TECHNICAL REPORT

ISO/TR 9241-514

First edition
2020-08

Ergonomics of human-system interaction —

Part 514:
Guidance for the application of anthropometric data in the ISO 9241-500 series

Reference number
ISO/TR 9241-514:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee 159, *Ergonomics,* Subcommittee SC 4, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The use of interactive systems takes place within a physical environment. The design of the physical environment is decisive with regard to the outcome of the interaction between a variety of sizes of users and the physical environment. As described in the system concept of ISO 26800, the physical environment is embedded in an organizational and a social and cultural environment.

This document deals with the physical environment in which a physically diverse user group is assigned to one or more workplaces, or spatial environments, to accomplish a task. The entirety of the spatial environments assigned to a user is called environment of use. The relevant physical attributes of the environment of use include issues such as air quality, thermal conditions, lighting, noise, spatial layout and furniture. Specifically, this document discusses concepts for the spatial layout of workplaces so that they match the physical anthropometric characteristics of the intended user population.

Ergonomics of human-system interaction —

Part 514:
Guidance for the application of anthropometric data in the ISO 9241-500 series

1 Scope

This document is intended to provide guidance in the use of anthropometric data within the ISO 9241-500 series.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
anthropometric accommodation
percentage of individuals in the intended user population whose anthropometric measurement values are concurrently within specified values for all anthropometric variables of interest pertinent to the design of some object

3.2
multivariate accommodation
percentage of individuals in the intended user population whose anthropometric measurement values are concurrently within specified values for multiple anthropometric variables

3.3
percentile
percentage of the measurement values that are less than the given value

3.4
user population
group of people having some common environment or activity

Note 1 to entry: These groups can be as diverse as geographically defined populations or specified age groups.

3.5
univariate accommodation
percentage of individuals in the intended user population whose anthropometric measurement values are within specified values for a single anthropometric variable

3.6
weighting
assignment of a statistically determined multiplier to an individual's anthropometric data in order to reflect its relative importance in making the sample representative of the intended user population's anthropometry

4 Accommodation estimates are statistical inferences based on samples drawn from the intended user population

4.1 Population samples

4.1.1 Samples

In order to estimate anthropometric accommodation, the intended user population needs to be defined. For example, Japanese adult civilians between the ages of 18 and 70, or all Finnish children between the age of 0 months and 24 months.

The sample should be large enough to be statistically representative of the intended user population. Often, the extremes of the data, the largest or smallest measurements, are of great interest to designers. The sample should be large enough that those individuals whose measurements are in the extremes are well represented in terms of count, thus avoiding over-reliance on too few individuals in the extremes of the measurement distribution. According to the BIFMA G1 Guideline (BIFMA 2013)[4], "typically 1 000 or more individuals are needed for each gender to ensure good precision in the tails of the distribution where the design decisions are made".

Similarly, the sample should accurately reflect the demographics of the intended user population. For example, a sample of anthropometric measurements of military personnel are generally not representative of the civilian population as they are based on younger individuals who are likely fitter and leaner than the civilian population from which the military are drawn.

4.1.2 Weighting

In some cases, the sample of anthropometric data does not exactly match the demography of the intended users. For example, military data often do not exactly match civilian data on variables such as height, mass and age. A practical solution is to statistically weight individuals within the sample in proportion to their representation in the population of intended users[7]. However, as Gordon[6] has emphasized, the technique of statistically weighting the sample data is useful in representing the target population, but its utility does not extend to intended user populations that differ from the sample. For example, there are sufficient differences in the range of height between the Korean and Dutch populations that one cannot be weighted to represent the other.

4.2 Univariate accommodation estimates

The simplest accommodation estimates are those where only one variable, such as height, is involved. In such cases, a percentile value gives a useful estimate of accommodation. For example, a designer can want to design the ceiling of a room in an air terminal so that it provides a 20-cm clearance above the heads of at least 95 % of all males from anywhere in the world. Then, a design height that is 20 cm greater than the greatest 95th percentile value of males' height in ISO/TR 7250-2 would reasonably be expected to accommodate at least 95 % of all males worldwide. An even greater proportion of females would be accommodated as men are generally taller than women.

NOTE The air terminal designer notes that the tallest males in the ISO/TR 7250-2 data set are from the Netherlands, and that the 95th percentile value for their height is 195,9 cm. The designer adds 20 cm to the 95th percentile value and is reasonably confident that a ceiling height of 215,9 cm comfortably accommodates at least 95 % of all male travellers.

A similar accommodation estimate can be made using a 5th percentile value. Consider a situation where a protective grid with square openings is placed in front of a piece of rotating machinery. The size of the openings can be defined by the 5th percentile value of females' index finger breadth.

This opening would prevent at least 95 % of females' fingers from coming into contact with the rotating machinery. A larger percentage of males' fingers would be excluded as their fingers are generally larger than females.

4.3 Multivariate accommodation estimates

More often, multiple variables should be accommodated simultaneously in the design of a product. For example, a chair seat can have three dimensions of interest: seat depth, seat width, and seat height above the floor. In such cases, the use of multivariate techniques needs to estimate the proportion of users concurrently, or simultaneously, accommodated on all three variables.

The existence of a representative sample of anthropometric data enables several types of multivariate analyses. Two types are discussed here, the virtual fit test (VFT) and principal component analysis (PCA).

4.3.1 Virtual fit test (VFT)

One type of multivariate technique is the virtual fit test described by Parkinson and Reed[9], Reed and Parkinson[11] and partially anticipated in ANSI/HFES 100:2007, A.1.6[3]. In this technique, measurement values are first specified for all the variables of interest. Then, the number of individuals in the sample who are simultaneously accommodated for all the measurement values are counted and converted to a percent of the total.

For example, suppose that a designer wants to know what percentage of a user population will be accommodated by a proposed chair seat design if the chair seat depth is 400 mm, the chair seat width is 500 mm and the chair seat height is 450 mm. The designer defines an accommodated individual as an individual whose measurements are simultaneously less than or equal to the proposed seat depth, width and height measurements of 400 mm, 500 mm and 450 mm, respectively. The analysis shown in Figure 1 notes that about 78 % of a 50:50 mix of males and females are concurrently accommodated on all three dimensions.

In the next step, the designer counts all the individuals in the sample whose anthropometric dimensions for seat depth, width and height are simultaneously less than or equal to 400 mm, 500 mm and 450 mm, respectively. This count is generally done using a spreadsheet. The count of these individuals divided by the total number of individuals in the sample gives the estimate of the proportion accommodated.

The VFT technique is straightforward and can readily be implemented through the use of computer spreadsheets to analyse the anthropometric data of interest. It does not require any assumptions regarding the distribution of the anthropometric data, for example, whether or not it is Gaussian-distributed.

One limitation is that a representative sample of the population is necessary. A second limitation is that all variables of interest to the designer should either be present in the sample or be capable as being determined by combinations of variables present in the sample.

Multivariate Accommodation Testing Tool											
Change only green cells											
Fraction Male	0.5	between 0 and 1									
							Associated Dimension Value				
	Quantiles - Men			Quantiles - Women			Low	High	Percent Accommodated		
Measures	5 %	50 %	95 %	5 %	50 %	95 %	% Greater	% Less	Men	Women	Both
Stature (mm)	1634	1758	1882	1501	1621	1741					
BMI (kg/m^2)	21	28	39	20	28	43					
Seated Measures											
Abdominal Extension Depth (mm)	228	290	420	212	288	424	0	0			
Buttock-Knee Length (mm)	559	616	679	532	591	656	0	0			
Buttock-Popliteal Length (mm)	440	486	548	420	474	529	400	0	99,9 %	98,1 %	99,0 %
Elbow Rest Height, Sitting (mm)	193	242	290	192	235	281	0	0			
Eye Height, Sitting (mm)	736	802	859	686	748	805	0	0			
Forearm-Forearm Breadth (mm)	482	566	681	410	491	633	0	0			
Hip Breadth, Sitting (mm)	333	382	455	353	421	530	0	500	98,7 %	89,1 %	93,9 %
Knee Height (mm)	508	557	606	459	504	550	0	0			
Popliteal Height (mm)	390	434	478	338	382	426	0	450	70,6 %	99,3 %	85,0 %
Shoulder Breadth (mm)	444	498	562	387	436	524	0	0			
Thigh Clearance (mm)	138	168	204	124	150	196	0	0			
Elbow Height Above Floor Estimated (mm)	615	679	739	554	618	681	0	0			
Thigh Clearance Above Floor Estimated (mm)	540	602	662	480	536	594	0	0			
Knee Depth Estimated (mm)	214	319	387	180	299	371	0	0			
Foot Depth Estimated (mm)	334	460	544	283	422	511	0	0			
Standing Measures											
Eye Height, Standing (mm)	1517	1640	1762	1400	1512	1631	0	0			
Elbow-Fingertip Length (mm)	431	470	512	386	421	462	0	0			
Elbow Rest Height, Standing (mm)	997	1084	1177	914	1001	1090	0	0			
Foot Length (mm)	244	266	291	220	239	260	0	0			
Total Accommodation									**69,5 %**	**86,9 %**	**78,2 %**

Figure 1 — Screenshot of a virtual fit tool (VFT) showing accommodation on each variable separately and concurrently (total accommodation)

4.3.2 Principal component analysis (PCA) and boundary cases

PCA is a technique for determining the number of components necessary to explain a desired proportion of the total variance within a sample of individuals drawn from the intended user population.

For an n-variable multivariate design, all the variance is completely explained by all n components. However, it is often possible to demonstrate mathematically that a smaller number of components explains some desired proportion of the total variance, for example, x of n components, where x is less than n, can explain 90 % of the total variance. It is important to note that each of the n components is a combination of the input variables, and that each component is independent of all the others. Each of the x components has an associated value v, which is related to the amount of the total variance that it explains.

When using PCA, one first determines the number of principal components (x) whose summed variance values ($\sum v$) explain the desired proportion of the total variance. For example, if the desired level of accommodation is 90 %, then the variance explained by each of the x variables sums to 90 %, e.g. $v_1 + v_2 + \ldots v_x = 90\ \%$.

Because the components are independent of one another, their axes are necessarily orthogonal to all the other components. These axes of the x principal component values, along with their associated variance values, determine an ellipsoidal solid in an x-dimensional space. Under the assumption of multivariate normal data distributions, the ellipsoid contains the desired proportion of all individuals in the sample.

A group of individual boundary cases equitably distributed on the surface of the ellipsoid is identified. Each individual boundary case has measurements for all n variables.

The minimum and maximum values for each of the n variables of the boundary cases are assumed to include the desired proportion of all individuals, e.g. 90 %. Reed and Park[10] provide a general description of this boundary manikin process. Gordon[6] provides a good description of this process as applied to design of a seated workspace where only three components were necessary to explain 90 % of the total variance in ten body dimensions.

A limitation of the PCA methodology is that it assumes normally distributed data, although it appears to be relatively robust in the face of non-normally distributed data, especially as the number of variables increases. A second limitation is that it can set somewhat extreme values of each variable of interest in order to achieve the desired level of accommodation.

4.3.3 Dealing with limited data

On occasion designers may not have a complete data set, that is, a measurement for each variable for each individual in the sample. For example, a designer can have access only to a table of percentile values for each anthropometric dimension of interest for the intended user population. Rather than having the height and weight data for each individual in the sample of the user population, the designer can have only the 5th, 50th and 95th percentile values of height and weight for all individuals.

A naïve assumption is that using combinations of percentile values such as the 95th percentile values will accommodate 95 % of the intended users. While this is possible, it is statistically improbable, and would happen only if each variable was perfectly correlated with every other variable. The actual accommodation achieved depends on the correlation between the variables of interest.

There are two common situations, or cases, encountered when a designer has access only to percentile data with which to estimate accommodation. In the first case, the designer wants to know what proportion of individuals will be accommodated if certain percentile values are used to design some object. For example, the designer wants to know what percent of individuals will be accommodated for a chair seat design if the 95th percentile measurements of the variables relevant to chair seat depth, width and height are combined to define the chair seat's size.

4.3.4 Estimating concurrent accommodation for two or more variables using percentile values

The percent accommodated when the dimensions of an object are determined using percentile values for variables A and B, depends on the correlation between the variables. For example, if the 95th percentile values of seat width (P95W) and seat depth (P95D) are used to define a chair seat width and depth dimensions, then the percent accommodated is exactly 95 % only if they are perfectly correlated and the correlation value is 1,0.

If they are not at all correlated (linearly independent), then the accommodation is $0{,}95^2$, just slightly more than 0,90. If three 95th percentile values for seat height, seat width and seat depth are combined, then if the anthropometric variables are perfectly correlated, 95 % of the users is accommodated. If all three are independent (not at all correlated), then the proportion accommodated is $0{,}95^3$, about 86 %.

It is possible to estimate the accommodation achieved by combinations of two percentile values as the intersection of two sets of measurements A and B. The percentile values can be thought of as probability values. For example, the probability that a measurement value of variable A will be less than or equal to the 95th percentile value of A is 0,95. Then, the probability that any individual will concurrently have measurement values less than or equal to the specified percentile values can be expressed as Formula (1).

$$\mathrm{P}(A \cap B) = (\mathrm{r}_{AB}(\mathrm{Sd}_A{*}\mathrm{Sd}_B) + (\mathrm{P}(A){*}\mathrm{P}(B)) \qquad (1)$$

where

r_{AB} is the correlation between A and B;

Sd_A is defined as $(P(A)*(1-P(A)))^{1/2}$;

Sd_B is defined as $(P(B)*(1-P(B)))^{1/2}$ [1][2][8].

Accommodation estimates for more than two variables can be achieved by concatenation. First, the intersection of two variables is estimated. Then, the intersection of the combined variable with the third is determined. The process is repeated until all variables have been combined.

If the actual correlation values are not known, the average correlation of all the anthropometric variables of interest can be used to make an estimate of the intersection of the two variables.

EXAMPLE 1 Suppose that a designer wants to estimate how many individuals will be accommodated if the 90th percentile values corresponding to seat depth (D) and seat width (W) are used to design a chair seat. The designer knows that the two variables have an average correlation value of 0,5. Then the intersection of the two sets can be determined as $P(D \cap W)$ = (0,5*0,3*0,3) + 0,81, or 0,855. Approximately 85,5 % of the intended users will likely be accommodated if the seat's width and depth dimensions are defined by the respective 90th percentile values.

EXAMPLE 2 The designer decides to add a third dimension, seat height (H) and combines the 90th percentile value corresponding to seat height with the accommodation estimate for the combination of seat width and depth. The average correlation value is 0,5. The accommodation estimate is determined by $P(WD \cap H)$ = (0,5*0,3*0,35) + 0,9*0,85, or 0,82. About 82 % of the intended users will be accommodated by the design determined by the 90th percentile values of seat height, width and depth.

4.3.5 Estimating concurrent accommodation for two or more variables using percentile values

In the second case referred to in 4.3.3, the designer wants to approximate an unmeasured anthropometric variable using a combination of two or more percentile values. For example, a designer can need to know what percent of individuals will be accommodated for seated eye height above the floor if he/she approximates the desired dimension by adding the 90th percentile value of seat height above the floor and the 90th percentile value of seated eye height above the seat. One method of accomplishing this is the use of z-score multipliers.

4.3.6 Z-score multipliers in addition and subtraction of percentile values

McConville and Robinette[12] noted that the sum of the percentile (values) is not the percentile of the sum (of the percentile values). For example, suppose that a designer wishes to estimate a dimension C by adding the 90th percentile value of variable A (93 cm) and the 90th percentile value of variable B (57 cm). Their sum is 150 cm, but generally this is not the 90th percentile value for variable C. How can he/she estimate the accommodation on variable C?

When only percentile values are available to the designer, a Kreifeldt-Nah (KN) multiplier[13][1] can be used to determine the percentage of individuals who will be accommodated on a dimension estimated by combining two equally-valued percentile values, for example by adding or subtracting two 90th percentile values.

The KN multiplier assumes that the data have a Gaussian distribution. Then the z-score for any percentile value is known. For example, the z-score for the 90th percentile value is 1,282. When two percentile values are added, the z-score for the percentile value of the resulting sum is the original z-score multiplied by the KN multiplier.

The KN multiplier for equal-valued percentiles can be determined using Formula (2):

$$KN = 2/(2 + 2\, r_{AB})^{1/2} \qquad (2)$$

where r_{AB} is the correlation between the two variables that are combined[1].

