Should include an adjustment range from 973 mm (38.3 in.) to 1237 mm (48.7 in.) as measured to the top of the surface
Monitor Placement	8.4	
Distance to Monitor – Sitting or Standing	8.4.1	Distance to monitor should be a minimum of 400 mm (15.7 in.)
Monitor Height Range – Sitting	8.4.2	Seated postures - top line of screen should be adjustable from 1091 mm (43.0 in.) to 1371 mm (54.0 in.).
Monitor Height Range – Standing	8.4.2	Standing postures - top line of screen should be adjustable from 1442 mm (56.8 in.) to 1813 mm (71.4 in.).
Other Related Topics		
Laptops	9.1	No specific recommendation, see Discussion and Ultimate Test For Fit.
Multiple Monitors	9.2	No specific recommendation, see Discussion and Ultimate Test For Fit.

11 Other Relevant Principles from ISO 9241-5

The following ISO references may influence comfort, performance and safety.

- *ISO 4.1* *"Workplace design should be preceded by an analysis of the tasks that it is to support."*

- *ISO 4.2* *"…workstation design should be appropriate for the range of tasks to be performed…taking into account user characteristics."*

- *ISO 4.4* *"The workplace organization, the task and the furniture should encourage voluntary postural changes."*

  "Postures adopted by users and the need for changes in posture are very markedly influenced by work organization and in particular, task requirements."

- *ISO 4.5* *"The users should be informed why and how the furniture and other devices (e.g. support for the visual display unit) should be adjusted."*

  "…training should ensure that users are familiar with the mechanisms of adjustment and how to decide when furniture adjustment for the individual user and task is needed."

- *ISO 5.3* *"Furniture adjustment controls should be convenient and designed so that they encourage correct use.*

  - *they should preferably be operable from the usual working position;*
  - *they should not require undue force for actuation;*
  - *they should not require any special training or special tools before adjustment can be made;*
  - *controls should be designed to prevent unintentional actuation."*

- *ISO 5.4.4* *"The finish of the work surfaces should not exceed silky matt (corresponding to 45 gloss units or to a 60º reflectometer value of less than 20) to minimize specular reflections."*

  "There should be no sharp edges or corners on work surfaces and their supporting framework which could cause injury or discomfort to users."

- *ISO 5.4.5* *"If drawers are part of the workstation, it shall not be possible to pull a drawer out unintentionally so that it falls."*

- *ISO 5.5.3.4 "The type of castor shall suit the properties of the floor surface…The work chair shall not move away easily when unoccupied. Castors with a low resistance cannot be used safely on a hard floor surface."*

- *ISO 5.6.1 "In tasks where the Computer user works from hard copy, a document holder is recommended. It allows the source document to be positioned at a height, visual distance and plane similar to that of the display itself."*

12 Recommended Reading

- US Dept. of Justice — 2010 ADA Standards for Accessible Design.
- BIFMA/CMD-1 — Universal Measurement Procedure© for the Use of BIFMA Chair Measuring Device® (CMD)
- BIFMA PD-1-2011 — Mechanical Test Standards - Compiled Definitions
- ANSI/BIFMA X5.1 — American National Standard for Office Furnishings – General Purpose Office Chairs – Tests
- ANSI/BIFMA X5.5 — American National Standard for Office Furnishings – Desk/Table Products – Tests
- ANSI/BIFMA X5.6 — American National Standard for Office Furnishings – Panel Systems Tests
- ISO 9241-2 — Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 2: Guidance on Task Requirements
- ISO 9241-302 — Ergonomics requirements of human-system interaction – Part 302: Terminology for electronic visual displays
- ISO 9241-303 — Ergonomics requirements of human-system interaction – Part 303: Requirements for electronic visual displays
- ISO 9241-5 — Ergonomic requirements for office work with visual display terminals (VDTs) – Part 5: Workstation layout and postural requirements
- ISO 9241-6 — Ergonomic requirements for office work with visual display terminals (VDTs) – Part 6: Guidance on the work environment
- ISO 9241-9 — Ergonomic requirements for office work with visual display terminals (VDTs) – Part 9: Requirements for non-keyboard input devices
- ISO/TR 7250-1 — Basic human body measurements for technological design -- Part 1: Body measurement definitions and landmarks
- ISO/TR 7250-2 — Basic human body measurements for technological design – Part 2: Statistical summaries of body measurement from individual ISO populations

- ISO TR 24496:2012 — Office furniture – Office work chairs – Methods for the determination of dimensions
- CSA-Z412 — Guideline on Office Ergonomics
- CAN/CGSB 44-232 — Task Chairs for Office Environments
- CAN/CGSB 44-227 — Freestanding Office Desk Products and Components
- ANSI/HFES 100 — Human Factors Engineering of Computer Workstations
- Occupational Safety and Health Series — International Data on Anthropometry & Health Series Nº 65 International Labour Office, Geneva
- NATICK/TR-89/044 — The 1987-88 anthropometric survey of Army personnel prepared for the United States Army Natick Research, Development and Engineering Center in Natick, Massachusetts. Copies of the NATICK report may be obtained from the National Technical Information Service using accession number AD A225 094.
- CAESAR Final Report Vol. I — Civilian American and European Surface Anthropometry Resource (CAESAR) Final Report, Volume I: Experimental Designs & Data Descriptions, June 2002.
- CAESAR Final Report Vol. II — Civilian American and European Surface Anthropometry Resource (CAESAR) Final Report, Volume II: Detailed Methodology & Descriptions, June 2002.

Appendix A - Anthropometric Measurement Methodology

Much of the text in this Appendix is derived from the following conference proceedings, and is used with permission from the authors.

Openshaw, S., & Trippany, D. (2010). Panel Discussion: Methodology for creating an anthropometric database for workstation setup using CAESAR, NATICK and NHANES. Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting, San Francisco, California, 54 1776-1779. doi:10.1518/107118110794002945

A.1 Anthropometric Methodology Introduction

This appendix describes the methodology used to analyze the 2002 CAESAR anthropometric dataset and its use within this Guideline. It is the intent of this Guideline to accommodate a specific user population meant to represent today's office workers, encompassing the 5th percentile female through the 95th percentile male (or in some cases female) for any single dimension relevant to workstation design using a univariate approach. This Guideline does not address the multivariate analysis (See Appendix C for an introduction to multivariate analysis).

A.2 Military vs. Civilian Datasets

Most of the design guidelines and standards that are used by engineers, designers, and manufacturers (e.g., BIFMA G1-2002, ANSI/HFES 100-2007) are based on anthropometric data from the US Army collected in the 1980s (Gordon et. al., 1988). This data (referred to as the NATICK or ANSUR database) has been a great resource for the past 25 years as an estimation of user anthropometrics, but since military subjects were primarily younger and more fit than the general public, there were some limitations to using the data to represent the civilian working population. The changing demographics of the population in the United States show that there is an increase in obesity in the population. The US Center for Disease Control has published statistics tracking this trend since 1985 (CDC, 2008). This increase can affect the design of workstations and products that are used by consumers.

In the late 1990s, several companies and organizations worked together to create a civilian-based anthropometric dataset from North American and European subjects. The Civilian American and European Surface Anthropometry Resource (known as CAESAR) collected traditional anthropometric measurements and 3-dimensional body scans of volunteers throughout the United States & Canada, Italy, and the Netherlands. The North American dataset has been incorporated into this Guideline because it allows for the specification of furniture design and work environments in a way that is more reflective of contemporary civilians than a military-based survey from the 1980s.

A.3 Choosing a Dataset

This Guideline references certain anthropometric measurements to make recommendations for product dimensions and adjustability ranges. A review of the CAESAR dataset shows that it contains a set of measurements that are “equivalent” or comparable to the traditional measurements used from the NATICK dataset in the previous Guideline (BIFMA G1-2002). Traditional measures are often taken with the subject by palpating bony prominences and measuring distances in vivo. Some measurements were not collected in CAESAR the same way that they were collected in NATICK (i.e., popliteal height, abdominal extension depth). In these situations the CAESAR 3D scan images were used to extract data from markers that were placed on the subjects’ bodies and in some cases from “virtual landmarks” that were inserted after the scans were taken (Robinette et. al., 2002a, 2002b).

A.3.1 Extracted Measurements

The use of extracted measurements allows BIFMA to discern dimensions that were omitted or not planned in the original data collection process. Extracted measures are taken by manipulating a 3D object in software and extracting XYZ coordinates to measure dimensions.

A.3.2 Extracted vs. Traditional Measurements

For this Guideline, CAESAR measurements were selected that were equivalent to the NATICK measurements. For CAESAR measurements that did not have equivalent, extracted measures that were similar to the traditional measurement were chosen, with the understanding that they may not represent the dimension in exactly the same way as the traditional measurements. Table A1 shows the measurements that were used and whether they were equivalent or not between the NATICK and CAESAR datasets.

During data analysis, BIFMA found that there was an algorithm error in about 400 of the roughly 2400 data points for the Seating Reference Point Y (SRP Y). The data showed that these points were outliers and were not calculated correctly. BIFMA funded a project to have the data reanalyzed and corrected so that those data points could be included for the analysis.

Table A1 Natick vs. CAESAR Anthropometric Measurements

G1 Parameters	NATICK Measurements	CAESAR Measurements	Equivalent
Seat Height	Popliteal Height	Pose C (Popliteal), Extracted	No
Seat Depth	Buttock-Popliteal Length	Popliteal Fossa Pose C – SRP Z Pose C, Extracted	No
Seat Width	Hip Breadth, Sitting	Hip Breath, Sitting	Yes
Lower Backrest Height	None	Tenth Rib Midspine, Sitting	No
Upper Backrest Height	Acromial Height, Sitting	Acromial Height, Sitting	Yes
Lower Backrest Width	Waist Breadth	Bi-Cristale Breadth, Extracted	No
Arm Rest Height	Elbow Height, Sitting (Right)	Elbow Height, Sitting (Right)	Yes
Arm Rest Length	Abdominal Extension Depth, Sitting	Abdominal Extension Depth, Pose C, Extracted	No
Inside Distance Between Arms	Hip Breadth, Sitting	Hip Breadth, Sitting	Yes
Height Clearance for Legs, Sitting	Thigh Clearance (Right)	Thigh Clearance, Extracted (Coverage Pose)	No
Height Clearance for Legs, Sitting	Knee Height, Sitting (Right)	Knee Height, Sitting (Right)	Yes
Depth Clearance for Knees, Sitting	Buttock-Knee Length (Right)	Buttock-Knee Length (Right)	Yes
Depth Clearance for Knees, Sitting	Abdominal Extension Depth	Abdominal Extension Depth, Pose C, Extracted	No
Width Clearance for Legs, Sitting	Hip Breadth, Sitting	Bi-Lateral Femoral Epicondyle Breadth, Sitting	No
Height Clearance at Foot Level	Lateral Malleolus Height (Right)	Lateral Malleolus (Ankle Height - Right), Extracted	No
Depth Clearance at Foot Level, Sitting	Buttock-Popliteal Length	Popliteal Fossa Pose C - SRP Z, Pose C	No
Depth Clearance at Foot Level, Sitting	Foot Length (Right)	Foot Length (Right)	Yes
Depth Clearance at Foot Level, Sitting	Abdominal Extension Depth	Abdominal Extension Depth, Pose C, Extracted	No
Height Clearance for Feet, Standing	Lateral Malleolus Height (Right)	Lateral Malleolus (Ankle Height - Right), Extracted	No
Depth Clearance for Feet, Standing	None	N/A	N/A
Width Clearance for Feet, Standing	Hip Breadth, Sitting	Hip Breadth, Sitting	Yes
Support Surface Height for Input Devices, Sitting	Popliteal Height	Pose C (Popliteal), Extracted	No

G1 Parameters	NATICK Measurements	CAESAR Measurements	Equivalent
Support Surface Height for Input Devices, Sitting	Elbow Height, Sitting (Right)	Elbow Height, Sitting (Right)	Yes
Support Surface Height for Input Devices, Standing	Elbow Height, Standing (Right)	Elbow Height, Standing (Right)	Yes
Distance to Monitor, Sitting or Standing	None	N/A	N/A
Monitor Height Range, Sitting	Eye Height, Sitting (Right)	Eye Height, Sitting (Right)	Yes
Monitor Height Range, Sitting	Popliteal Height	Pose C (Popliteal), Extracted	No
Monitor Height Range, Standing	Eye Height, Standing (Right)	Calculated as Stature – "[Sitting Height – Eye Height, Sitting]"	No

A.4 Using NHANES to Establish Weighting Criteria

Because CAESAR used a volunteer sampling methodology that was not representative of the civilian population, there was a need to statistically weight the CAESAR dataset in order to extrapolate it to match the demographics of the current US population. The technical report from CAESAR (Robinette et. al., 2002a, 2002b) states that researchers used a weighting stratification criteria based on gender, race, age, height, and weight to help assign different weighting categories to the 2376 data points from North America. The original CAESAR dataset used NHANES III data to create subject weights for the CAESAR data so that it would be comparable to the 2000 US population for data analysis. BIFMA conducted the analysis averaging the NHANES 2007-2008 and 2009-2010 surveys, as recommended by NHANES (CDC, 2010) for subjects between the ages of 18-65. The methodology used to categorize the NHANES data was a modification of the CAESAR Technical Report (Robinette, 2002) and NHANES Weighting Procedures (CDC, 2010).

A.4.1 Weighting the Dataset

The CAESAR dataset was initially sub-divided into 5 different categories based on height and weight, as shown in Figure A1 (Harrison, 2002).

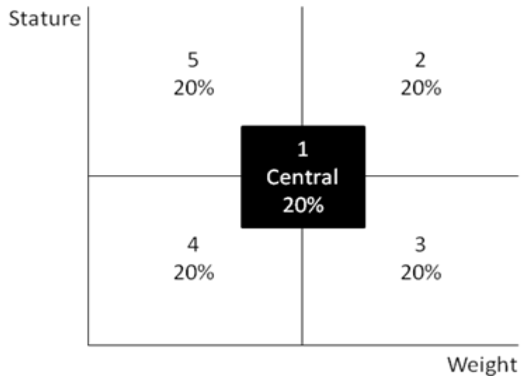

Figure A1 - 5-zone Stratification

Because of the potentially large quadrant sizes used in the original methodology, equal weight was being placed on individuals that might be very disparate. In discussions with anthropometric experts and statisticians, it was recommended that BIFMA consider splitting the data into more than 5 categories for height and weight. In addition to using the mean height and weight, we added stratifications for the 25th and 75th quartiles, thus creating a stratification of 16 zones for anthropometric weighting categories (Figure A2). The 16-zone division allows for similar subject heights and weights to be evaluated together.

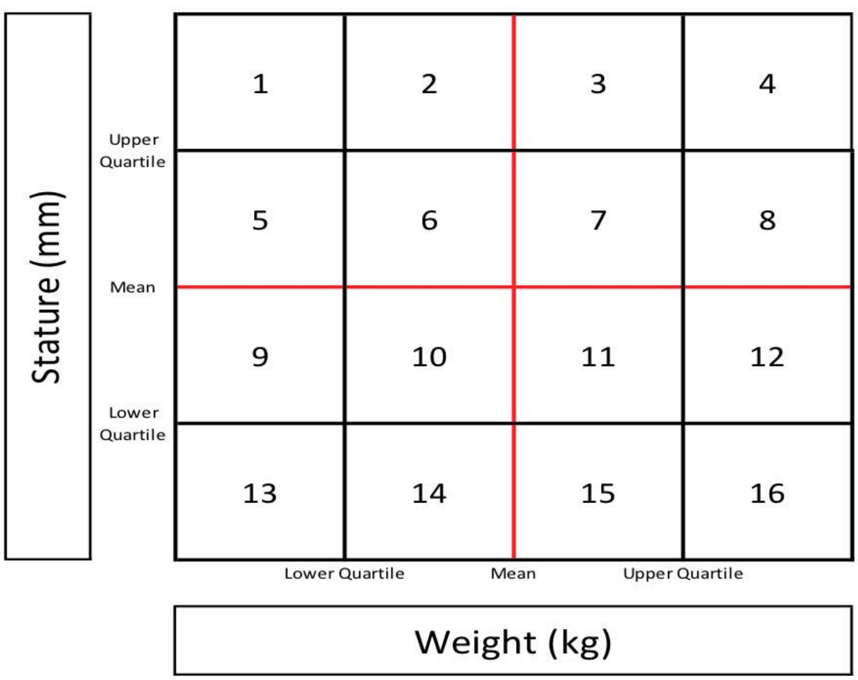

Figure A2 – 16-zone Stratification

As done in the original CAESAR weighting methodology, weighting of the CAESAR dataset by BIFMA was based on gender, race, age, height, and weight. The 16-zone anthropometric stratification resulted in 288 (2x3x3x16) different demographic/anthropometric weighting cells as shown in Table A2.

Table A2. 16-zone variables and categories

Variable	Categories
Gender	Male, Female
Ages	18-29, 30-44, 45-65
Race	White, Black, Other
Height	Based on NHANES 2007-2008 and 2009-2010 25th, 50th, and 75th quartiles for height
Weight	Based on NHANES 2007-2008 and 2009-2010 25th, 50th, and 75th quartiles for weight

The weights were calculated by taking the relative frequency of CAESAR subjects in each of the 288 categories and dividing it by the relative frequency of individuals in similar categories in the NHANES dataset.

Equation A1

$$\left(\frac{\frac{NHANES\ Total\ in\ Category\ 1\ to\ 288}{Total\ NHANES\ Subjects}}{\frac{CAESAR\ Total\ in\ Category\ 1\ to\ 288}{Total\ CAESAR\ Subjects}}\right) = Weight$$

The weights for the CAESAR dataset, as used in this Guideline per the described methodology, ranged from 0.25 to 11.50 for males and 0.19 to 14.52 for females with a mean weight of 1.01 and 0.99, respectively.

A.4.2 Weighting Stratification Tables

The following tables demonstrate the distribution of weighting for CAESAR subjects in each of the 288 stratification categories that were used in the BIFMA methodology. The tables show the height in each row, and the weight and age in the columns. The numbers in each cell represent the weighting for that stratification level. If the cell is blank, then there were no subjects in CAESAR that were represented by that stratification.

Table A3. White Female CAESAR Subject Stratification Weights

Female / White	AGE											
WEIGHT	Light			Med Light			Med Heavy			Heavy		
HEIGHT	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
Tall	0.53	0.21	0.70	0.33	0.19	0.30	0.95	0.40	0.43	2.59	0.76	1.30
Med Tall	0.64	0.23	0.31	0.97	0.42	0.41	1.44	1.66	0.66	4.60	1.18	1.04
Med Short	0.39	0.30	0.34	0.78	0.33	0.58	1.10	1.23	0.92	1.73	0.89	2.68
Short	0.68	0.39	0.30	4.89	0.49	0.80	1.87	1.09	0.84		1.73	1.05

Table A4. Black Female CAESAR Subject Stratification Weights

Female / Black	AGE											
WEIGHT	Light			Med Light			Med Heavy			Heavy		
HEIGHT	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
Tall	1.29	1.73	2.01	0.91	1.44	2.88	2.11	0.94	2.78	2.24	2.25	
Med Tall	0.92		2.01	1.15	1.05		0.86	3.88	6.04	3.16	1.63	6.04
Med Short	1.61	2.88	1.73	2.01	2.73	4.89	5.46		1.52	1.50	7.48	4.22
Short	1.73	0.79	2.59	2.59	0.93	1.82	3.02	2.59	2.30	4.89	1.15	3.83

Table A5. Other Female CAESAR Subject Stratification Weights

Female Other		AGE											
		18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
HEIGHT	Tall	1.44			1.01			4.31			2.44		
	Med Tall	1.25			2.20			4.31	5.75	6.04	8.05	3.02	
	Med Short	0.70	2.73	2.73	3.02	3.74	8.63	5.18	3.07	10.93	5.46	3.45	
	Short	1.22	1.62	3.77	11.65	7.12	11.65	8.05	14.52			14.09	
		Light			Med Light			Med Heavy			Heavy		
		WEIGHT											

Table A6. White Male CAESAR Subject Stratification Weights

Male White		AGE											
		18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
HEIGHT	Tall	0.64	0.43	0.33	0.96	0.33	0.65	0.41	0.32	0.57	0.89	0.51	0.68
	Med Tall	0.66	0.29	0.66	0.53	0.35	0.75	0.43	0.53	0.74	0.81	1.01	0.89
	Med Short	0.75	0.54	0.64	0.66	0.34	0.60	2.01	0.59	0.98		1.68	2.97
	Short	0.55	0.66	0.47	0.58	0.25	0.93	1.73	0.58	1.09		1.44	0.90
		Light			Med Light			Med Heavy			Heavy		
		WEIGHT											

Table A7. Black Male CAESAR Subject Stratification Weights

Male		AGE											
Black		18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
HEIGHT	Tall		0.72			1.29		2.59	1.53		1.06	2.52	3.36
	Med Tall	11.50			0.81	1.65			1.82	2.40	1.37	1.09	4.22
	Med Short	3.31	0.47	4.03	2.30	5.75	2.59	4.31	1.37	3.64	2.01	6.90	
	Short	4.46	1.01	3.45	4.03	0.72	2.44		1.25	1.82			
		Light			Med Light			Med Heavy			Heavy		
		WEIGHT											

Table A8. Other Male CAESAR Subject Stratification Weights

Male		AGE											
Other		18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65	18-29	30-44	45-65
HEIGHT	Tall	2.01			2.01	1.15		1.29	1.87		2.73	5.18	2.01
	Med Tall	2.11	0.29		5.46	3.16	3.45	4.89	3.31	1.82			
	Med Short	1.52	0.91	1.15	2.68	1.07	8.63	3.02	2.59	3.45		6.33	
	Short	3.41	2.12	3.77	2.01	2.38	9.59	1.73	8.91		5.18		6.04
		Light			Med Light			Med Heavy			Heavy		
		WEIGHT											

A.5 Eliminating Outliers

The weighted dataset was analyzed using JMP 9.0 (JMP, 2010) to create stem leaf plots used to identify possible anomalies in the data. Outliers were defined using the following questions:

(a) On the stem leaf diagram, how far away is the outlying value(s) from the other points?
(b) Is the data point within the design parameter range specified by BIFMA G1-2002?
(c) What does the 3D scan of the individual look like for this individual value—is it really an outlier value?

Based on the answers to these questions, it was determined if the points would be considered outliers or not. This procedure was followed for each of the anthropometric variables used in this Guideline. This resulted in 48 subjects being removed from the dataset.

A.6 Statistical Methodology

JMP 9.0 (JMP, 2010) statistical software was employed to perform univariate analysis on the weighted resultant dataset. The analysis calculated the 5th, 50th and 95th percentile of the normal distribution of each gender for all of the anthropometric variables utilized in this Guideline.

A.7 Acknowledgements

BIFMA would like to recognize the time and efforts of Dr. Claire Gordon, Biological Anthropologist, U.S. Army Natick Soldier Center, for consulting with BIFMA on the methodology and techniques used in analyzing the CAESAR dataset with NHANES 2007-2008 and 2009-2010 datasets.

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Appendix B1 – Empirical Percentile Tables (Males / Metric Units)

MALES	METRIC UNITS													
Empirical Percentile	10th Rib Midspine (mm)	Abdominal Extension Depth (mm)	Acromial Ht Sit Rt (mm)	Ankle Ht Rt (Malleolus, Lateral) (mm)	Bicristale Brth (mm)	Bi-lateral Femoral Epicondyle Brth Sit (mm)	Buttock-Knee Length (mm)	Butt-Pop Length, Calculated (mm)	Depth at Feet, Sitting (mm)	Depth at Knees (mm)	Digit II to Meta-Phal V (mm)	Elbow Height, Sitting (mm)	Elbow Ht From Floor, Sitting (mm)	Elbow Ht Stand Rt (mm)
1%	226	214	505	58	267	343	531	420	297	170	66	179	599	1004
2%	234	218	513	60	274	362	544	426	317	191	69	184	605	1019
3%	240	222	525	60	281	371	552	430	334	207	71	190	609	1028
5%	250	228	537	62	288	383	559	438	356	236	74	196	618	1042
10%	260	238	548	64	301	401	570	448	381	256	78	207	628	1062
15%	266	246	555	66	309	411	583	458	401	272	81	213	639	1077
20%	272	254	561	66	316	420	590	464	413	284	83	219	646	1088
25%	276	260	568	68	321	428	595	470	425	293	85	224	652	1096
30%	280	264	575	68	328	436	601	472	433	300	87	229	659	1105
35%	284	268	581	70	333	442	605	476	441	307	88	232	665	1112
40%	288	276	587	70	338	449	608	480	450	313	90	236	671	1122
45%	292	282	591	70	343	455	612	484	458	318	91	239	675	1129
50%	294	288	595	72	348	461	617	488	465	324	93	243	681	1137
55%	298	296	599	72	353	469	620	492	471	330	94	246	686	1142
60%	302	302	603	74	359	477	625	495	476	337	95	250	692	1150
65%	306	308	609	74	365	484	629	498	482	343	97	254	696	1158
70%	310	316	613	76	371	490	634	504	488	348	98	258	702	1166
75%	314	326	619	76	377	502	640	509	496	354	100	262	706	1174
80%	320	336	625	78	388	513	646	513	506	359	101	266	712	1182
85%	324	354	631	80	396	525	654	519	515	367	103	272	721	1195
90%	330	368	639	80	412	541	665	528	525	378	106	278	729	1214
95%	346	406	651	84	424	574	677	542	544	389	109	289	742	1232
97%	358	436	657	86	438	591	686	554	554	397	111	294	749	1246
98%	366	448	664	86	447	602	692	558	566	402	113	296	754	1254
99%	380	474	675	88	474	623	704	565	581	411	116	306	764	1268

Appendix B1 – Empirical Percentile Tables (Males / Metric Units) - continued

MALES	METRIC UNITS													
Empirical Percentile	Eye Height, Sitting (mm)	Eye Ht Sitting from floor (mm)	Eye Ht Standing, from floor (mm)	Foot Length (mm)	Height at Thighs from floor, Sitting (mm)	Hip Breadth, Sitting (mm)	Knee Height (mm)	Meta-Phal V Breadth, Standing (mm)	Popliteal Height (Coverage Pose - C) (mm)	Radiale-Stylion Length, Right (mm)	Sitting Height (mm)	Stature (mm)	Thigh Height Pose C (mm)	Weight (kg)
1%	715	1109	1484	235	510	310	488	342	374	227	828	1600	120	54.9
2%	722	1125	1498	238	526	319	493	353	380	232	835	1611	130	57.8
3%	729	1135	1510	240	534	325	499	361	386	235	846	1623	134	59.2
5%	741	1146	1519	244	542	333	508	371	392	238	855	1634	138	62.8
10%	757	1171	1557	249	556	342	520	386	402	244	873	1671	144	67.3
15%	765	1183	1574	253	568	350	528	397	408	247	881	1690	148	69.4
20%	776	1195	1592	255	576	356	534	405	414	250	889	1708	152	72.3
25%	781	1203	1602	258	582	359	539	410	420	252	896	1718	154	74.6
30%	786	1213	1612	260	586	364	544	416	424	255	901	1729	158	76.4
35%	790	1220	1624	262	591	368	549	422	428	258	907	1741	160	78.5
40%	795	1227	1634	263	596	372	554	428	430	260	912	1750	162	80.5
45%	799	1234	1641	265	600	376	557	434	434	262	916	1758	164	82.8
50%	805	1241	1648	266	604	380	561	440	438	263	922	1766	166	85.5
55%	809	1247	1656	268	609	384	563	448	442	266	928	1775	168	88.0
60%	814	1253	1664	270	614	387	567	454	444	267	932	1782	170	90.5
65%	819	1262	1674	273	617	393	570	461	448	269	937	1793	174	92.5
70%	824	1268	1685	275	622	399	576	468	452	272	943	1805	176	95.0
75%	830	1282	1697	277	626	405	580	475	456	274	949	1815	178	98.0
80%	836	1292	1714	280	634	412	585	487	458	277	955	1831	180	102.0
85%	843	1300	1730	282	639	418	591	500	464	280	963	1850	185	106.6
90%	853	1315	1756	286	648	431	599	517	472	284	971	1872	190	112.5
95%	869	1341	1783	291	668	447	613	539	482	291	986	1901	199	120.6
97%	882	1353	1802	295	675	463	621	561	490	294	999	1917	203	131.3
98%	887	1369	1815	298	680	474	627	567	494	297	1004	1940	206	136.3
99%	894	1382	1836	304	690	502	636	579	504	304	1015	1964	210	144.2

Appendix B2 – Empirical Percentile Tables (Females / Metric Units)

FEMALES	METRIC UNITS													
Empirical Percentile	10th Rib Midspine (mm)	Abdominal Extension Depth (mm)	Acromial Ht Sit Rt (mm)	Ankle Ht Rt (Malleolus, Lateral) (mm)	Bicristale Brth (mm)	Bi-lateral Femoral Epicondyle Brth Sit (mm)	Buttock-Knee Length (mm)	Butt-Pop Length, Calculated (mm)	Depth at Feet, Sitting (mm)	Depth at Knees (mm)	Digit II to Meta-Phal V (mm)	Elbow Height, Sitting (mm)	Elbow Ht From Floor, Sitting (mm)	Elbow Ht Stand Rt (mm)
1%	228	190	493	52	257	227	508	401	256	167	55	176	547	940
2%	234	194	501	52	263	247	519	412	269	176	59	183	560	952
3%	236	202	507	54	266	256	525	418	277	185	61	189	563	954
5%	244	208	515	54	271	269	532	425	297	205	63	195	570	968
10%	252	220	525	58	279	294	544	434	328	227	68	205	580	988
15%	258	230	532	58	285	310	553	442	349	241	70	211	589	1002
20%	262	236	537	60	290	320	559	448	366	254	72	215	596	1010
25%	267	244	542	62	295	331	565	452	378	264	74	220	602	1018
30%	270	252	545	62	300	341	570	456	391	273	76	225	606	1024
35%	274	260	549	64	304	349	576	460	401	282	77	228	610	1031
40%	278	268	555	64	308	355	580	464	410	289	79	231	614	1039
45%	282	274	557	64	313	363	584	468	418	296	80	234	619	1044
50%	286	284	561	66	318	370	588	470	427	303	81	238	622	1050
55%	288	290	565	66	323	375	595	476	435	311	83	241	627	1055
60%	292	300	569	68	330	388	598	479	442	316	84	245	632	1061
65%	294	308	573	68	336	394	604	484	451	323	85	248	636	1068
70%	298	318	577	68	343	405	611	488	458	328	87	252	641	1073
75%	302	332	583	70	352	416	617	492	468	335	88	255	646	1080
80%	308	346	587	70	360	432	624	498	475	344	89	262	652	1092
85%	316	366	594	72	370	446	630	504	484	353	91	266	658	1102
90%	334	386	603	74	384	463	643	510	498	361	93	274	668	1118
95%	354	418	613	76	404	488	653	526	515	376	97	281	685	1140
97%	362	434	623	78	417	516	672	536	525	387	100	291	697	1154
98%	368	446	633	80	424	524	687	540	537	394	101	295	706	1170
99%	384	460	645	80	434	545	691	552	556	409	105	304	714	1208

Appendix B2 – Empirical Percentile Tables (Females / Metric Units) - continued

FEMALES	METRIC UNITS													
Empirical Percentile	Eye Height, Sitting (mm)	Eye Ht Sitting from floor (mm)	Eye Ht Standing, from floor (mm)	Foot Length (mm)	Height at Thighs from floor, Sitting (mm)	Hip Breadth, Sitting (mm)	Knee Height (mm)	Meta-Phal V Breadth, Standing (mm)	Popliteal Height (Coverage Pose - C) (mm)	Radiale-Stylion Length, Right (mm)	Sitting Height (mm)	Stature (mm)	Thigh Height Pose C (mm)	Weight (kg)
1%	672	1028	1381	213	468	335	449	239	326	203	779	1490	114	45.1
2%	685	1045	1400	216	476	342	458	251	334	209	791	1504	118	47.2
3%	694	1052	1405	219	480	347	462	261	340	212	801	1511	122	48.8
5%	700	1061	1412	221	485	352	465	271	346	215	809	1519	124	51.0
10%	712	1074	1439	224	498	364	476	289	354	218	817	1548	129	53.7
15%	719	1089	1454	227	504	371	480	299	358	222	826	1561	132	56.2
20%	726	1098	1467	229	510	378	485	307	362	224	834	1574	134	58.3
25%	731	1105	1474	231	516	384	489	316	368	227	840	1584	136	60.3
30%	737	1113	1486	233	520	391	493	323	372	229	845	1594	140	62.4
35%	742	1118	1498	235	524	398	496	330	376	230	850	1604	142	64.2
40%	745	1125	1505	236	528	403	500	336	378	232	854	1612	144	65.8
45%	748	1131	1513	238	530	410	503	341	382	234	857	1620	146	67.8
50%	753	1138	1521	240	536	415	507	348	386	236	861	1630	148	70.7
55%	757	1143	1529	242	540	422	510	353	388	237	865	1637	150	72.8
60%	760	1149	1536	243	542	429	513	359	392	240	868	1645	152	75.3
65%	764	1156	1545	245	548	435	517	367	396	241	873	1653	155	77.6
70%	768	1162	1555	247	552	443	521	376	400	243	877	1664	158	80.7
75%	773	1169	1565	249	556	451	526	384	404	246	883	1676	162	85.0
80%	780	1178	1577	251	562	461	532	394	408	249	890	1688	166	89.1
85%	787	1191	1595	254	568	473	537	406	414	253	898	1704	170	93.9
90%	797	1207	1618	256	576	489	545	422	420	257	909	1729	174	101.1
95%	810	1230	1652	262	587	517	557	457	430	263	925	1768	180	113.8
97%	820	1252	1676	266	596	535	564	473	436	268	938	1793	184	116.6
98%	830	1260	1690	269	608	537	573	495	440	270	943	1810	190	120.4
99%	837	1274	1714	273	616	558	580	511	448	278	953	1831	196	129.7

Appendix B3 – Empirical Percentile Tables (Males / English Units)

MALES	ENGLISH UNITS													
Empirical Percentile	10th Rib Midspine (mm)	Abdominal Extension Depth (mm)	Acromial Ht Sit Rt (mm)	Ankle Ht Rt (Malleolus, Lateral) (mm)	Bicristale Brth (mm)	Bi-lateral Femoral Epicondyle Brth Sit (mm)	Buttock-Knee Length (mm)	Butt-Pop Length, Calculated (mm)	Depth at Feet, Sitting (mm)	Depth at Knees (mm)	Digit II to Meta-Phal V (mm)	Elbow Height, Sitting (mm)	Elbow Ht From Floor, Sitting (mm)	Elbow Ht Stand Rt (mm)
1%	8.9	8.4	19.9	2.3	10.5	13.5	20.9	16.5	11.7	6.7	2.6	7.0	23.6	39.5
2%	9.2	8.6	20.2	2.4	10.8	14.3	21.4	16.8	12.5	7.5	2.7	7.2	23.8	40.1
3%	9.4	8.7	20.7	2.4	11.1	14.6	21.7	16.9	13.1	8.1	2.8	7.5	24.0	40.5
5%	9.8	9.0	21.1	2.4	11.3	15.1	22.0	17.2	14.0	9.3	2.9	7.7	24.3	41.0
10%	10.2	9.4	21.6	2.5	11.9	15.8	22.4	17.6	15.0	10.1	3.1	8.1	24.7	41.8
15%	10.5	9.7	21.9	2.6	12.1	16.2	23.0	18.0	15.8	10.7	3.2	8.4	25.2	42.4
20%	10.7	10.0	22.1	2.6	12.4	16.5	23.2	18.3	16.3	11.2	3.3	8.6	25.4	42.8
25%	10.9	10.2	22.4	2.7	12.6	16.8	23.4	18.5	16.7	11.5	3.3	8.8	25.7	43.1
30%	11.0	10.4	22.6	2.7	12.9	17.2	23.7	18.6	17.0	11.8	3.4	9.0	25.9	43.5
35%	11.2	10.6	22.9	2.8	13.1	17.4	23.8	18.7	17.4	12.1	3.5	9.1	26.2	43.8
40%	11.3	10.9	23.1	2.8	13.3	17.7	23.9	18.9	17.7	12.3	3.6	9.3	26.4	44.2
45%	11.5	11.1	23.3	2.8	13.5	17.9	24.1	19.1	18.0	12.5	3.6	9.4	26.6	44.4
50%	11.6	11.3	23.4	2.8	13.7	18.1	24.3	19.2	18.3	12.8	3.7	9.6	26.8	44.8
55%	11.7	11.7	23.6	2.8	13.9	18.5	24.4	19.4	18.5	13.0	3.7	9.7	27.0	45.0
60%	11.9	11.9	23.7	2.9	14.1	18.8	24.6	19.5	18.7	13.3	3.8	9.8	27.2	45.3
65%	12.0	12.1	24.0	2.9	14.4	19.0	24.8	19.6	19.0	13.5	3.8	10.0	27.4	45.6
70%	12.2	12.4	24.1	3.0	14.6	19.3	25.0	19.8	19.2	13.7	3.9	10.2	27.6	45.9
75%	12.4	12.8	24.4	3.0	14.9	19.8	25.2	20.0	19.5	13.9	3.9	10.3	27.8	46.2
80%	12.6	13.2	24.6	3.1	15.3	20.2	25.4	20.2	19.9	14.1	4.0	10.5	28.0	46.5
85%	12.8	13.9	24.8	3.1	15.6	20.7	25.7	20.4	20.3	14.4	4.1	10.7	28.4	47.0
90%	13.0	14.5	25.2	3.1	16.2	21.3	26.2	20.8	20.7	14.9	4.2	10.9	28.7	47.8
95%	13.6	16.0	25.6	3.3	16.7	22.6	26.7	21.3	21.4	15.3	4.3	11.4	29.2	48.5
97%	14.1	17.2	25.9	3.4	17.2	23.3	27.0	21.8	21.8	15.6	4.4	11.6	29.5	49.1
98%	14.4	17.6	26.1	3.4	17.6	23.7	27.2	22.0	22.3	15.8	4.5	11.7	29.7	49.4
99%	15.0	18.7	26.6	3.5	18.7	24.5	27.7	22.3	22.9	16.2	4.6	12.0	30.1	49.9

Appendix B3 – Empirical Percentile Tables (Males / English Units) - continued

MALES	ENGLISH UNITS													
Empirical Percentile	Eye Height, Sitting (mm)	Eye Ht Sitting from floor (mm)	Eye Ht Standing, from floor (mm)	Foot Length (mm)	Height at Thighs from floor, Sitting (mm)	Hip Breadth, Sitting (mm)	Knee Height (mm)	Meta-Phal V Breadth, Standing (mm)	Popliteal Height (Coverage Pose - C) (mm)	Radiale-Stylion Length, Right (mm)	Sitting Height (mm)	Stature (mm)	Thigh Height Pose C (mm)	Weight (kg)
1%	28.1	43.7	58.4	9.3	20.1	12.2	19.2	13.5	14.7	8.9	32.6	63.0	4.7	121
2%	28.4	44.3	59.0	9.4	20.7	12.6	19.4	13.9	15.0	9.1	32.9	63.4	5.1	127
3%	28.7	44.7	59.4	9.4	21.0	12.8	19.6	14.2	15.2	9.3	33.3	63.9	5.3	130
5%	29.2	45.1	59.8	9.6	21.3	13.1	20.0	14.6	15.4	9.4	33.7	64.3	5.4	138
10%	29.8	46.1	61.3	9.8	21.9	13.5	20.5	15.2	15.8	9.6	34.4	65.8	5.7	148
15%	30.1	46.6	62.0	10.0	22.4	13.8	20.8	15.6	16.1	9.7	34.7	66.5	5.8	153
20%	30.6	47.0	62.7	10.0	22.7	14.0	21.0	16.0	16.3	9.8	35.0	67.2	6.0	159
25%	30.7	47.4	63.1	10.2	22.9	14.1	21.2	16.2	16.5	9.9	35.3	67.6	6.1	164
30%	30.9	47.8	63.5	10.2	23.1	14.3	21.4	16.4	16.7	10.0	35.5	68.1	6.2	168
35%	31.1	48.0	63.9	10.3	23.3	14.5	21.6	16.6	16.9	10.1	35.7	68.5	6.3	173
40%	31.3	48.3	64.3	10.4	23.5	14.6	21.8	16.9	16.9	10.2	35.9	68.9	6.4	177
45%	31.5	48.6	64.6	10.4	23.6	14.8	21.9	17.1	17.1	10.3	36.1	69.2	6.5	182
50%	31.7	48.9	64.9	10.5	23.8	15.0	22.1	17.3	17.2	10.4	36.3	69.5	6.5	188
55%	31.9	49.1	65.2	10.6	24.0	15.1	22.2	17.6	17.4	10.5	36.5	69.9	6.6	194
60%	32.0	49.3	65.5	10.6	24.2	15.2	22.3	17.9	17.5	10.5	36.7	70.2	6.7	199
65%	32.2	49.7	65.9	10.7	24.3	15.5	22.4	18.1	17.6	10.6	36.9	70.6	6.9	204
70%	32.4	49.9	66.3	10.8	24.5	15.7	22.7	18.4	17.8	10.7	37.1	71.1	6.9	209
75%	32.7	50.5	66.8	10.9	24.6	15.9	22.8	18.7	18.0	10.8	37.4	71.5	7.0	216
80%	32.9	50.9	67.5	11.0	25.0	16.2	23.0	19.2	18.0	10.9	37.6	72.1	7.1	225
85%	33.2	51.2	68.1	11.1	25.1	16.5	23.3	19.7	18.3	11.0	37.9	72.8	7.3	235
90%	33.6	51.8	69.1	11.3	25.5	17.0	23.6	20.4	18.6	11.2	38.2	73.7	7.5	248
95%	34.2	52.8	70.2	11.5	26.3	17.6	24.1	21.2	19.0	11.5	38.8	74.8	7.8	266
97%	34.7	53.3	70.9	11.6	26.6	18.2	24.4	22.1	19.3	11.6	39.3	75.5	8.0	289
98%	34.9	53.9	71.5	11.7	26.8	18.7	24.7	22.3	19.4	11.7	39.5	76.4	8.1	300
99%	35.2	54.4	72.3	12.0	27.2	19.8	25.0	22.8	19.8	12.0	40.0	77.3	8.3	318

Appendix B4 – Empirical Percentile Tables (Females / English Units)

FEMALES	ENGLISH UNITS													
Empirical Percentile	10th Rib Midspine (mm)	Abdominal Extension Depth (mm)	Acromial Ht Sit Rt (mm)	Ankle Ht Rt (Malleolus, Lateral) (mm)	Bicristale Brth (mm)	Bi-lateral Femoral Epicondyle Brth Sit (mm)	Buttock-Knee Length (mm)	Butt-Pop Length, Calculated (mm)	Depth at Feet, Sitting (mm)	Depth at Knees (mm)	Digit II to Meta-Phal V (mm)	Elbow Height, Sitting (mm)	Elbow Ht From Floor, Sitting (mm)	Elbow Ht Stand Rt (mm)
1%	9.0	7.5	19.4	2.0	10.1	8.9	20.0	15.8	10.1	6.6	2.1	6.9	21.5	37.0
2%	9.2	7.6	19.7	2.0	10.3	9.7	20.4	16.2	10.6	6.9	2.3	7.2	22.0	37.5
3%	9.3	8.0	20.0	2.1	10.5	10.1	20.7	16.5	10.9	7.3	2.4	7.4	22.2	37.6
5%	9.6	8.2	20.3	2.1	10.7	10.6	20.9	16.7	11.7	8.1	2.5	7.7	22.4	38.1
10%	9.9	8.7	20.7	2.3	11.0	11.6	21.4	17.1	12.9	8.9	2.7	8.1	22.8	38.9
15%	10.2	9.1	20.9	2.3	11.2	12.2	21.8	17.4	13.7	9.5	2.8	8.3	23.2	39.4
20%	10.3	9.3	21.1	2.4	11.4	12.6	22.0	17.6	14.4	10.0	2.8	8.5	23.5	39.8
25%	10.5	9.6	21.3	2.4	11.6	13.0	22.2	17.8	14.9	10.4	2.9	8.7	23.7	40.1
30%	10.6	9.9	21.5	2.4	11.8	13.4	22.4	18.0	15.4	10.7	3.0	8.9	23.9	40.3
35%	10.8	10.2	21.6	2.5	11.9	13.8	22.7	18.1	15.8	11.1	3.0	9.0	24.0	40.6
40%	10.9	10.6	21.9	2.5	12.1	14.0	22.8	18.3	16.1	11.4	3.1	9.1	24.2	40.9
45%	11.1	10.8	21.9	2.5	12.3	14.3	23.0	18.4	16.5	11.7	3.1	9.2	24.4	41.1
50%	11.3	11.2	22.1	2.6	12.5	14.6	23.1	18.5	16.8	11.9	3.2	9.4	24.5	41.3
55%	11.3	11.4	22.2	2.6	12.7	14.8	23.4	18.7	17.1	12.2	3.3	9.5	24.7	41.5
60%	11.5	11.8	22.4	2.7	13.0	15.3	23.5	18.8	17.4	12.4	3.3	9.6	24.9	41.8
65%	11.6	12.1	22.6	2.7	13.2	15.5	23.8	19.1	17.8	12.7	3.4	9.8	25.0	42.0
70%	11.7	12.5	22.7	2.7	13.5	16.0	24.1	19.2	18.0	12.9	3.4	9.9	25.2	42.2
75%	11.9	13.1	23.0	2.8	13.9	16.4	24.3	19.4	18.4	13.2	3.5	10.0	25.4	42.5
80%	12.1	13.6	23.1	2.8	14.2	17.0	24.6	19.6	18.7	13.5	3.5	10.3	25.7	43.0
85%	12.4	14.4	23.4	2.8	14.6	17.5	24.8	19.8	19.1	13.9	3.6	10.5	25.9	43.4
90%	13.1	15.2	23.7	2.9	15.1	18.2	25.3	20.1	19.6	14.2	3.7	10.8	26.3	44.0
95%	13.9	16.5	24.1	3.0	15.9	19.2	25.7	20.7	20.3	14.8	3.8	11.1	27.0	44.9
97%	14.3	17.1	24.5	3.1	16.4	20.3	26.5	21.1	20.7	15.2	3.9	11.5	27.4	45.4
98%	14.5	17.6	24.9	3.1	16.7	20.6	27.0	21.3	21.1	15.5	4.0	11.6	27.8	46.1
99%	15.1	18.1	25.4	3.1	17.1	21.5	27.2	21.7	21.9	16.1	4.1	12.0	28.1	47.6

Appendix B4 – Empirical Percentile Tables (Females / English Units) - continued

FEMALES	ENGLISH UNITS													
Empirical Percentile	Eye Height, Sitting (mm)	Eye Ht Sitting from floor (mm)	Eye Ht Standing, from floor (mm)	Foot Length (mm)	Height at Thighs from floor, Sitting (mm)	Hip Breadth, Sitting (mm)	Knee Height (mm)	Meta-Phal V Breadth, Standing (mm)	Popliteal Height (Coverage Pose - C) (mm)	Radiale-Stylion Length, Right (mm)	Sitting Height (mm)	Stature (mm)	Thigh Height Pose C (mm)	Weight (kg)
1%	26.5	40.5	54.4	8.4	18.4	13.2	17.7	9.4	12.8	8.0	30.7	58.7	4.5	99
2%	27.0	41.1	55.1	8.5	18.7	13.5	18.0	9.9	13.1	8.2	31.1	59.2	4.6	104
3%	27.3	41.4	55.3	8.6	18.9	13.7	18.2	10.3	13.4	8.3	31.5	59.5	4.8	107
5%	27.6	41.8	55.6	8.7	19.1	13.9	18.3	10.7	13.6	8.5	31.9	59.8	4.9	112
10%	28.0	42.3	56.7	8.8	19.6	14.3	18.7	11.4	13.9	8.6	32.2	60.9	5.1	118
15%	28.3	42.9	57.2	8.9	19.8	14.6	18.9	11.8	14.1	8.7	32.5	61.5	5.2	124
20%	28.6	43.2	57.8	9.0	20.1	14.9	19.1	12.1	14.3	8.8	32.8	62.0	5.3	128
25%	28.8	43.5	58.0	9.1	20.3	15.1	19.3	12.4	14.5	8.9	33.1	62.4	5.4	133
30%	29.0	43.8	58.5	9.2	20.5	15.4	19.4	12.7	14.6	9.0	33.3	62.8	5.5	137
35%	29.2	44.0	59.0	9.3	20.6	15.7	19.5	13.0	14.8	9.1	33.5	63.1	5.6	141
40%	29.3	44.3	59.3	9.3	20.8	15.9	19.7	13.2	14.9	9.1	33.6	63.5	5.7	145
45%	29.4	44.5	59.6	9.4	20.9	16.1	19.8	13.4	15.0	9.2	33.7	63.8	5.7	149
50%	29.6	44.8	59.9	9.4	21.1	16.3	20.0	13.7	15.2	9.3	33.9	64.2	5.8	156
55%	29.8	45.0	60.2	9.5	21.3	16.6	20.1	13.9	15.3	9.3	34.1	64.4	5.9	160
60%	29.9	45.2	60.5	9.6	21.3	16.9	20.2	14.1	15.4	9.4	34.2	64.8	6.0	166
65%	30.1	45.5	60.8	9.6	21.6	17.1	20.4	14.5	15.6	9.5	34.4	65.1	6.1	171
70%	30.2	45.7	61.2	9.7	21.7	17.4	20.5	14.8	15.7	9.6	34.5	65.5	6.2	178
75%	30.4	46.0	61.6	9.8	21.9	17.8	20.7	15.1	15.9	9.7	34.8	66.0	6.4	187
80%	30.7	46.4	62.1	9.9	22.1	18.1	20.9	15.5	16.1	9.8	35.0	66.5	6.5	196
85%	31.0	46.9	62.8	10.0	22.4	18.6	21.1	16.0	16.3	9.9	35.4	67.1	6.7	207
90%	31.4	47.5	63.7	10.1	22.7	19.2	21.5	16.6	16.5	10.1	35.8	68.1	6.9	223
95%	31.9	48.4	65.0	10.3	23.1	20.4	21.9	18.0	16.9	10.4	36.4	69.6	7.1	251
97%	32.3	49.3	66.0	10.5	23.5	21.1	22.2	18.6	17.2	10.5	36.9	70.6	7.2	257
98%	32.7	49.6	66.5	10.6	23.9	21.1	22.6	19.5	17.3	10.6	37.1	71.3	7.5	265
99%	33.0	50.2	67.5	10.7	24.3	22.0	22.8	20.1	17.6	11.0	37.5	72.1	7.7	286

Preface to Appendix C from the BIFMA G1 Ergonomics Subcommittee

The information in this appendix is presented to introduce users of this document to the multivariate approach and have an understanding of how it may be used in product design. Expert anthropologists suggest a multivariate approach is helpful in determining the percentage of a user population that would be accommodated by a product. Such an approach, however, does not lend itself to providing any specific recommendation for a given dimension. Supporting the use of percentiles (univariate approach) is the fact that specific criteria for individual dimensions, combined with repeatable and reproducible measurement procedures, provide a readily documented and objective means of determining compliance with a particular guideline or standard.

If a multivariate approach is used in an attempt to fit the 5th to 95th percentile user, it is expected that, in general, such an analysis would provide a larger range of values for "fit" in any given dimension. While it seems reasonable to provide a direct comparison of these values to show the differences between percentiles and multivariate dimensions, such an analysis is impractical because multivariate analysis, regardless of the implementation, doesn't lend itself to such a comparison. The problem is that there are literally an infinite number of ways to achieve a given level of accommodation.

Percentile-based guidelines are of considerable benefit as a starting point for design. For these reasons, BIFMA continues to utilize percentiles in this document. BIFMA will continue to monitor and consider the use of multivariate approaches in development of future guidance documents.

Appendix C Informative - Multivariate Considerations in Selecting Chair Dimensions Based on Anthropometry

Written by Matthew Parkinson, Ph.D., Associate Professor at Pennsylvania State University; and Matthew Reed, Ph.D, Research Associate Professor and Head, University of Michigan. (2012)

Abstract

Guidelines for the specification of furniture dimensions have traditionally been determined by examining the distribution of each of the relevant body measures across the target user population. Appropriate limits for each measure, beyond which only a small number (e.g., 5%) of users will be disaccommodated, are then identified. This process of considering each relevant body dimension and the associated design dimension(s) one-at-a-time is called a "univariate" approach. While common practice, univariate approaches have a number of critical limitations that reduce their utility.

This Appendix summarizes the limitations of univariate approaches and provides an introduction to multivariate analysis using Virtual Fit Testing (VFT). When detailed anthropometric data for the target user population are available, a Virtual Fit Test (VFT) is an effective strategy for predicting design performance across a number of critical dimensions simultaneously. An analogue to the familiar Ultimate Fit Test, VFT consists of the evaluation of a candidate design by each member of a virtual target user population. The population, which might consist of thousands of individuals, is selected such that it is representative of the variability in potential users. Since virtual users are each evaluated on all the relevant dimensions simultaneously, a true estimate of the overall accommodation level for the population can be obtained.

VFT is compared with case-selection based on principal component analysis (PCA), a commonly used multivariate statistical technique. The PCA-Gaussian Boundary Manikin method (PCA-GBM) chooses evaluation cases based on the assumption that the distribution of the data on the principal components is multivariate normal. The limitations of PCA-GBM favor the use of VFT when it is feasible to evaluate the design using a large number of cases. The strengths and limitations of selecting evaluation cases using PCA and a multivariate normal approximation are discussed.

Univariate vs. Multivariate Analyses

Good designers would like as many individuals as possible to be able to use their products in the intended manner. These *accommodated* individuals have a safe and positive interaction with the design, be it a chair, desk, or environment. Guidelines for the sizing of these designed artifacts have traditionally been determined by examining the distribution of each of the relevant body measures across the target user population and identifying an appropriate limit to that measure beyond which only a small number (e.g., 5%) of users will be disaccommodated. This *univariate* approach to design has a number of important limitations. These are made more relevant by the increased variability within user populations. The increased prevalence of obesity and changing demographics of workers necessitate an improved approach to design that allows designers to consider multiple variables simultaneously and explore trade-offs within design scenarios.

The n^{th}-percentile is the value in a distribution below which n% of samples fall. Consequently, 100-n% of samples lie above that point. For example, in a distribution of stature (standing height), 5% of individuals will be shorter than—and 95% taller than—the 5^{th}-percentile stature value. The recommendations in this Guideline are based on the 5^{th}- and 95^{th}-percentile values of various body dimensions that are related to important chair and workstation dimensions. For example, seat dimensions are based on the 5^{th} percentile of buttock-popliteal length (seat depth) in women and the 95^{th}-percentile value seated hip breadth in women. The percentage of women who are accommodated on *both* dimensions depends on the correlation between the two variables.

To illustrate the issue, Figure C1 shows seated hip breadth plotted against buttock-popliteal length for 1000 men and 1000 women randomly selected—with likelihood determined by their statistical weights—from the weighted CAESAR population used in this Guideline (see Appendix B). The values for 5^{th}-percentile buttock-popliteal length and 95^{th}-percentile seated hip breadth are marked with horizontal and vertical lines, respectively. Since there are 1000 women, there should be approximately 50 individuals—5%—in each of the excluded regions. However, it is apparent from the figure that there is little overlap in the individuals excluded by each criterion. Consequently, a designer expecting to accommodate 95% of women may be surprised to find that only slightly over 90% of women will fit in the intended manner.

The figure also illustrates a second issue with the application of the traditional univariate approaches. It is often assumed that there is little overlap across genders in the tails of distributions. For example, one might expect that no men are shorter than the 5^{th}-percentile female stature. For measures of length this assumption is fairly reasonable, but more overlap in the distributions is observed for measures of breadth. Obesity and demographic trends in the U.S. have increased the overlap. Consequently, as Figure C1 shows, a number of men are excluded on both measures, further reducing the number of accommodated individuals.

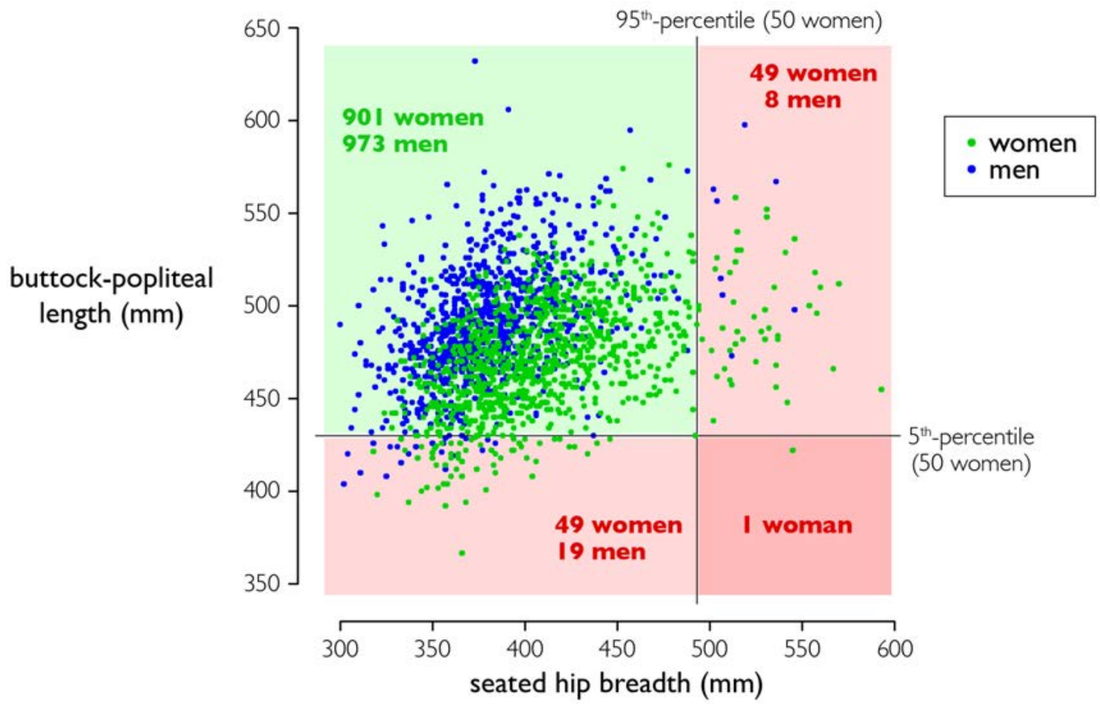

Figure C1- The bivariate distribution of buttock-popliteal length and seated hip breadth for 1000 men and 1000 women. The lines shown 5th-percentile female buttock-popliteal length and 95th-percentile female-seated hip breadth.

Virtual Fit Testing
Univariate percentiles are widely used because they can be easily documented and communicated, as in the body of this Guideline. Text tables containing percentiles for appropriate measures are included in textbooks and other resources. However, without additional information about covariances and the shapes of the dimension distributions, multivariate analyses cannot be accurately conducted using this information. Instead, experienced designers make conservative guesses (e.g., using 1st or 99th percentiles) to achieve high levels of accommodation. An alternative approach is to employ *Virtual Fit Testing (VFT).*

VFT uses detailed anthropometry for individuals in the target population, rather than summary statistics. In the terms used by HFES 300, VFT evaluates a design using a large sample of *distributed cases* rather than a small number of *boundary cases* selected based on one or more dimensions. VFT is a simulated Ultimate Test for Fit, with individuals from an anthropometric database standing in for the intended users.

Using VFT, a candidate design is evaluated on behalf of each individual in the population. Their body size, shape, and preferences are assessed within the context of the design. In this manner the proportion of users for whom the design works as intended can be estimated. The virtual population must consist of enough individuals to ensure that a large portion of the variability within the target user population is captured.

Typically 1000 or more individuals are needed for each gender to ensure good precision in the tails of the distribution where the design decisions are made. To be practical, such assessment must be done using computer software, but the calculations can be nearly instantaneous.

For the examples that follow, a virtual population of target users was created from the database used to calculate the percentile values found in the body of this Guideline. The database includes anthropometric measurements (i.e., seated hip breadth, buttock-popliteal length, etc.) for several thousand men and women. Chair design is used as the example throughout, but the principles apply to all design for human variability.

Virtual Fit Test: Bivariate Analysis of Seat Dimensions

To illustrate the method, the accommodation provided by the recommended dimensions for seat depth and width was assessed as shown in Table C1. The associated measures from each individual in the population were compared to the constraints, 415 mm of depth (including the 10 mm clearance margin) and 517 mm of width. Individuals within the population that were disaccommodated on one or both measures were then identified. Overall, after weighting for a 50/50 male/female population, 93.8% of the virtual population was accommodated. Seat depth would disaccommodate 3.4% of users and seat width 2.7%. Only 0.1% of users would be expected to experience problems with both.

Table C1 - The results of Virtual Fit Testing (VFT) using 2 Variables: The percentage of a 50/50 Male/Female user population disaccommodated by a seat with a Seat Depth = 415 mm and Seat Width = 517 mm.

	seat depth = 415 mm	seat width = 517 mm	**total**
seat depth = 415 mm	3.4	0.1	**3.5**
seat width = 517 mm		2.7	**2.7**
			6.2
	Total Accommodation		**93.80%**

Virtual Fit Test: Chair Design with Five Variables

The reduced levels of accommodation that occur when univariate approaches are used to solve multivariate problems become greater as the number of variables involved increases. For example, consider a chair created according to recommendations in the body of this Guideline for five dimensions. The seat width and depth, the seat height range, backrest height, and the armrest height range were all evaluated using the virtual population. Table C2 shows the individual and cumulative effect of each of these variables on the estimated accommodation of a target user population with equal numbers of men and women.

Table C2 - The results of Virtual Fit Testing (VFT) using 5 variables: The percentage of disaccommodated users when using 5th-/95th-percentile values from this guideline. Values are in mm and include appropriate clearances and margins.

	seat height	seat depth	seat width	backrest height	armrest height	**total**
seat height >376 & <512	3.1	0.4	0.2	0.1	0.2	**4.0**
seat depth =415		2.9	0.1	0	0	**3.0**
seat width =517			1.2	0.3	0.1	**1.6**
backrest height =354				2.4	0.8	**3.2**
armrest height >195 & <289					7.2	**7.2**
					subtotal	**19.0**
					3 and 3+ interactions	**0.9**
					total	**19.9**
					Total Accommodation	**80.1%**

A designer using 5th and 95th percentiles to set chair dimensions might expect levels of accommodation of 90% or above. A more accurate estimate, however, is 80%, because each of the variables disaccommodates a different group of users. In fact, Table C2 shows that 2/3 of the users unable to interact with the chair in the intended manner are only disaccommodated on a single measure. Of all of the elements of the chair, the armrests cause the most issues, for two reasons: (1) arm rest height disaccommodates on both tails of the distribution (short and tall) and (2) as with buttock-popliteal length (Figure C1) the seated elbow height distributions of men and women overlap considerably.

Using Virtual Fit Testing in Design

The analysis in Table C1 demonstrated that a seat width based on hip breadth of 517 mm and seat depth based on buttock-popliteal length of 425 mm would accommodate approximately 94% of a population of men and women (excluding all other measures). What if higher levels of accommodation were desired? Another strength of VFT is the ability to systematically evaluate many candidate designs. For example, using virtual fit testing, 1000 candidate seat designs based on different combinations of seat depth and width were systematically evaluated. The resulting data are shown graphically in Figure C2. The contour lines illustrate the various combinations of the two measures that will achieve a desired level of accommodation. The selection from among candidate designs can be based on concerns such as external constraints (if we design to 525 mm will the chair be too wide to fit under our desks?), comfort (if the seat depth is too short will some users be adversely affected?), or cost (what does it cost to make the chair wider?). The combination that best meets the needs of the particular situation can be identified.

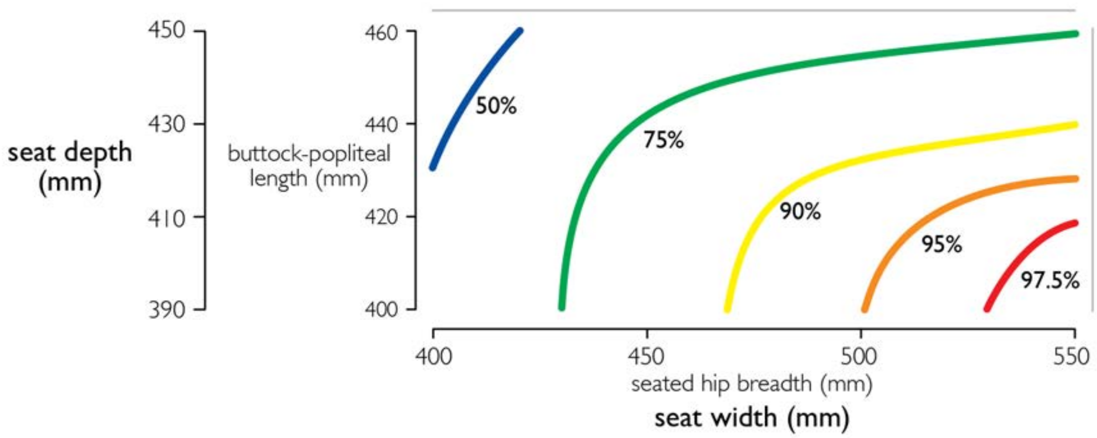

Figure C2 - A plot showing the tradeoff between two seat dimensions and the resulting overall accommodation. Seated hip breadth is used directly to calculate seat width while a 10 mm clearance margin is subtracted from butt-pop length.

Virtual fit testing can assist in design decisions related to sizing. For example, vertical seat adjustability may be one consideration in whether or not to offer multiple sizes of a chair. A chair might be offered in a single size with a multi-stage height adjust cylinder or two sizes with less expensive hardware. Consider a scenario in which seat depth is based on the 1st-percentile buttock-popliteal length and seat width on the 99th-percentile seated hip breadth (other dimensions are ignored here to simplify the example). The relationship between the amount of vertical adjustability and accommodation can be explored by conducting virtual fit testing with candidate designs of those dimensions and a number of seat adjustment ranges. Each adjustment range was centered at the 50th-percentile popliteal height of the target user population. Accommodation on seat height was determined by the popliteal height + 30 mm shoe heel margin. Figure C3 shows the resulting data. For a given level of accommodation (e.g., 90% or 95%), the required amount of adjustability is indicated. This may guide the decision to offer multiple sizes or single or multi-stage adjusters. Once the vertical adjustability decision is made, the other parameters can be tuned to the selected strategy.

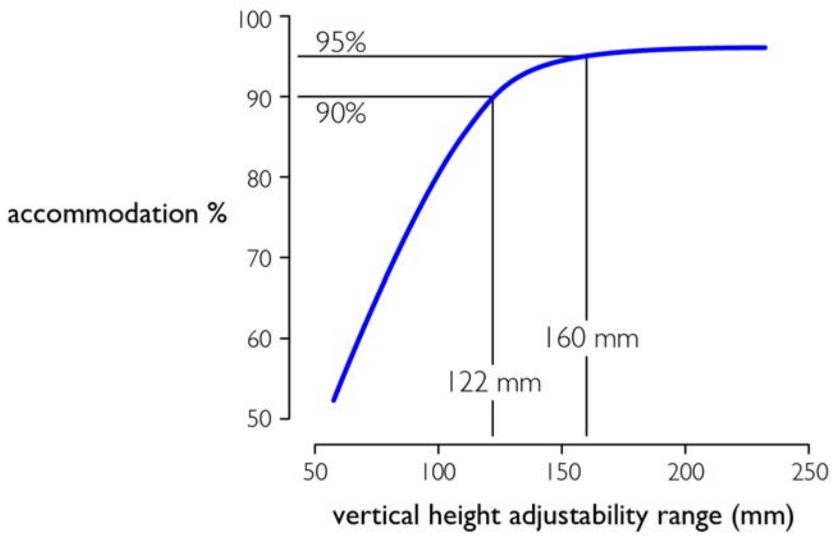

Figure C3 - The percentage of the target user population that is accommodated for different seat height adjustment ranges (height range is centered).

Designing to the Extremes

The foregoing discussion makes clear that achieving high levels of accommodation (say, 90% or greater of the target population) for a chair or workstation requires choosing dimensions that are far into the tails of univariate anthropometric distributions. Table C3 lists 1^{st}- and 99^{th}-percentile values applicable to chair design along with their 5^{th}- and 95^{th}-percentile counterparts. The values are from the combined 50/50 male/female population. Figure C4 shows quantiles for seated hip breadth for this same population. The table and figure make clear that relatively large adjustments in dimensions are needed to go from the 5^{th}- or 95^{th}-percentile values to 1^{st} or 99^{th} percentiles.

One important consideration when designing in the tails of the distribution is the reduced precision of the percentile estimates and the sensitivity of the results to small numbers of individuals in the population. At the extreme, the maximum and minimum values are determined by single individuals, so any resampling from the population would usually produce different values. For this reason data collection efforts should “oversample the tails” of the distribution. That is, individuals likely to be in the tails of the distribution on some measure should be sampled at a disproportionately high rate.

Table C3 - Quantiles of body dimensions without allowances. Both 5th- and 95th-percentile values come from the combined 50/50 male/female population.

chair parameter	critical body dimension	percentile	value* (mm)	percentile	value* (mm)
seat height (min)	popliteal height	5th	354	1st	334
seat height (max)	popliteal height	95th	472	99th	494
seat depth	buttock-popliteal length	5th	430	1st	408
seat width	seated hip breadth	95th	493	99th	542
backrest height (min)	10th rib midspine sitting	95th	350	99th	380
armrest height (min)	seated elbow height	5th	195	1st	178
armrest height (max)	seated elbow height	95th	286	99th	305

* shoe allowance and other clearances are not included

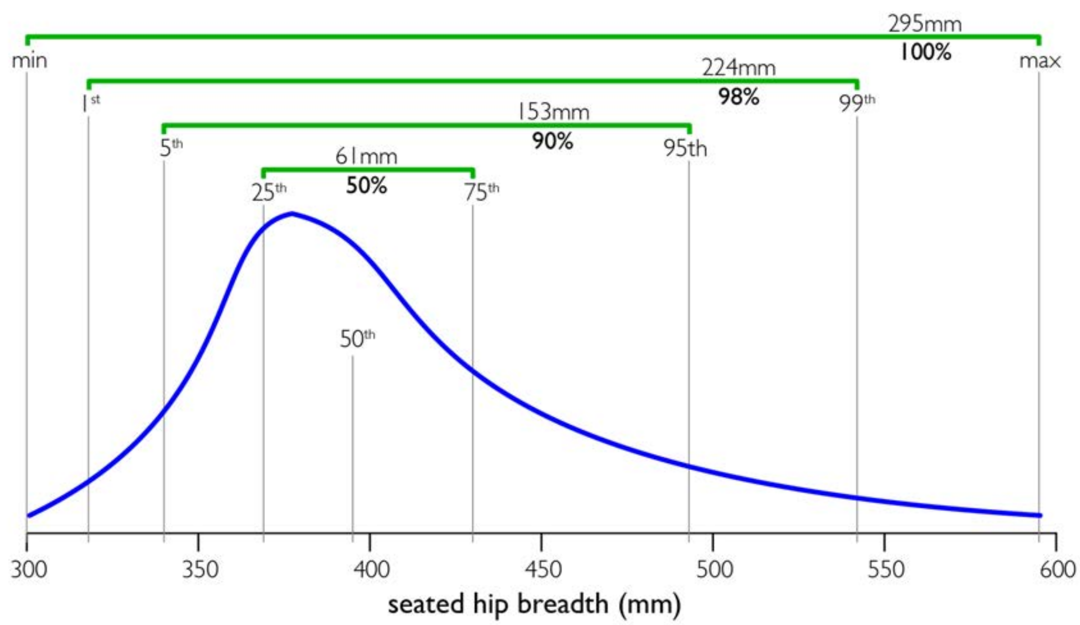

Figure C4 - Illustration of percentiles of seated hip breadth for a 50/50 male/female population. Accommodating the central 50% of users is much easier than accommodating the remaining 50%.

Alternative Multivariate Methods: Principal Component Analysis

The virtual fit testing approach used here requires the ability to compare body dimensions from thousands of individuals to candidate dimensions. In practice, this can be done rapidly using spreadsheet software or other custom tools. In contrast, most other multivariate analysis procedures used in anthropometry are motivated by an assumption that only a relatively small number of assessments will be feasible due to technological limitations. For example, most current analyses using three-dimensional human figure models require substantial user interaction, limiting the number of cases that can be quickly evaluated. When confronting this situation, designers will often employ only a small number of “boundary cases” (in the terminology of HFES 300).

Boundary cases can be selected using univariate percentiles, but problems immediately emerge from the fact that each case must include all of the dimensions of interest. If one dimension is set to, for example, a 95^{th}-percentile value, what values should be chosen for the other dimensions? Because body dimensions are not perfectly correlated, an individual who is 95^{th}-percentile on one dimension is likely to be closer to the median (less extreme) on other dimensions. Consequently, combining multiple extreme dimensions in one case produces an unrealistic individual.

Two approaches to fill out the anthropometric data for boundary cases are widely used. First, regression calculations in the reference dataset can be used to estimate typical (mean) dimensions for the dimensions not set to boundary values. However, the evaluation of the case no longer has meaning except for the boundary dimension. Second, a combined analysis of dimension distributions can be conducted to select a *family* of cases (often called *boundary manikins*) that collectively “represent” a desired fraction of the population.

Conceptually, a set of individuals who lie on the outer edges of the multivariate anthropometric distribution are selected for evaluating the design. These boundary cases are often chosen with the intent that a design accommodating these cases will accommodate a particular fraction of the design population, often 95 percent.

The most common method for choosing multivariate boundary cases employs *principal component analysis* (PCA). PCA is a widely used mathematical technique that rotates the data (here, a set of *N* anthropometric dimensions from a population) so that most of the variance in the data can be represented by a number of *principal components* smaller than *N*. PCA is particularly effective for anthropometric data because many of the dimensions commonly selected are well correlated in broad populations such as adult men.

Figure C5 shows the PCA for a simple example with two variables. The first *principal component* (PC) is the direction along which the data have the highest variance. The second PC is the direction orthogonal to the first PC with the highest variance, and so on up to *N* PCs. Each PC in sequence can be said to account for a certain decreasing percentage of the variance in the data set, so that the first *k* PCs account for *X*% of the variance.

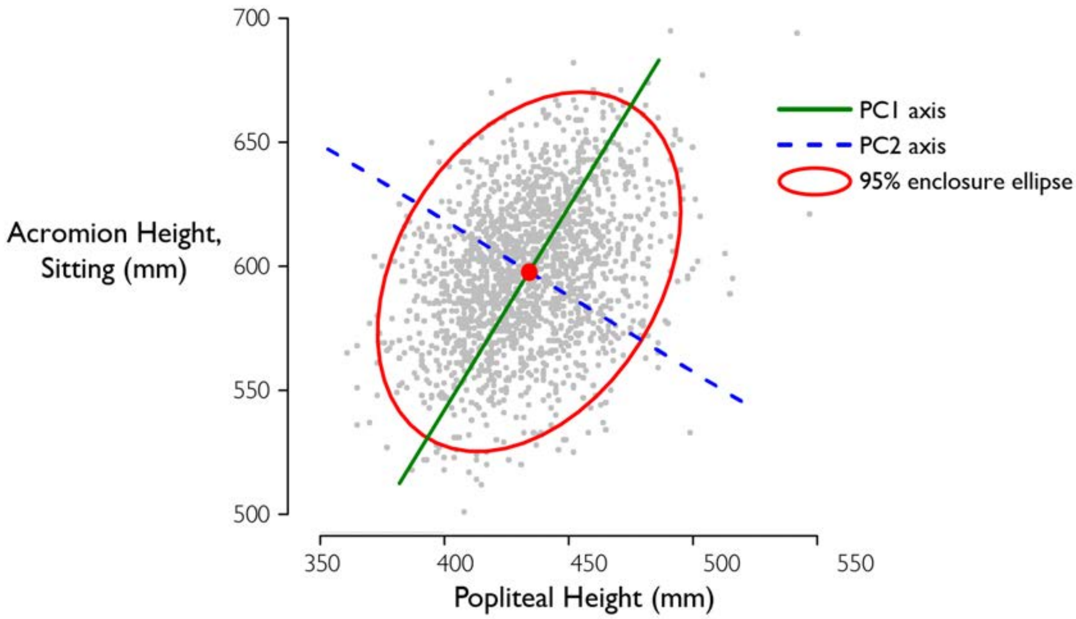

Figure C5 - Schematic illustration of PCA in two dimensions.

For anthropometry applications, PCA is conducted using a set of anthropometric dimensions that are relevant to the design problem. For chairs and workstations, the dimensions discussed in the body of this Guideline might be chosen. Often 10 or more dimensions are deemed relevant and the PCs are calculated from the covariance of these dimensions. A small number of PCs (often 3) are retained to use in creating boundary cases.

At this point, several key assumptions are made. First, the distribution of PC scores is assumed to be multivariate normal (that is, Gaussian). Under the multivariate-normal assumption, an ellipse (ellipsoid in 3 or more dimensions) can be constructed that encloses a desired percentage of the population, as shown in Figure C5. Second, individuals lying within the ellipsoid are assumed to be accommodated if the boundary cases are accommodated, while those outside the ellipse are disaccommodated.

Cases to be used in the design evaluation are then selected along the ellipsoid boundary using strategies designed to cover the surface more or less uniformly. Often boundary cases are chosen along the PC axes and at midpoints between them, yielding 14 or more cases in 3 dimensions for each gender.

The PCA/Gaussian/Boundary method (PCA-GBM) provides a mathematical approach to establishing a small number of cases (boundary manikins) that can be used for design evaluation. In many situations, designs developed using boundary manikins are likely to be superior to those developed using univariate percentile values.

PCA-GBM has several important limitations:

- The analysis is strongly dependent on the selection of variables and their scaling. For example, if waist circumference rather than waist depth is used, girth-related measures will have more importance in the analysis. In general, the PCA-GBM methodology treats each variable as equally important, except that variables with larger values (for example, stature compared with popliteal height) have greater effect in determining the dimensions of the boundary cases.

- The symmetrical approach to selecting boundary cases assumes that disaccommodation on both sides of a candidate dimension (for example, both too long and too short) are equally likely and important. As noted in the case of seat width and depth, many accommodation problems affect only one tail of the associated body dimension distribution.

- The assumption that the PC scores are normally distributed, which is essential to the interpretation of the boundary ellipsoid, is often not appropriate. Moreover, the shapes of the PC score distributions are dependent on the selection of variables and how they are scaled. For example, because hip breadth distributions within gender are skewed (distinctly non-Gaussian, e.g., Figure C4), a PC related to girth dimensions is also likely to be non-Gaussian. With careful scaling of the input dimensions and the PC scores, a reasonably multivariate normal distribution can sometimes be achieved, but the careful choices needed to achieve that end highlight a lack of objectivity in the process.

- The standard interpretation of PCA-GBM analysis is that accommodation of all boundary manikins implies accommodation of the same fraction of the user population as was spanned by the boundary ellipsoid (typically 95%). As noted above, this is not necessarily true when disaccommodation is single-tailed. More generally, a design that accommodates all boundary manikins on a 95%-enclosure ellipsoid will often accommodate more or fewer if the design is evaluated using virtual fit testing.

Consequently, PCA-GBM is useful only when the time required to complete an analysis with each case is too large to permit the virtual fit testing approach. Even then, PCA-GBM is more qualitative than quantitative. Testing a diverse set of cases provides the designer with a better understanding of how people will interact with the product than examining only univariate boundaries, but an accurate quantitative accommodation analysis is not possible.

DISCUSSION

Virtual fit testing is the best available method to assess the percentage of the user population who will be accommodated by the product, but several important limitations and caveats must be kept in mind.

Data Availability – The biggest challenge in conducting an anthropometric analysis is access to a suitably large population of detailed anthropometric data for the intended user population. The current analysis uses data from two large and expensive surveys (CAESAR and NHANES). Data to support designs for other countries and subpopulations within a country are often more difficult to find, or only summary statistics are available. Although having recent data gathered for the specific design population is ideal, often another dataset (for example, CAESAR) can be weighted to represent the target if some basic demographic information is available. Another common problem is that dimensions of interest are missing for the target population. In this case, relationships among variables in a detailed database such as CAESAR or ANSUR can be used to estimate the missing data.

The issue of data availability often prompts a needed investigation into the actual characteristics of the design population. The recommendations in the body of this Guideline are based on an analysis of a generic U.S. adult population under age 65. However, few products are equally likely to be used by all U.S. adults of working age. Certain chairs, for example, might be more likely to be used by women than men due to their target application. Because so many dimensional decisions are influenced primarily by the tails of single-gender distributions, the gender ratio in the target population is an extremely important variable. Often uncertainty in the true gender ratio can swamp differences due to, for example, out-of-date anthropometric data. Every effort should be made to define the target population as well as possible with respect to gender, race/ethnicity, and age, and to select and/or weight the available anthropometric data appropriately to represent that population.

Cost of Disaccommodation – The preceding analysis assumes that any individual who has one or more body dimensions inconsistent with the chair dimensions (larger or smaller, depending on the dimension) is disaccommodated, and all disaccommodations are treated equally. In practice, some disaccommodations are worse than others. For example, a seat that is slightly narrower than seated hip breadth could provide excellent comfort and support if sufficient clearance is available above the seat, while a seat depth greater than a sitter's buttock-popliteal length will often create substantial discomfort and render the lumbar support ineffective. When possible, knowledge of the relative costs of different sorts of disaccommodation should be taken into account when selecting chair and workstation dimensions.

Posture Variability – Seated postures in office chairs are usually substantially different from the erect seated posture in which the dimensions analyzed here are measured. In particular, sitters usually choose postures with considerably more lumbar spine flexion (by definition, the standard anthropometry posture is maximally upright). Lumbar spine flexion and the concomitant rearward tilt of the pelvis in typical seated postures lengthen the distance from the back of the sitter to the back of the knee and lower the elbows. Some sitters who would be disaccommodated on seat depth if they sat erect may be accommodated in their normal working postures.

Postural variability unrelated to body size affects some dimensions considerably, and in general will shuffle the locations of sitters relative to the distribution. This is particularly the case for chair height adjustment: sitters with long legs, who might be expected to choose high chair heights, are frequently observed to choose lower chair heights than shorter sitters. This brings into question the extent that a chair not adjusting as high as a sitter's popliteal height can be said to be equivalent to a chair not adjusting low enough.

Virtual fit testing can incorporate information on posture and posture variability when such data are available. Stochastic simulation approaches based on virtual fit testing evaluate the fit of thousands of virtual individuals with variable posture preferences. This approach has considerable advantages when component adjustment behavior (e.g., selecting seat and armrest height) interacts with constraints in the environment (e.g., work surface height).

The technology to perform virtual fit testing as described in this Appendix has been around for at least 20 years, and the advantages are substantial. In this context, the persistence of univariate, percentile-based approaches to design guidelines and standards deserves examination. Supporting the use of the current approach is the fact that specific criteria for individual dimensions, combined with repeatable and reproducible measurement procedures, provide a readily documented and objective means of determining compliance with a particular guideline or standard. Quantitative guidelines are also of considerable benefit as a starting point for design.

However, the accommodation provided by products meeting dimensions specified using this approach is not well quantified, as illustrated above. Moreover, such an approach reduces design flexibility, particularly for products designed for subpopulations, including a range of gender ratios. In an era in which an electronic spreadsheet is more easily distributed than a hardcopy document, a virtual fit test can be readily specified. For a general-purpose document such as the current Guideline, a reference population of a few thousand individuals could be made available for all to use in conjunction with the Guideline. Procedures similar to those described above would be recommended, with the overall accommodation as the target, rather than the dimensions of any particular feature. This approach would provide greater design flexibility and also achieve better accommodation for users.

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