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Anthropometry and Designing : Problems, Prospects and Research Strategies

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ABSTRACT Man though a product of biological evolution, stands distinctly apart from other animals by virtue of having culture and the ability to develop technology to meet challenges of survival. With each advent of technological development, the significance of designing is paramounting. The emphasis is being laid on maxmising efficiency, safety and comfort in the designing of products. The necessity of considering human variabilty in designing has increased the application of anthropometry in designing. Fallacy of an average man in designing, application of percentiles, and the research strategies in the development of designs of work space, personal equipment and garments, and controls and devices are some of the issues discussed in this paper. It is our contention that the new technological developments and emerging new situations will make the scope of designing wide and the future of anthropometry bright.

Anthropologists have focussed their attention, since the inception of their discipline, on explaining interpopulation and intrapopulation variations in human groups. They have also examined the factors that are responsible for causing these variations, leading to the differentiation and formation of new populations. Therefore, the understanding of the processes of micro-evolution and mega-evolution has been their primary interest. During the course of evolution man has passed from a stage where nature controlled him to a stage where he is trying to control nature. Although a product of biological evolution, man stands distinctly apart by virtue of having culture and the capacity to fabricate tools. With each technological development the significance of designing each and every product is increasing. For achieving objectivity, anthropologists have tried to quantify the variations, thus perfecting the skill of measurements. Anthropometry, the science of measurements on human body has developed to a great extent, and its applications are also well recognised. However, in this paper, only those applications which are relevant in designing have been emphasized.

Designing of any product or equipment considering human variability is a complex one. It requires understanding and close cooperation between three groups of people, *viz.* the users, the anthropologists or designers and the manufacturers or engineers. The role of one is as important as that of the other, but the role of anthropologists is pivotal. On the one hand, they are expected to provide information to the users about the product and help them in differentiating between a good and a bad design. Their role becomes crucial particularly if the efficiency of the equipment or machine is dependant on human variability. It is expected that once the users are aware of the quality of the design they will demand and use only well designed products. On the other hand, the anthropologists have to provide basic data on human variability and information in such a simple manner that it is easy to understand and ready to apply. For the manufacturers, the customer's acceptance, maximisation of sales and minimum legal liabilities are the major concerns. The anthropologists/designers should help in achieving these goals.

Providing data on human variability for designing products is not an easy task. Many of the complexities of transforming human variability data for designing, unwillingness of some of the manufacturers to lay emphasis on designing until forced upon, callous attitude of the users to the quality of design are some of the reasons that have prevented the designing of the quality products. But once the importance of a well designed product is realised, its design improves drastically.

Three factors that collectively determine the quality of man-machine relationship are efficiency, safety and comfort. The efficiency of machine depends on the input-output ratio. Lower input and higher output reflect greater efficiency. It is now realised that the efficiency does not solely depend on the quality of the machine but also on the work environment in general and man-machine interface in particular (Malik et al., 1990, 1991). The basic idea is that the machines are meant for man and not *vice versa*. The efficiency of a machine can be drastically improved if due weightage is given to the man-machine interface considering human variability. Safety of the operator is the foremost factor that has to be kept in mind while designing a product. Strict safety regulations are forthcoming with the realisation that the poor designs not only cause more accidents but may also lead to poor job performance, low job satisfaction, waste of time and increase morbidity (Damon et al., 1966; Grandjean, 1984; Pheasant 1987; Snook and Webster, 1987). Comfort to the operator not only decreases fatigue but also increases efficiency and promotes sales. Also, the maintenance of proper work posture enhances the quality of man-machine interface (Davies, 1972; Corlett and Bishop; Zacharkow, 1988; Mittal and Malik, 1986, 1990, 1991).

The term Anthropometry was first coined by Quetlet (1871). The credit of further developing this field goes to the German scientist, Martin, who published in 1928 the famous title, *Lehrbuch der Anthropologie* (Martin, 1928). The revised edition of this book, co-authored by Saller, in three volumes, is still one of the most consulted literatures in the field of anthropometry (Martin and Saller, 1957). Knussmann has recently edited two volumes covering various facets of anthropometry, based on Martin's work (Knussmann, 1990, 1992).

The ergonomic implications of variability in human size and shape were not realised until World War II, in spite of several classical studies conducted earlier (Fisher, 1906; Lay and Fisher, 1940; Hooton, 1945). The pioneering work in India in this field was conducted by Verma (1959, 1963). The maximisation of efficiency of the war machinery catering to the needs of the soldiers was seriously attempted during World War II. A much wider application of the ergonomic principles has come about since then in the field of domestic and industrial set up (LeGros Clarke, 1949; Roberts, 1964). Apparatus, equipment and work spaces have also been designed using ergonomic principles (Akerblom, 1948; Lundervold, 1958; McFarland et al., 1958; Croney, 1981; Malik et al., 1984).

DESIGN REQUIREMENTS

Design requirements may be classified into three groups, *viz.* workspace design, clothing and personal equipment design, and components and devices. Workspace design includes designing of any space for human occupancy during work, recreation, rest, treatment, travel, education, etc. The workspace designing aims to ensure that the occupant or the operator has adequate work space and proper location of controls, displays and devices (Malik et al., 1991). Designing of automobile interior, furnitures and mattresses, aircraft cockpits, hotels and cinema halls, seating apparatus, hatches and tunnels, doors and ladders are some of the many possible examples that fall under the purview of workspace designing. The measurements required in designing workspace include reach limits, body clearances and clothing allowances, forces, mobility, volume, eye location, etc.

Clothing and personal equipment design and development include designing of garments, pressure suits, helmets and gloves, cooling and heating garments, etc. The designing of clothing and personal equipment aims to assure proper fit to the wearer, minimise restriction of movements, define range of sizes and the number of items required to prevent overstock, and to ensure proper workspace interface. The body measurements that are generally required for designing clothing and personal equipment include circumferences, body contours, areas, volumes, limb movements and restriction, etc.

Designing of components and devices include designing of small appliances, instruments and products, such as electric switches, knobs, levers, handholds, latches, wheels, stick control.

AVERAGE MAN IN DESIGNING — A FALLACY

Designing on the basis of the values of an average man is a fallacy (Daniels and Chruchill, 1952; Damon et al., 1966; McConville, 1978). This misconcept eluded anthropologists for quite some time as they were accustomed of presenting anthropometric data in terms of mean values and standard deviation, and not percentiles. The concept of average man was so much ingrained in the minds of the anthropologists that they were unable to realise that the machines could not be designed on the basis of average value. However, it is clear now that the indiscriminate and unguarded use of average values may lead to improper designing.

There are two misconceptions associated with average man. The first is easy to understand and is, therefore, well recognised. An equipment designed on the basis of average values will have the clearance sufficient for only one half of the population and the controls will be approachable by the other half. For example, a door constructed on the basis of average value would permit smooth thoroughfare only to half of the population and obstruct the rest, who are taller than the average. Similarly, the controls set up on the basis of average value will hardly be approachable by one half of the population, who are shorter than the rest. Any equipment that combines both reaches and clearances, if designed on the basis of average values will be suitable almost to none, except the ones close to the average values. For instance, garments designed for industrial workers on the basis of average chest dimension will not fit nearly 50 per cent workers having chest larger than the average. To rest, the garments would be loosely fitted which may not be safe in the machine environment. It is now well recognised that the clearances are to be based on the value of 95th or 99th percentile and reaches on the value of 1st or 5th percentile.

The other error associated with the concept of an average man in designing has been well documented by Daniels and Churchill (1952). This error originates from the misconception that an individual has the same percentile for all his body dimensions. Nothing could be farther from truth than this. Contrary to this it is rare that an individual has the same percentile value for several body dimensions. The chances that an individual will have the same percentile for a number of measurements will depend on the intercorrelation between measurements and the number of measurements. The chances would decrease with increasing number of measurements and decreasing value of correlation. This error is further amplified when individuals on the tail ends of the normal distribution (*e.g.* 1st percentile; 99th percentile) are considered. McConville (1978) illustrated this point by adding 95th percentile values of 14 linear measurements comprising stature. The total was not only greater than the stature of 95th or 99th percentile person, but was more than the stature of the tallest man in the series. The average man, therefore, represents no one in the population.

Many examples have been cited to illustrate the fallacy of an average man in designing. In a situation where the seat of a car, with a small front glass, is designed according to the average man's values the visual field of a tall person may not include the traffic lights and a small woman is not likely to see a dog or a small boy running down the street. Similarly a door or a tunnel constructed on the basis of average values would not permit smooth thoroughfare to the persons of higher percentiles. A lift constructed on the basis of average weight may not be able to bear the weight of heavy persons (higher percentile of weight) if they happen to contravel. Similarly a small female may not be able to conveniently pick up materials from the cupboards constructed considering the height of average man.

Because of the proportional differences existing in body dimensions of the two sexes (Hall, 1982; Wells, 1985), even the concept that a large female can be represented by the body dimension of an average male or that the dimensions of a small male are similar to that of an average female has been found to be both inappropriate and misleading. Similarly proportional differences also exist between children and adult or simply a child does not represent the miniature figure of an adult. Hence the idea of average man is a deception, an illusion and a fallacy in designing.

PERCENTILES AND THEIR APPLICATIONS IN DESIGNING

A percentile refers to a point on the scale, when a series of data is arranged in an ascending order for a measurement. A percentile scale is an ordinal scale; it shows merely the order of rating on the scale. It does not provide information on the size of intervals between the ratings. For example, for a given body dimension, the interval between 45th to 50th percentile may be 5 mm whereas between 10th and 15th it may be 200 mm. In anthropometry, a percentile refers to one and only one body dimension. For instance, a person may be 5th percentile in stature, or 25th percentile in weight or 10th percentile in sitting height, and so on. It is rare that a person has the same percentile value for a series of body dimensions. For example, it would be extremely rare that a 5th percentile stature man will also be 5th percentile in weight, sitting height, biacromial breadth, and bicristal breadth. With each addition of the body dimension the chances would drop drastically. In fact, a person is generally represented by different percentiles for different body dimensions, as there is no perfect correlation between the percentiles of different dimensions (Table 1). Thus the magnitude of percentile ratings of one dimension, say stature, can not be used for inferring the rating of the other dimension, for example weight. Bivariate frequency table illustrating interrelationship of anthropometric data demonstrate that the relationship between variables is generally not perfect (except when correlation between two variables is 1). Clauser et al. (1972) have observed that the spread of frequencies in a bivariate frequency table is inversely related to the correlation values between the variables.

Table 1: A hypothetical bivariate table showing relationship between two body measurements

Stature	*Biacromial Breadth*						
	80-85	*85-90*	*90-95*	*95-100*	*100-105*	*105-110*	*110-115*
145-150	3	11	25	5			
150-155	5	18	38	8			
155-160		17	53	45	11		
160-165		21	43	130	63	8	
165-170		7	65	145	91	32	2
170-175			13	85	178	36	4
175-180			6	32	95	61	11
180-185				12	20	31	11
185-190				5	10	12	14

In most of the anthropological studies, anthropometric data are represented in the form of mean values and standard deviations, and not percentiles. Knowing that the percentiles are crucial for the development of designs, these data cannot be used. It is fortunate, however, that most of the body dimensions, apart from weight and skinfolds, are normally distributed. This permits easy calculation of

Table 2: Factors for the calculation of percentiles from mean and standard deviation

1st %ile = Mean — 2.326 SD	99th %ile = Mean + 2.326 SD
2nd %ile = Mean — 2.054 SD	98th %ile = Mean + 2.054 SD
3rd %ile = Mean — 1.881 SD	97th %ile = Mean + 1.881 SD
4th %ile = Mean — 1.751 SD	96th %ile = Mean + 1.751 SD
5th %ile = Mean — 1.645 SD	95th %ile = Mean + 1.645 SD
6th %ile = Mean — 1.555 SD	94th %ile = Mean + 1.555 SD
7th %ile = Mean — 1.476 SD	93rd %ile = Mean + 1.476 SD
8th %ile = Mean — 1.405 SD	92nd %ile = Mean + 1.405 SD
9th %ile = Mean — 1.341 SD	91st %ile = Mean + 1.341 SD
10th %ile = Mean — 1.282 SD	90th %ile = Mean + 1.282 SD
11th %ile = Mean — 1.227 SD	89th %ile = Mean + 1.227 SD
12th %ile = Mean — 1.175 SD	88th %ile = Mean + 1.175 SD
13th %ile = Mean — 1.126 SD	87th %ile = Mean + 1.126 SD
14th %ile = Mean — 1.080 SD	86th %ile = Mean + 1.080 SD
15th %ile = Mean — 1.036 SD	85th %ile = Mean + 1.036 SD
16th %ile = Mean — 0.994 SD	84th %ile = Mean + 0.994 SD
17th %ile = Mean — 0.954 SD	83rd %ile = Mean + 0.954 SD
18th %ile = Mean — 0.915 SD	82nd %ile = Mean + 0.915 SD
19th %ile = Mean — 0.878 SD	81st %ile = Mean + 0.878 SD
20th %ile = Mean — 0.842 SD	80th %ile = Mean + 0.842 SD
21st %ile = Mean — 0.806 SD	79th %ile = Mean + 0.806 SD
22nd %ile = Mean — 0.772 SD	78th %ile = Mean + 0.772 SD
23rd %ile = Mean — 0.739 SD	77th %ile = Mean + 0.739 SD
24th %ile = Mean — 0.706 SD	76th %ile = Mean + 0.706 SD
25th %ile = Mean — 0.674 SD	75th %ile = Mean + 0.674 SD
26th %ile = Mean — 0.643 SD	74th %ile = Mean + 0.643 SD
27th %ile = Mean — 0.613 SD	73rd %ile = Mean + 0.613 SD
28th %ile = Mean — 0.583 SD	72nd %ile = Mean + 0.583 SD
29th %ile = Mean — 0.553 SD	71st %ile = Mean + 0.553 SD
30th %ile = Mean — 0.524 SD	70th %ile = Mean + 0.524 SD
31st %ile = Mean — 0.496 SD	69th %ile = Mean + 0.496 SD
32nd %ile = Mean — 0.468 SD	68th %ile = Mean + 0.468 SD
33rd %ile = Mean — 0.440 SD	67th %ile = Mean + 0.440 SD
34th %ile = Mean — 0.412 SD	66th %ile = Mean + 0.412 SD
35th %ile = Mean — 0.385 SD	65th %ile = Mean + 0.385 SD
36th %ile = Mean — 0.358 SD	64th %ile = Mean + 0.358 SD
37th %ile = Mean — 0.332 SD	63rd %ile = Mean + 0.332 SD
38th %ile = Mean — 0.305 SD	62nd %ile = Mean + 0.305 SD
39th %ile = Mean — 0.279 SD	61st %ile = Mean + 0.279 SD
40th %ile = Mean — 0.253 SD	60th %ile = Mean + 0.253 SD
41st %ile = Mean — 0.228 SD	59th %ile = Mean + 0.228 SD
42nd %ile = Mean — 0.202 SD	58th %ile = Mean + 0.202 SD
43rd %ile = Mean — 0.176 SD	57th %ile = Mean + 0.176 SD
44th %ile = Mean — 0.151 SD	56th %ile = Mean + 0.151 SD
45th %ile = Mean — 0.126 SD	55th %ile = Mean + 0.126 SD
46th %ile = Mean — 0.100 SD	54th %ile = Mean + 0.100 SD
47th %ile = Mean — 0.075 SD	53rd %ile = Mean + 0.075 SD
48th %ile = Mean — 0.050 SD	52nd %ile = Mean + 0.050 SD
49th %ile = Mean — 0.025 SD	51st %ile = Mean + 0.025 SD
50th %ile = Mean (Median)	

SD = Standard deviation

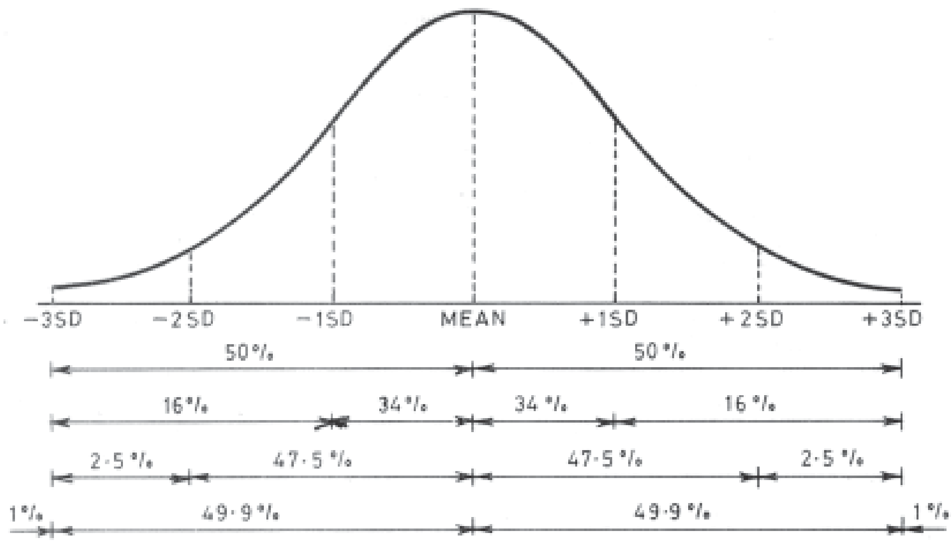

Fig. 1.

various percentiles from mean and standard deviation (Table 2).

In a normal distribution curve the range or width of interval increases from the centre to the tail ends. There is a maximum concenteration in the middle which decreases on both sides. Figure 1 illustrates that the area covered between $\bar{X}$ - 1.0 SD to $\bar{X}$ + 1.0 SD is nearly 68 per cent, whereas there is an increase of 27% when the area between $\bar{X}$ - 2.0 SD to $\bar{X}$ + 2.0 SD is considered. And the increase in area in less than 5 per cent when another SD is added ($\bar{X}$ - 3.0 SD and $\bar{X}$ + 3.0 SD). Churchill (1978) estimated the width between various percentiles (Table 3) It is clear that the width of interval increases towards the tail ends as compared to the centre. This means that the increasing adjustments have to be made in designing to accommodate the last few.

Table 3: The width or range of intervals expressed in different percentiles considering the width of interval between 50th and 51st percentile as a unit

Percentiles	*Width of interval*
50th to 51st	1.00 unit
60th to 61st	1.04 units
70th to 71st	1.16 units
80th to 81st	1.45 units
90th to 91st	2.36 units
91st to 92nd	2.56 units
92nd to 93rd	2.82 units
93rd to 94th	3.15 units
94th to 95th	3.59 units
96th to 97th	4.22 units
97th to 98th	5.18 units
98th to 99th	6.88 units
99th to 99.5th	10.86 units
99.5th to 99.9th	51.24 units

There are two crucial elements in designing, *viz.* clearance and reach. In a proper design even an individual with the shortest dimensions (5th or 1st percentile) is able to reach the controls effectively and simultaneously an individual with the largest dimensions (95th or 90th percentile) has the clearance. The background idea is that if the shortest person is able to reach the control the rest of the persons will also be able to do so. Similarly, if a large person is able to have the clearance, the smaller ones will have no difficulty.

Knowledge of percentiles helps in ascertaining and controlling the percentage of population that can be accommodated in a design system. Also, in the evaluation and testing phase, the prototypes are tested on a small sample of known percentiles. For a specialised and often complex machine, the individuals with a known percentile values for different body dimensions have to be selected. The knowledge of percentiles has, thus, a lot of application in the field of designing.

MAJOR STEPS IN ANTHROPOMETRIC SIZING PROGRAM DEVELOPMENT

1) Identification of User Population

For the development of effective design, it is important of identify the user population and to determine its general and specific characteristics. Inter-population variations in body size, shape, and strength are well documented in anthropological literature (Carter, 1975; Roebuck et al., 1975; Eveleth and Tanner, 1976.). Also the variation in these characteristics due to age, sex, occupation, socioecomomic status within the same population is well known (Tanner, 1962; Johnston et al., 1980). Since the variation in size, shape, strength, body contours, etc., influence the design, it is important to identify clearly the target population (Damon et al., 1966; Roebuck et al., 1975; Panero and Zelinik, 1979).

2) Identification of Relevant Body Measurements

This step in the process of designing is critical as well as difficult. To draw a list of body measurements that are relevant for designing a product requires both experience and expertise. However, the best procedure is to identify first all the measurements which one may find useful in designing the product. Then the measurements can be arranged according to their relative significance. The measurements which replicate information, or those which do not substantially contribute to it, may be omitted. In this way the relevant body measurements can be identified.

3) Population Description

If information is available on the relevant body measurements of the target population it can be used directly. But it is rare. Data on the relevant body measurements if available for a population similar to the target population can also be utilised by making necessary amendments, since the cost, time and energy required for collecting fresh data may often be quite high. In its absence, and in the most ideal conditions fresh data should be collected on all the relevant body measurements on a sample that represents the target population.

4) Selection of Key Body Dimensions

In the development of size categories, the selection of key body dimensions plays a vital role, which is rather a difficult process. Other than the researcher's own experience, the selection of the key dimensions depends on the following characteristics. (i) The key dimensions are basic to the design of the product; (ii) they are among the body measurements that are significant in designing the product; (iii) they are the ones that can be measured conveniently and accurately; and (iv) they have high order correlation with the relevant measurements and have low order correlation with one other. In practice, the first key measurement is selected from the basic list of measurements either by experience or by selecting the measurement that shows high order correlation with most of the other measurement. The second key measurement is selected on the basis that it has low correlation with the first key measurement but has high correlation with the other basic measurements. Like the second, third key measurement is also selected, if required. The fourth key measurement is seldom selected.

But the procedure remains the same as followed in the selection of second and third key body dimensions. By selecting the key body measurements in this way the maximum variability in body dimensions can be considered. However, in most cases the selection of key measurements is intuitive than statistical.

5) Selection of Size Intervals

The main consideration in making the size intervals is that each size category should be as homogeneous as possible. The least which is required is that the variation in individuals in a size category should not be large enough to cause a misfit of design of the final product. The number of size categories depends on the number of key measurements and numbers of size intervals in key measurements. In fact, the number of size categories is equal to the multiple of size intervals of all key dimensions. For example, if there are three key dimensions, of which the first and the third have two size intervals and the second one has three, then the total number of size categories will be equal to 12 (2 * 3 * 2). The choice of selecting the number of key dimensions and the size intervals is thus not independent. Also, neither of them can be increased without adequate consideration because this would increase the number of size categories. For instance, if the fourth key dimension with three size intervals is added to the last example, the size categories would increase from 12 to 36. And if the fifth key dimension is added with three size intervals, the number of size categories would increase radically to 108. The increase of size categories to this level would reduce the importance of designing. On the other hand, the limit on the number of size categories constrains a good fit to all, specially to the extreme individuals. But a design with limited size categories, providing a good fit to the maximum number of individuals can be considered to be good. It may be reiterated that for a design to be effective the individuals in each size category should be as homogeneous as possible.

6) Representation of Body Dimensional Data in Each Size Category

Once the sizing categories have been developed, the next step is to represent data of all the relevant body measurements separately for each size category. Proper presentation of mean, standard deviation, range and percentiles of all the relevant body measurements in each size category is crucial for further development of the design. A scrutiny of the percentile values at this stage helps in deciphering how homogeneous are the size categories with respect to various body measurements. The quality of fitting of the product can also be adjudged from these data.

7) Conversion of Summary Data into Design Values

Depending on the design requisites the statistical function (mean or a particular percentile value) has to be converted in to a design value. Design value is that value of a given variable which is meaningful for designing a particular item. It is a functional value which is necessary for making the end product. For example, if the chest size of a shirt has to be designed on the basis of chest dimension, a few centimeters have to be added to the value of chest circumference.

8) Determination of the Sizing Tariff

The number of items required in different size categories is not the same. Therefore, the number of items required to be manufactured in each size category has to be estimated from the proportion of the population falling within the limits of each category. The knowledge of normal distribution helps a great deal in estimating these proportions. This exercise helps in avoiding understocks and overstocks of items in different size categories.

Some simple criteria have also to be developed so that the user can identify his size category. Generally one of the basic measurements that has been used for manufacturing the product is considered. This measurement should be simple to take and should not require the help of a trained technician for measuring it.

9) Evaluation and Testing

This is the final step in the designing of a product. Once the summary data of all the relevant body measurements has been converted into design values, the prototype for each size category is manufactured. The prototype of each category is then tested on the individuals that fall in that size category.

CONCLUSION

It may be concluded that many of the problems in the application of anthropometry in designing are being slowly resolved. The challenge that the vast human variability poses in designing is being handled effectively by the anthropometrists. Automation in technological development has increased accuracy and precision. The use of computers is a great asset in storing and retrieving the data on human variability. Interdisciplinary approach, where anthropologists work in cooperation with engineers, designers, physiologists, biomechanists, has helped a great deal in designing quality products. New research strategies have been developed to meet the new challenges of complex designs and the emergence of new occupations. In the fast technologically developing world the application of anthropometry will grow further. The aims of making the designs better and improve man-machine interface would keep the future of anthropometry bright in the field of designing.

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