The Ergonomic Relevance of Anthropometrical Proportions —Part I: Body Length Measures

Gerd Küchmeister¹⁾, Kay Behrenbruch¹⁾, Pieper Ursula¹⁾ and Dieter Leyk^{2),3)}

1) Research Group Physiological Anthropology, University of Kiel, Germany

2) Central Institute of the Federal Armed Forces Medical Services Koblenz, Department IV,
Military Ergonomics and Exercise Physiology, Germany

3) German Sport University Cologne, Department of Physiology and Anatomy, Germany

Abstract Anthropometrical findings about proportions of the human body have a long tradition; most of them, however, are rather theoretical. To improve this situation a pragmatic and applicable definition of proportions, normal as well as deviating, is needed. The purpose of this paper is to set up three proportion types for body length measures: *leggy-normal-stocky*, and their rate in the population of adults in an industrial society (Germany). Based on queries of an actual anthropometrical database metrical limits for these three types are suggested regarding their influence on the most important body length measures in standing and sitting positions. The number of cases with *normal* proportions is about 60%, *leggy* and *stocky* types both reaching up to 20%. The metrical limits are proposed in order to account for differences between those proportion types which are relevant for ergonomics. When solving complex multidimensional design tasks (e.g. workplaces, vehicle interior design, personal equipment) users of anthropometrical data who do not have the opportunity to work with multivariate databases need supplementary information about the proportions of the human body. For this reason such supplementary information concerning proportions is being given here by physiological anthropologists. The application of the findings presented is exemplified in scenarios of ergonomic relevance. *J Physiol Anthropol* 28(4): 173–179, 2009 <http://www.jstage.jst.go.jp/browse/jpa2>
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Introduction

Proportions of the human body have been the focus of

anthropologists ever since the beginning of their research (Martin, 1928; Steegmann, 2006). As far as length measures are concerned, the ratio between stature and partitions of the full body height (trunk, extremities) has been well observed and classified (Knußmann, 1988).

Data for stature in a population are still the most basic and frequent anthropometrical data offered for the demands of practical application, even though stature is often not that important for dimensioning workplaces, equipment, and products with man-machine-interaction. In the field of simulation, especially with CAD-manikins like *Ramsis* (Human solutions, 2008) or *Santos* (Abdel-Malek, 2006), progress has been made: Different proportion types are provided for the user and can be integrated into the program. But it is crucial to focus on the distribution of proportion types in a population and the ergonomic relevance of the differences between proportion types (Eynard, 2000). Designers of workplaces and products might know that there exist different ratios into which the measure for stature can be broken down to measures for trunk and extremities. But it is not easy for these users to get information about the question of how many individuals within a population are of normal or deviating proportions and whether the quantitative differences between proportion groups are relevant in a concrete situation (Greil, 1997).

Based on actual anthropometrical research (Leyk, 2006) suggestions are made regarding how to answer the following questions:

- To which extent are length proportions relevant as anthropometric data when applied in ergonomics?
- How can a population be divided into proportion types relevant for technical application in ergonomics as well as personnel assignment?
- Which length measures are affected by different proportion types?
- Are there differences in proportion between outstanding

tall or small people?

- To which extent does the relation between legs and trunk differ between individuals with the same stature?

Data applications in ergonomics always depend on precise situations which have to be considered. A high degree of flexibility is needed when arranging the anthropometrical as well as technical environments. Physiological anthropologists cannot foresee all possible applications of their anthropometric data published, but sources of irritation should be taken into account as early as possible.

Since the understanding of these coherences is essential for the users, it is necessary to develop a handy tool to deal with differences in proportion. This is therefore the primary ambition of the study. As relative sitting height is a classic and often used anthropometrical variable in this context, thus generally serving as the basis for a suggestive classification that defines which individual shows deviating proportions, it should prove to be relevant for characteristic ergonomic problems. This will be discussed in a section to follow.

Material and Methods

This study is based on the analysis of extensive anthropometrical measurements of 2,013 male and female subjects which include a wide range of relevant ergonomic variables. Before the methods and statistical analyses are presented, the following classification system concerning the individual proportion status for body length measures is suggested¹: It amounts to three groups of length proportions (relative to stature), including two deviating proportions as illustrated in Fig. 1 and 2:

- **leggy**: deviating proportion, relatively long extremities, and short trunk
- **normal**: nondeviating proportion as to ergonomic relevance
- **stocky**: deviating proportion, relatively short extremities, and long trunk

The main purpose of this classification is to raise the awareness of physiological anthropologists from this perspective towards a higher biofidelity in data application scenarios, especially when only a reduced list of body measures is available for the user and multivariate queries cannot be carried out. This is the case, for example, when users of anthropometrical data have access to percentile tables only (e.g. Jürgens et al., 1988; Jürgens et al., 1990).

Subjects

- 2013 adults of working age
- 1498 males
- 515 females

Fig. 1 Body measures in standing position; individuals of the same stature, proportion types *stocky* and *leggy*.

Fig. 2 Body measures in sitting position; individuals of the same stature, proportion types *stocky* and *leggy*.

Population

- 1457 army applicants and soldiers, German army
- 556 civil workers, Germany
- age groups: 18–25 years (n=1448), >25 years (n=565)
- race component: >99% European
- period of measurements: 2004–2007

¹ In some languages, the *leggy* type is known as the “sitting dwarf”, the *stocky* type as the “sitting giant” owing to the difference between the appearance of a person in the sitting position compared to the expectation based on the appearance when the person is standing (*stocky*: smaller than expected; *leggy*: taller than expected).

Body measures

The anthropometrical survey was conducted using traditional methods and instruments (ISO 7250:1996; ISO 15535:2003): anthropometer for body length measures, beam and slide anthropometers for hand and foot measures, measuring chair plus anthropometer for sitting height. Measures were taken in erect standing or sitting position; subjects were unclothed.

The following measures are part of the anthropometrical program and will be considered as the base for the discussion of length proportions:

- stature
- sitting height
- vertical grip reach standing
- buttock-knee length
- knee height sitting
- shoulder-elbow length
- forearm-hand length
- hand length
- foot length
- acromial height standing

Calculated factors

- relative sitting height²
- leg length³
- elbow height sitting (elbow rest height)⁴

Stature classification

All subjects were separated into five stature groups as a base for differentiated analyses whether smaller or taller persons are more likely to have deviating length proportions. The five groups (S1 to S5) are distinguished by 10cm-steps between the following limits:

- S1: stature values between 150 and <160 cm
- S2: stature values between 160 and <170 cm
- S3: stature values between 170 and <180 cm
- S4: stature values between 180 and <190 cm
- S5: stature values between 190 and <200 cm

Persons shorter than 150 cm (n=9) and taller than 200 cm (n=1) were excluded from this procedure.

Length proportion classification leggy–normal–stocky

There are theoretical attempts to gain body length proportions in a population by mere statistical analyses (You and Ryu, 2005). To achieve a more realistic method to describe the variability of human body length measures and point out proportion limits relevant for applications in ergonomics the data have been classified as follows:

- Take the mean value of relative sitting height [%] of the population and add 1 percentage point to define the limiting value between *normal* and *stocky* individuals. For

Table 1 Proportion groups, definitions and limits for the calculation with respect to relative sitting height

All individuals with a relative sitting height...	Proportion grouping
...of more than one percentage point lower than the average:	<i>leggy</i>
...closer to the average than one percentage point:	<i>normal</i>
...of more than one percentage point higher than the average:	<i>stocky</i>

the breakup between *normal* and *leggy* individuals use the mean of relative sitting height minus 1 percentage point as a limit.

- These limiting values constitute three clusters: *leggy*, *normal*, and *stocky*.

For the usefulness and ergonomic relevance of this classification see *Results*, *Classification by relative sitting height*.

The decision for this classification limit was driven by the practical experience that metrical differences are of ergonomic relevance when they exceed at least 10 mm. To be sure to meet this practical demand, the proportion classification group *normal* has been given a range of two percentage points (Table 1). Thus, depending on the percentile of stature, the range for the proportion group *normal* is at least 30 mm.

Statistics

Mean differences were tested with an Independent T-Test (2-tailed), and Levene's Test was used for equality of variances. All displayed correlations are Pearson Correlations.

Results

Stature and proportions

Stature can be seen as composed of the length of the trunk and the length of the leg. Table 2 shows the means of relative sitting height, sitting height, and leg length for the five stature classification groups (S1–S5), including the differences between them. It becomes evident that relative sitting height declines with increase in stature. This leads to the general conclusion that taller individuals tend to be *leggy* while small-sized individuals tend to be *stocky*. This fact is due to the higher changes in leg length than in sitting height between the five respective groups. Leg length increases more than sitting height dependent on the increase in stature. This fact applies for absolute values, and is even consolidated by the fact that leg length is altogether less than sitting height.

Additionally the results displayed have undergone a

² Sitting height value in % of stature value.

³ Stature value minus sitting height value.

⁴ Sitting height value minus (stature value minus acromial height standing) minus (shoulder elbow length value).

Table 2 Means for relative sitting height, sitting height, and leg length, stature groups S1–S5 and differences

	Relative sitting height [% of stature]	Sitting height [mm]	leg length* [mm]
S1	54.3	850.7	716.6
<i>S1 minus S2</i>	<i>0.7</i>	<i>−38.0</i>	<i>−51.3</i>
S2	53.6	888.7	767.9
<i>S2 minus S3</i>	<i>0.7</i>	<i>−38.9</i>	<i>−56.5</i>
S3	52.9	927.6	824.4
<i>S3 minus S4</i>	<i>0.7</i>	<i>−32.7</i>	<i>−54.0</i>
S4	52.2	960.3	848.4
<i>S4 minus S5</i>	<i>0.7</i>	<i>−33.2</i>	<i>−56.1</i>
S5	51.5	993.5	934.5

* leg length = stature minus sitting height.

statistical analysis for all length measures considered, including legs, arms, feet, and hands.

Stature was correlated with the following measures according to the Pearson correlation coefficient: sitting height, buttock-knee length, knee height sitting, shoulder-elbow length, forearm-hand length, hand length, and foot length. For all variables, high coefficients with stature were found ranging from 0.77 for foot length to 0.93 for leg length. All correlations are significant at the 0.01 level (2-tailed). In addition, mean differences were found between the five groups S1–S5 which are significant at the 0.01 level (2-tailed) for all length measures. On the basis of these facts, the statement that tall individuals tend to be *leggy* can be extended further: Tall individuals tend to have long arms, hands, and feet, whereas small ones do not only tend to be *stocky* but have especially short arms, hands, and feet as compared to tall individuals.

Classification by relative sitting height

Table 3 displays the results of the classification of subjects into three clusters (*leggy*, *normal*, *stocky*). The limiting values for relative sitting height are based on the mean of the population: Mean is raised/diminished about one point to form the upper/lower value. For both sexes, limiting values divide the subjects into two groups of equal percentage (*leggy* and *stocky*). The number of subjects in the cluster *normal* is approximately three times higher. The limiting values are approximately consistent with the percentiles P20/P80.

Table 4 displays the correlations of relative sitting height with the other body measures and indicates their statistical significance respectively. First, attention should be drawn to the fact that all length measures show a high negative correlation coefficient with relative sitting height. The findings

Table 3 Limits for relative sitting height, percentile values, and rate within the population investigated

Relative sitting height (rsh)			
Proportion group	<i>male</i>		Number of subjects
	rsh [% of stature]	rsh percentile	
<i>leggy</i>	<51.7	<P22	294
<i>normal</i>	51.7 to 53.7	P22 to P78	900
<i>stocky</i>	>53.7	>P78	304
Total			1498 males
Proportion group	<i>female</i>		
	rsh [% of stature]	rsh percentile	
<i>leggy</i>	<52.4	<P21	109
<i>normal</i>	52.4 to 54.4	P21 to P79	292
<i>stocky</i>	>54.4	>P79	114
Total			515 females

Table 4 Pearson Correlation with relative sitting height, test for significance (2-tailed)

Body measures	Male subjects (n=1498)	Female subjects (n=515)
Knee height sitting	−0.556*	−0.598*
Buttock-knee length	−0.502*	−0.486*
Forearm-hand length	−0.485*	−0.529*
Shoulder-elbow length	−0.470*	−0.526*
Acromial height standing	−0.459*	−0.504*
Vertical grip reach standing	−0.424*	−0.456*
Hand length	−0.284*	−0.387*
Foot length	−0.237*	−0.363*

* Significance at the 0.01 level.

of a T-Test (2-tailed) comparing the means for all body measures mentioned between the clusters *leggy* and *normal* and between the clusters *stocky* and *normal* show significant differences (significance level 0.01).

In Table 5 the results for the proportion groups are organized according to the 5th and 95th percentile values of selected body measures. These two percentile groups of the population are considered as critical values due to the fact that they are potentially problematic in ergonomic applications. In

Table 5 Variability of proportion groups with respect to percentiles: rate [%] below the 5th and above the 95th percentile of different body measures

<P 05 of						
Proportion group	Vertical grip reach standing	Buttock-knee length	Knee height sitting	Elbow height sitting (elbow rest height)	Shoulder-elbow length	Forearm-hand length
<i>leggy</i>	3%	3%	0%	72%	3%	3%
<i>normal</i>	26%	23%	24%	26%	26%	34%
<i>stocky</i>	71%	74%	76%	2%	71%	63%
Total	100%	100%	100%	100%	100%	100%
>P 95 of						
Proportion group	Vertical grip reach standing	Buttock-knee length	Knee height sitting	Elbow height sitting (elbow rest height)	Shoulder-elbow length	Forearm-hand length
<i>leggy</i>	61%	71%	80%	2%	69%	66%
<i>normal</i>	32%	27%	19%	35%	28%	31%
<i>stocky</i>	7%	2%	1%	63%	3%	3%
Total	100%	100%	100%	100%	100%	100%

the following chapter, therefore, the practical consequences of our findings are discussed in different ergonomic scenarios.

Discussion

The present findings based on an actual anthropometrical survey in Germany show that the amount of deviating proportions of body length measures is highly relevant for their application in ergonomics. In the population investigated, more than 40% of the individuals had such deviating proportions, with absolute metrical differences of more than 30 mm. These differences are not negligible for ergonomic design processes, especially when it comes to multidimensional metric decisions such as car seat adjustments, body space calculations, and personal equipment sizing-features that are of genuine interest for the international market. Publications that provide data for relative sitting height are available (e.g. Fernandez et al., 1989); a possible transfer, however, of the presented results to other populations can only be carried out with direct access to raw data. An international pool of combined anthropometrical data collected using the same methods is not only desirable but absolutely necessary. So far however, one does not exist.

The data given here are not presented as results of a hypothesis-driven investigation but as a proposal for the estimation of how far the anthropological fact of deviating proportions can affect the biofidelity of mere stature percentile values. Ignoring these coherences might cause critical situations for the user; they can, however, be avoided by considering proportion type rates in a given population.

There are different tools that help solve metrical tasks

with anthropometrical data. For this purpose ergonomists, designers, and engineers can find tables with body measures, templates, or digital simulation tools (CAD-manikins). Most of these tools name or show the possibility of deviating proportions of the human body within a population. Some of them offer the possibility of generating different body types (Human Solutions, 2008). But in most cases such databases will not offer any information about the rate of normal or deviating proportions and the consequences for any given body measure the user may want to apply. For these body measures (especially for body sitting height and all arm- and leg-length measures) an understandable marker indicating the fact and—ideally—the quantitative impact of proportion influences should be provided.

While this section clarified the ergonomic relevance of the conducted classification in a general way, the following three scenarios will specify the practical importance of selected body length measures.

Scenario 1: Ergonomic design of a driver's seat

It is crucial that adjustability permit a safe and comfortable sitting position in the vehicle for as many individuals as possible. Body measures taken into consideration are buttock-knee length, knee height sitting, shoulder-elbow length, and forearm-hand length. These measures dictate the range of the horizontal adjustability of a driver's seat. Extreme high and low values are of special interest.

Scenario 2: Vertical reach in a standing position

Accessibility of highly stored goods is a typical workplace

planning situation. An especially low vertical grip reach standing is a matter of significant interest in this context.

Scenario 3: Sitting at a desktop in a workplace situation

In this scenario the focus is on sitting at a desk. Buttock-knee length and knee height sitting are of special interest, but only inasmuch as they prevent the feet from reaching the ground and the back from having contact with the backrest of the chair. Thus, the concentration anthropometrically lies on unusually short legs. The elbow height sitting (elbow rest height) is an equally relevant dimension, because it determines the requirements concerning the adjustability of the chair (and/or table).

In Table 5 (see *Results*), the distribution of values below P 05 or above P 95 of the body measures mentioned for all subjects fragmented into the three clusters *leggy*, *normal*, and *stocky* has been displayed. These data allow for the foreseeing of ergonomic problems in the described scenarios of data application with respect to dimensions of workplaces and industrial products:

Scenario 1: Ergonomic design of a driver's seat

At least two thirds of the ergonomic-challenging individuals belong to the *leggy* or to the *stocky* group respectively. Persons of the *leggy* group require a lot of space (forward and back), while for the *stocky* group an unexpectedly short horizontal distance (between seat, steering wheel, manual controls, and pedals) would be sufficient for the construction of a workplace or the driver's seat in a car.

Scenario 2: Vertical reach in standing position

More than 70% of the individuals will not be able to reach goods stored in high places in the *stocky*-person group. In contrast, *leggy* individuals with such problems are rare.

Scenario 3: Sitting at a desktop as a workplace situation

Persons with an unexpectedly high relative sitting height (*stocky*) are likely to raise ergonomic problems in a desktop sitting situation: About 75% must be expected not to be able to reach the ground and the backrest. Additionally, more than 60% of the individuals in this group demand a great deal of flexibility of vertical adjustability, for example, an extremely low seat position. A high seat position is most likely needed by members of the *leggy* cluster⁵.

The rate of potentially problematic individuals in the group *normal* is continuously succeeded either by the *leggy* or the *stocky* group. The percentage for the individuals with normal relative sitting height fluctuates for all measures between 19 and 35%. This is especially remarkable as the *normal* group is three times as large as each of the other two groups.

Conclusion

The proposed classification into the three clusters *leggy*, *normal*, and *stocky* matches the known correlations between relative sitting height and other body measures. The classification is based on mean values and arranges the subjects into groups of equal scope without the need for an elaborated analysis of data. About 60% of the subjects are categorized as being of *normal* proportion, 20% as *stocky*, and the remaining 20% as *leggy*. These quantitative findings are in line with former results of anthropometrical research in Germany (Greil, 2000), but so far no one has considered the question of where to set the ergonomically relevant numerical limits between proportion groups. The ratio stated serves as a reasonable base for ergonomic problem-solving.

The application of the three suggested proportion groups in exemplary ergonomic scenarios has illustrated the ergonomic relevance of the classification of body proportions. Comparing individuals belonging to the two groups showing deviating proportions with individuals of *normal* proportions, the *leggy* and *stocky* persons cause approximately twice as many metrical problems in ergonomics. This fact underlines the practical aspect of a classification according to body proportions in ergonomics.

In the investigation step to follow this study, aging and job-related influences on body-length measures as well as on measures of body width/breadth and body circumferences depending on lifestyle will be taken into consideration. With respect to these interrelations, the analysis will focus on anthropometrical differences between occupational and social groups of individuals.

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Correspondence to: Gerd Küchmeister, Research Group Physiological Anthropology, University of Kiel, Germany

Phone: +49–431–386–56–60

Fax: +49–431–658–74–06

e-mail: g.kuechmeister@anthropol.uni-kiel.de