Introduction to the Special Issue, Anthropometry in Design

Albin, Tom; Molenbroek, Johan

DOI
10.1177/10648046231168448

Publication date
2023

Document Version
Final published version

Published in
Ergonomics in Design

Citation (APA)
Albin, T., & Molenbroek, J. (2023). Introduction to the Special Issue, Anthropometry in Design. *Ergonomics in Design*, *31*(3), 3-6. https://doi.org/10.1177/10648046231168448

Introduction to the Special Issue, Anthropometry in Design

By Tom Albin & Johan Molenbroek

FEATURE AT A GLANCE:
Welcome to the special issue on anthropometry! This discussion will cover a range of differently sized topics to fit your interests. De Bruin and Castelluci discuss the problems of designing school furniture that fits students, noting that "Regarding School furniture dimensions, students are usually exposed to furniture with fixed dimensions, which makes it almost impossible to adjust to the 'growing' anthropometrics along their school life and neither does it accommodate multidimensional fit very well." Griffin et al. discuss developing an "understanding [of] body dimensions in relation to how a body functions, moves, and changes" that "is fundamental to creating compatible wearable products" for aging women. Alemany et al. discuss 4D scanning, observing that "This technology is able to capture the human body surface in motion at high frequency with a high resolution" and offers "an enormous potential to advance in ergonomic design and biomechanics." Bradtmiller describes the "nearly infinite combination of head/facial characteristics" and that "This combination of traits allows us to recognize unique individuals but increases the challenge of designing head and face products that fit a wide variety of individuals with a relatively small number of sizes."

KEYWORDS:
anthropometry, head and face anthropometry, multivariate accommodation, anthropometry of movement, anthropometry of aging populations, anthropometry of school children

Half a century ago, Etienne Grandjean, a pioneer of occupational ergonomics, advised us to "Fit the work to the worker" (Grandjean, 1963). Achieving a physical fit between the user and an object, such as a chair or a tool, is complex. People vary widely in shape and size; while two individuals may be the same height, they will almost certainly differ in other dimensions. Anticipating the physical dimensions and capabilities of the individuals who will use objects, such as tools, furniture, or clothing, is critical in ensuring the physical usability of the objects. A poor match between the dimensions of an object and the physical size or strength of the person using it often adversely affects the ability to use the object and may increase the risk of injury or discomfort.

Anthropometric data describe these variations in size, shape, and strength, and are basic to the design of physical objects that fit the person using the object. Anthropometry is the study of human body measurements and characteristics such as strength, circumferences, and segment lengths. It incorporates the processes of measuring, recording, summarizing, and documenting the measurement data. It also includes the design of user interfaces to facilitate the ability of designers and ergonomists to manipulate and analyze measurement data.

What do we mean when we say that an object "fits" the user? At its most basic, fit is a match between the physical characteristics of an individual and the dimensions of the object that individual is using. For example, the inseam length of a pair of pants should match the inseam length of the person wearing them, or the surface height of an office desk should match the elbow height of the person seated at it. However, the definition of fit is somewhat fluid, and it often differs by situation. For example, the characteristics that define the fit of a glove designed for thermal protection differ from the characteristics that define fit of a surgeon's glove. A mitten design may fit quite satisfactorily if the goal is thermal protection but would be entirely unsatisfactory for the dexterity required by a surgeon.

Several approaches to utilize anthropometric data have been tried. One approach, often of limited satisfaction to the user, is the "one size fits all" approach, such as a chair in a public waiting room. A second, more inclusive approach is to utilize a range of sizes to match the variation within the user population. A third perspective is to design a range of adjustments that matches the range of variation in the user population. A fourth view is that of a one-time adjustment, for example, kitchen counters built with the surface at the intended user's elbow height. A fifth perspective is that of bespoke designs tailored to match each intended user's size and shape. While this has been prohibitively expensive in the past, the current ability to scan the user's body in three dimensions, combined with 3-dimensional printing or other fabrication methods, may soon make this more readily available.

Another issue of concern regarding the collection of anthropometric data is the change in measurements, such as body mass, over time (Molenbroek et al., 2017). In the Netherlands, for example, about 2.5 million people, or 15% of the population, have a body mass exceeding 100 kg. Designers and ergonomists must be aware of this phenomenon and design for plus-sized people (Marcus et al., 2002).

Further, individuals' anthropometric dimensions often change as a function of activity. Tissues deform under loads associated with changes in posture; for example, hip breadth of ANSUR2 males increased by approximately 10% when moving from standing to seated postures (Gordon et al., 2014). Lewis and Fowler (Lewis and Fowler, 2009) were able to measure changes in subjects' stature after only 15 minutes walking. Meunier and Yin (Meunier and Yin, 2000) noted that waist, chest, and neck circumferences varied when measured throughout the day. The amount of use which an object receives is also an important consideration; for example, a kitchen utensil may be used for only a few seconds per day, but an office chair may be used for eight or more hours per day.

Clothing designers deal with these dimensional changes through the concept of "functional ease" (Park and Langseth-Schmidt, 2016), which is defined as an increase in the nominal dimension to adapt to the user's movement. For example, Park and Langseth-Schmidt cite a functional ease allowance of "3–4 inches for the waist of semi-fitted pants" (Park and Langseth-Schmidt, 2016). Furniture designers often build in the ability to adjust dimensions to fit a range of sizes of individuals; for example, the height of a desk that can be adjusted to accommodate a range of seated elbow heights, often between a small and a large individual.

In the latter case, the range of desk height adjustment might include all dimensions between the 5th percentile female value of elbow height and the 95th percentile male value of elbow height. The desk height can be adjusted to fit any individual whose elbow height is within that range; we say that the design "accommodates" at least 90% of the intended user population (equal numbers of men and women). Rather than specifying the endpoints such as 5th and 95th percentile values, current practice is to define anthropometric accommodation as the proportion or percentage of intended users whose physical measurements fit within the design dimensions.

Poor anthropometric fit results in problematic postures. Problematic working postures "… not only decrease performance and productivity, in the long run they also affect well-being and health" (Grandjean, 1982). For example, Wiker et al. (Wiker et al., 1989) noted that above-shoulder reaching postures were associated with increases of 15–27% in performance time. Bhatnager et al. (Bhatnager et al., 1985) observed increases in the number of inspection errors and the time required to inspect individual circuit boards as a function of display height, and Berqvist et al. and Marcus and Gerr (Bergqvist et al., 1995; Marcus et al., 2002) identified mismatches between the desk height and the user's seated elbow height as a postural risk factor associated with discomfort and injury.

Historically, several problematic strategies have been utilized with the goal of accommodating anthropometric variation in a user population. The first is designing for the average user. While this strategy is attractive when dealing with multiple measurements, as the mean of a group of measurements is simply the sum of the individual means, this approach results in a design that is, by definition, too large for one half the user population and too small for the other half!

The second is the misuse of percentile values. Anthropometric data have often been presented as tables of percentile values. While percentile values are perfect tools for estimating accommodation when only a single variable is of interest, the use of percentile values must be interpreted with great care when multiple variables are combined.

There are two common forms to the misuse of percentile values. The first occurs when two percentile values are added to estimate a third. For example, the Army anthropometric survey ANSUR2 does not have a direct measurement of eye height above the floor while seated, but that dimension can be estimated by adding eye height above the seat and seat height. The problem occurs when the designer adds some percentile values for each dimension (e.g., the measurements for 90th percentile seat height +90th percentile eye height seated) and assumes that the summed estimate of seated eye height above the floor will accommodate 90% of the user population. Kreifeldt and Nah (1995) describe in detail the actual accommodation for sums of normally distributed percentile values.

A third misperception is to speak of an Xth-percentile person, for example, a 5th percentile female, as if each of that woman's anthropometric dimensions are also 5th percentile: stature, arm length, knee height, etc. As the number of variables increases, it becomes increasingly improbable that such an individual exists.

A fourth misuse of percentile values occurs when a designer specifies multiple dimensions for an object using percentile values, for example, 90th percentile length, 90th percentile depth, and 90th percentile width, and assumes that the object will accommodate 90% of the intended users. However, 90% accommodation is only achieved if the variables are perfectly positively correlated ($r = 1.0$). For a combination of three 90th percentile values, the possible accommodation proportions vary between about 70% and 90%, depending on the correlation value. Realistically, the maximum is less than 90% as the correlation value is rarely equal to 1.0. On the contrary, a correlation can easily reach the level of zero, such as in the application of elbow-height seated with buttock-popliteal length, which makes a large adjustability range for an armrest in an office chair necessary.

When a design incorporates multiple anthropometric dimensions, estimates of accommodation can be achieved using multivariate techniques such as principal component analysis (PCA) or virtual fit test (VFT).

PCA mathematically determines a number of components, or factors, equal to the number (n) of measurement variables. Each component accounts for a proportion of the total variance, though some account for more than the others. Ideally, a few components, much smaller in number than *n*, account for most of the variance. For example, suppose there are nine anthropometric variables of interest. A PCA identifies nine components, but it also indicates that three of the components account for 90% of the total variance. These three components, the principal components, are the bases used to estimate accommodation.

In PCA, the percent accommodation reported is a percentage of the variance accounted for by the selected principal components. The components are all independent from one another. In the example, three principal components explain 90% of the total variance. Separately, the accommodation percentage is specified as 90% of the total variance accounted for by the selected principal components. It is important to be aware that this means that the actual accommodation achieved is 90% of 90% of the total variance, or about 81% of the total variance, not 90%.

Friess suggests that one way around this limitation is to first set the desired accommodation goal (90% in the example) and then determine the required univariate accommodation level for each of the total number of components that would yield a multivariate accommodation of 90% (Friess, 2005).

In our example, there are nine variables and hence nine components, and all the components are independent from one another. To achieve 90% accommodation on all the components concurrently, we must solve the equation $X^9 = 0.9$ for X. In our example, we determine that X is equal to 0.988. If we then use the 98.8 percentile value from each of the nine components, the resultant concurrent or multivariate accommodation is approximately 90%.

However, this procedure can be problematic in application. Suppose the goal is to design an object that will accommodate 99% of the intended users for safety reasons. Then the required percentile value for each of the nine variables is 99.8. In practical terms, the designer must use the maximum value for each of the nine variables to achieve the desired accommodation, regardless of the feasibility of doing so.

A virtual fit test (VFT), as developed by Reed and Parkinson, takes a different approach to estimating multivariate accommodation. Rather than abstruse mathematical calculations, the VFT is at heart, a sorting operation performed on the measurement data of a representative sample of the intended users. It is often spreadsheet based.

An example of a VFT is one freely available from HFES at https://www.hfes.org/Publications/Technical-Standards#VFM. The user enters a measurement, or range of measurements, into the spreadsheet for the variables of interest. The spreadsheet is programmed to determine what percentage of users is concurrently accommodated by the specified range for each of the variables of interest individually and together in common.

As an example, a user might be curious to know what percent of users will be accommodated by a chair seat that is 500 mm wide and 400 mm deep. When they enter those values into the spreadsheet, the spreadsheet counts the number of individuals whose measurements are concurrently accommodated within the specified range for each of the variables of interest. The number of those individuals whose measurements are within the specified ranges for all the variables concurrently, divided by the total number of individuals in the sample, provides the estimate of the proportion or percentage of intended users who are accommodated.

In summary, multivariate anthropometric designs tools and workplaces that anticipate the variation in sizes and shapes of the people who will use the objects result in more efficient designs; benefits include enhanced productivity and quality as well as lowered risk of injury.

Some selected sources of anthropometric data are listed below. Here are some caveats that you should be aware of regarding anthropometric data sources.

Some dimensions, especially body circumferences, are changing over time (Molenbroek et al., 2017); hence, the age of the data must be considered. Military data may not accurately represent the full range of civilians, as previously mentioned. Anthropometric dimensions of the same body part may change as a function of movement or posture (body depth in lying or supine posture can be 12.5% less compared with standing or sitting (Molenbroek, 1994). Variation within a country is often greater than that between countries. The need for accuracy of fit often varies with the context of use, for example, a prosthesis may require fit within ±0.1 mm while ±10 mm may be satisfactory for shirt or trousers.

ANSUR2. ANSUR2 is an anthropometric survey of US Army personnel made publicly available in 2017. It includes 93 measurements of more than 6,000 soldiers, 4,082 males and 1,986 females. While there is much useful information here, some caution is advisable in using it to generalize to a civilian population, as it is based on a population which is generally younger, leaner, and fitter than civilians are. The data files can be downloaded here: https://phc.amedd.army.mil/topics/workplacehealth/ergo/Pages/Anthropometric-Database.aspx.

The CAESAR project is a civilian-based collection of anthropometric data from 5,000 people in Italy, the Netherlands, and the United States. The data were gathered between 1997 and 2001 utilizing one- and three-dimensional scans. The database includes physical dimensions, including body mass, for civilian men and women between the ages of 18 and 65. It includes a broader range of body sizes than military data. It is available for purchase here: http://www.shapeanalysis.com/CAESAR.htm.

DINED is a freely available anthropometric platform (https://dined.io.tudelft.nl/en) that includes one- and three-dimensional data, along with tools to utilize the data. It includes data collected in the Netherlands, USA, Italy, and Chile, as well as some dimensional estimates based on Jürgens et al. It also includes a discussion forum to discuss anthropometric issues.

The International Standards Organization (ISO) publication ISO TR 7250–2 (ISO 2010) provides summary data for nine countries in Africa, Asia, Europe, and North America. Fifth, fiftieth, and ninety-fifth percentile measurement values are reported, as are the mean and standard deviation. A strength of the publication is that the measurement protocols are consistent https://www.iso.org/standard/41249.html.

The Virtual Fit Tool (VFT) is based on the CAESAR data, which have been statistically weighted to match the US Civilian population as of 2014. It is freely available at https://www.hfes.org/Publications/Technical-Standards#VFM.

REFERENCES

Alemany, S., Valero, J., & Ballester, A. (2022) Advanced processing of 3D and 4D scanning captures to exploit body data in product design.

Bergqvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995). Musculoskeletal disorders among visual display terminal workers: Individual, ergonomic, and work organizational factors. *Ergonomics*, *38*(4), 763–776, https://doi.org/10.1080/00140139508925148

Bhatnager, V. D. C. G., Drury, C. G., & Schiro, S. G. (1985). Posture, postural discomfort, and performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *27*(2), 189–199, https://doi.org/10.1177/001872088502700206

Bradtmiller, B. (2022). 3D scanning and head mounted products.

DeBruin, R., & Castelluci, H. (2022). The knowing-doing gap of school furniture design and dimension: Experience form Chile and The Netherlands.

Friess, M. (2005). Multivariate accommodation models using traditional and 3D anthropometry. *SAE Transactions*, 859–862. https://doi.org/10.4271/2005-01-2735

Gordon, C. C., Blackwell, C. L., Bradtmiller, B., et al. (2014). *2012 anthropometric survey of us army personnel: Methods and summary statistics*. Army Natick Soldier Research Development and Engineering Center MA.

Grandjean, E. (1963). *Fitting the task to the man: An ergonomic approach*. New York, NY, USA: Taylor and Francis.

Grandjean, E. (1982) Postural research-the next challenge in anthropometrics and biomechanics: Theory and application. In Easterby, R., Kroemer, K. H. E. and Chaffin, D. B. (eds) NATO conference series III: Human factors, Volume 16, Plenum Press.

Griffin, L., Juhnke, B., Pokorny, C., Seifert, E., & Savvateev, E. (2022) The Body-Product relationship for aging women examined through the lens of functional anthropometry.

Kreifeldt, J. G., & Nah, K. (1995). Adding and Subtracting Percentiles—How bad can it be? In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 39, No. 5, pp. 301–305). Sage CA: Los Angeles, CA: SAGE Publications.

Lewis, S. E., & Fowler, N. E. (2009). Changes in intervertebral disk dimensions after a loading task and the relationship with stature change measurements.*Archives of Physical Medicine and Rehabilitation*, *90*(10), 1795–1799, https://doi.org/10.1016/j.apmr.2009.04.017

Marcus, M., Gerr, F., Monteilh, C., et al. (2002). A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. *American Journal of Industrial Medicine*, *41*(4), 236–249, https://doi.org/10.1002/ajim.10067

Meunier, P., & Yin, S. (2000). Performance of a 2D image-based anthropometric measurement and clothing sizing system. *Applied Ergonomics*, *31*(5), 445–451. https://doi.org/10.1016/s0003-6870(00)00023-5

Molenbroek, J. F. M. (1994). Op maat gemaakt (made to measure in Dutch), PhD thesis. Delft University Press. https://dined3d.io.tudelft.nl/en/how-it-works/more-sources

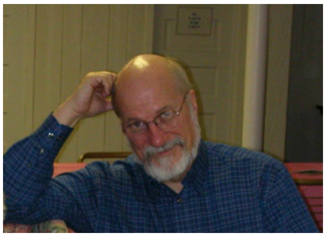
Molenbroek, J. F. M., Albin, T. J., & Vink, P. (2017). Thirty years of anthropometric changes relevant to the width and depth of transportation seating spaces, present and future. *Applied Ergonomics*, *65*, 130–138, https://doi.org/10.1016/j.apergo.2017.06.003

Molenbroek, J. F. M., de Bruin, R., & Albin, T. (2018). Design for plus size people. In Congress of the International Ergonomics Association, Florence, Italy, August 26–30, 2018. Springer, pp. 482–495.

Park, J., & Langseth-Schmidt, K. (2016). Anthropometric fit evaluation of firefighters' uniform pants: A sex comparison. *International Journal of Industrial Ergonomics*, *56*, 1–8, https://doi.org/10.1016/j.ergon.2016.08.011

Wiker, S. F., Langolf, G. D., & Chaffin, D. B. (1989). Arm posture and human movement capability. *Human Factors*, *31*(4), 421–441, https://orcid.org/0000-0002-9278-6578

__Johan Molenbroek__ is a retired associate professor in Industrial Design Engineering at TU Delft in the Netherlands, especially in anthropometry, applied ergonomics, and inclusive design. He started in 1978 as an assisted professor and worked 45 years at the same place doing research and teaching in these above-mentioned fields. He was initiating, coordinating, and participating in anthropometric projects covering the measurement of about 7,000 people. The results are made freely available for designers and researchers on. ORCID iD: https://orcid.org/0000-0002-9278-6578.



__Tom Albin__ is an engineer and a certified professional ergonomist (CPE). He holds a PhD in industrial design engineering from the Technical University of Delft in the Netherlands. Tom's consulting and research work has been principally concerned with physical ergonomics issues in office and industrial settings. Current projects deal with the evaluation of injury risk during push and pull tasks, applied anthropometry, and the application of ergonomics to prehistoric tool systems.

DOI: 10.1177/10648046231168448
Article reuse guidelines: sagepub.com/journals-permissions