Woodhead Publishing Series in Textiles

Anthropometry, apparel sizing and design

Edited by Deepti Gupta and Norsaadah Zakaria

The Textile Institute

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Anthropometry, apparel sizing and design

The Textile Institute and Woodhead Publishing

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Edited by

Deepti Gupta and Norsaadah Zakaria

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Preface

The last 20 years have seen a tremendous amount of work being done in the field of anthropometry and sizing of clothing. The need for finding solutions to the problem of garment sizing has been recognized for a long time but the sheer magnitude of time, human resource and money required to conduct anthropometric surveys acted as a deterrent. The remarkable technological developments of the last decade, particularly in the area of automated body scanning, have made the conduct of large scale surveys feasible in terms of time and funds required. They have greatly enhanced the domain of information available in terms of body volume, posture and shape which could not be obtained from the manual methods. These have been accompanied by concomitant developments in the field of image analysis. Together, these have taken the research and development activity in the field of anthropometry and garment sizing to hitherto unknown levels of advancement.

Although garment designers have historically used body measurements as a basis for development of body blocks, most knowledge in the field has been generated empirically and has no scientific basis. It is for this reason that the conventional size charts do not yield a satisfactory fit of garments for a large section of the target population. Garment designers have very little knowledge of the principles of anthropometry or for that matter ergonomics. With the focus of industry shifting rapidly from fashion clothing to high tech and high value added functional clothing, the need to understand and appreciate the basics of ergonomics as well as anthropometry, has become critical for all present and future designers. In clothing design, as in all fields of design, the concept of inclusive design is gaining popularity. This concept is based on the premise of understanding the differences between the shape, size, strength, activities and the psychological requirements of various divergent groups present in a population. It is about designing products based on their specific requirements rather than designing for the normal or the average. Since clothing is an intimate part of the human body, application of the principles of ergonomic design can greatly enhance the performance as well as efficiency of clothing and related products for all members of a population. Anthropometry, apparel sizing and design are important elements in manufacturing quality clothing products. The contents of this book deal with topics that are relevant for production of well fitting garments. It details the comprehensive process of sizing system development beginning from the collection of human data, which is the anthropometric survey, to the statistical analysis of the anthropometric data for a concrete sizing system and then the importance of designing the clothing incorporating the fit of different body shapes. This book was conceived with the idea of providing a state of the art treatise on the subject of anthropometry and its applications to the design and sizing of clothing for the designers and manufacturers of clothing and related products. There are several steps involved in the development of a sizing system. The process begins by design and conduct of an anthropometric survey; the next step involves data validation and data analysis. Several statistical tools and sophisticated data mining techniques can be used to analyse and classify the data to identify the basic shapes and sizes of bodies existing in a population. Image analysis techniques are used where the anthropometric data are available in the form of 3D scans; special techniques are used to analyse the size data of special population groups as part of the inclusive design approach; testing and analysis of fit of clothing in static as well as mobile mode is performed to validate the sizing systems; finally, the process ends by standardization of the apparel sizes and development of a logical size designation and labelling system for communicating the size information to the user. This book deals with all the above topics and brings to the reader the historical perspective as well as the latest research in the field of garment sizing with a glimpse of the exciting developments which are bound to change the way bodies will be measured and analysed and how in turn, garments will be designed in future.

The editors would like to thank all the authors for contributing valuable chapters to this book. Thanks are also due to Francis Dodds, Lucy Beg and Kate Hardcastle of Woodhead Publishing Limited for seeing the publication through to its logical completion.

Deepti Gupta and
Norsaadah Zakaria

Part I

Anthropometric methods

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1

Apparel sizing: existing sizing systems and the development of new sizing systems

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Abstract: The chapter begins by discussing the importance of a sizing system for clothing and reviewing the existing sizing systems that have been developed from 1941 to 2012. A comprehensive compilation of sizing systems based on the techniques is discussed, each according to its strengths and weakness. Next, this chapter demonstrates the development of a sizing system combining statistical methods and data mining techniques, illustrated with a flowchart. The last two sections briefly discuss future trends in selecting key dimensions and list additional sources of information and advice.

Key words: anthropometric data, sizing systems, ready-to-wear clothing, clustering, data analysis, data mining.

1.1 Introduction

Clothing is a necessity in human life, and it is important to wear the right size clothes so that they are comfortable and fit the body well. During the early eighteenth century all clothing was custom-made, each garment hand-sewn for a particular individual. This custom-made clothing exactly fit the individual's body size and shape. Various sizing methods were employed by the dressmakers and craftsmen of the time, but problems in sizing did not really exist because each item was tailored according to an individual's needs.[1] However, starting from the middle of the 1700s, there rose a demand for clothing to be mass-produced.[1] The demand started with military uniforms, which needed to be available in bulk. Mass-produced clothes are based on pre-assigned sizes according to classified groups, and are known as ready-to-wear (RTW); this is the type of clothing which is sold at retail stores. Starting in the 1940s, RTW garments began to be popular in retail stores and increasingly demanded by customers.[1] This was a change in clothing buying trends, from getting a garment tailored to buying it off the rack. Because RTW clothing was based on average sizes, people with different body variations and ranges often had problems finding clothing to fit them. This was the origin of the need for a standard sizing system, since RTW resulted in many returns to stores and mail-order houses due to ill-fitting clothing.

1.2 Existing sizing systems: strengths and weaknesses

Table 1.1 summarizes a comprehensive collection of literature on all the sizing systems that have been developed by researchers all over the world from 1941 to 2012. This summary has been carefully researched and obtained from the journal literature and compiled in order to give a good background for those who want to develop additional sizing systems.

Sizing systems have been developed and improved throughout the years using more and more sophisticated methods: simple mathematical techniques such as bivariate classification; statistical techniques like correlation coefficients; multivariate techniques, namely principal component analysis (PCA) and factor analysis; programming techniques like linear programming (LP) and integer programming and non-linear optimization; data mining techniques such as cluster and decision tree analysis; and artificial intelligence techniques including genetic algorithms, neural networks, fuzzy logic and self-organization methods (SOM). All these techniques are briefly described in the following paragraphs to show the range of techniques available for sizing system development.

Referring to Table 1.1, the first recorded sizing analysis was performed in 1941 and it applied bivariate classification to cluster women according to bust and hip girth. Before this time, the classification of body types was based on height and weight.[2] Thirty years later, other researchers applied the same technique (bivariate classification) to develop sizing systems for different target populations.[3,4] In her studies, Otieno[4] identified areas of fit problems such as bust and waist girth and hip and leg length. After selecting the key dimensions, she classified children into sizes, first according to the primary key dimension of height and then according to the secondary dimensions of bust for upper body garments and height and hip for lower body garments.

In 1985, Salusso *et al.*[5] developed a sizing system known as PCSS (principal component sizing system) using the PCA technique. However, their application of PCA differed from that of O'Brien and Shelton.[1] In previous research, PCA was applied to reduce the data and then the components were analyzed for the selection of only one key dimension from each component. But in Salusso's[5] research, PCA was applied to the classification of the population. Here, the relationship of variables is looked upon in terms of the loading of factors of those variables on each component (correlation between a variable and a component). If the loading is high, it means that the variable is strongly associated with the component. This sizing analysis showed that two components were most important, namely PC1 as laterality, associated mainly with body girth, arcs and widths, and PC2 as linearity, associated with heights and lengths. PCCS is based on partitioning the PC1 and PC2 geometrically.[5] PC1 and PC2 behave like the control dimensions in conventional sizing system construction. The height and weight distribution are used to identify the PCCS sizes. It was concluded that PCSS represents a better

Table 1.1 Development of sizing system literature

Author	Title	Year	Samples	Method
O' Brien, R. and Shelton, W.	*Women's measurements for garment and pattern construction*. Washington, DC: US Dept of Agriculture	1941	10 041 adult females	PCA /bivariate classification of body types
Staples, M. and DeLury, D.	A system for the sizing of women's garments. *Textile Research Journal*, 19: 346–354	1949	10 000 adult females, 19 years and above	Correlation coefficient and bivariate classification
Kemsley, R.	*Women's Measurements and Size MSO*. W. F. F. Joint Clothing Council Limited	1957		
Rodwell, W.	*Toward Metric Sizing*. London: Clothing Institute	1968		
Croney, J.E.	An anthropometric study of young fashion students including a factor analysis of body measurements. *Man*, 12: 448–496	1977	317 young women, 13 body dimensions	Correlation coefficient
Green, M.E.	An application of US Army women's anthropometric data to the derivation of hypothetical sizing/tariffing systems. *Clothing Research Journal*, 9: 16–32	1981		Factor analysis
Salusso, C., De Long, M. and Krohn, K.	A multivariate method of classifying body form variation for sizing women's apparel. *Clothing and Textiles Research Journal*, 4(1): 38	1982	Adult females over 55 years old	PCA classification
DOB-Verband, *DOB-Grössentabellen*	*Women's Outer Garment Size system development*. Köln, Germany	1983		

(*Continued*)

Table 1.1 Continued

Author	Title	Year	Samples	Method
Tryfos, P.	An integer programming approach to the apparel sizing problem. *Journal of the Operational Research Society*, 37: 1001–1006	1986	10 000 adult females	Integer programming to optimize number of sizes
Rosenblad, W.E.	An anthropometric study as the basis for sizing anatomically designed mittens. *Applied Ergonomics*, 18(4): 329–333	1987		
Workman, J.E.	Body measurement specifications for fit models as a factor in clothing size variation. *Clothing and Textiles Research Journal*, 18: 251–259	1991		
Chun-Yoon, J.	*Methodology for Devising an Anthropometric Size Description System for Women.* Vol.2, University of Wisconsin	1992		
Chun-Yoon, J. and Jasper, C.R.	Garment sizing systems: an international comparison. *International Journal of Clothing Science and Technology*, 5: 28–37	1993		
Yoon, J.C. and Radwin, R.G.	The accuracy of consumer-made body measurements for women's mail-order clothing. *Human Factors*, 36(3): 557–568	1994	103 females, 19–50 years old	
Chun-Yoon, J. and Jasper, C. R.	Key dimensions of women's ready to wear apparel: developing a consumer size labeling system. *Clothing and Textiles Research Journal*, 14 (1): 89–95	1996		

Paal, B.	Creating efficient apparel sizing systems: An optimization approach. Unpublished master's thesis	1997		
Beazley, A.	Size and fit: Procedures in undertaking a survey of body measurements. *Journal of Fashion Marketing and Management*, 2(1): 55–85	1997	100 females	Correlation coefficient and bivariate classification of body types
	Size and fit: formulation of body measurement tables and sizing systems – Part 2. *Journal of Fashion Marketing and Management*, 2(3): 18.	1998		
	Size and fit: the development of size charts for clothing – Part 3. *Journal of Fashion Marketing and Management*, 3(1): 66–84	1999		
McCulloch, C., Paal, B. and Ashdown, S.	An optimization approach to apparel sizing. *Journal of the Operational Research Society*, 49: 492–499	1998	2208 adult females	Optimization aggregate loss
Ashdown, S.	An investigation of the structure of sizing systems: A comparison of three multidimensional optimized sizing systems generated from anthropometric data with the ASTM standard D5585-94. *International Journal of Clothing Science and Technology*, 10(5): 324–341	1998	Adult female soldiers (US Army)	Nonlinear optimization method
Laing, R. and Holland, E.	Development of sizing system for protective clothing for adult males. *Ergonomics*, 42(10): 1249–1257	1999	691 adult males	Factor analysis and cluster analysis
Otieno, R.	Development of sizing system for female children in Kenya. *Journal of the Textile Institute*, 91(2): 143–152	2000	Female children 2–6 years old	Correlation coefficient and bivariate classification

(*Continued*)

Table 1.1 Continued

Author	Title	Year	Samples	Method
Meunier, P. and Yin, S.	Performance of a 2D image-based anthropometric measurement and clothing sizing system. *Applied Ergonomics*, 31(5): 445–554	2000		
Kang, Y. and Hee Do, H.	A study of sizing of children's wear. An analysis of the size increments utilized in children's wear based on anthropometric survey. *Journal of Korean Home Economics Association*, 2(1): 95–102	2001		
Szirovicza, L., Ujevic. D. and Drenovac, M.	The structure of body measurements for the determination of garment system for young Croatian men. *Collegium Antropologicum*, 26(1): 187–197	2002	4268 men, 18–22 years old	Discriminant analysis
Gupta, D. and Gangadhar, B.	A statistical model for developing body size charts for garments. *International Journal of Clothing Science and Technology*, 16(5): 458–469	2004	Indian adult females	Principal component analysis (PCA)
Yokota, M.	Head and facial anthropometry of mixed-race US Army male soldiers for military design and sizing: A pilot study. *Applied Ergonomics*, 36(3): 379–383	2005		
Hsu, C. and Wang, M.	Using decision tree based data mining to establish a sizing system for the manufacture of garments. *International Journal of Advanced Manufacturing Technology*, 26(5–6): 669–674	2005	Adult females	PCA and decision tree (classification and regression tree, CRT)

Huysteen, S.V.	Doctoral thesis: Development of standardised sizing systems for the South African children's wear market	2006	2600, 2–14 years old	Correlation coefficient and cluster analysis
Gupta, D., Garg, N., Arora, K. and Priyadarshini, N.	Developing body measurement charts for garment manufacturer based on a linear programming approach. *Journal of Textile and Apparel, Technology and Management*, 5(1): 1–13	2006	1900 Indian females	LP approach
Viktor, H., Paquet, E. and Guo, H.	Measuring to fit: virtual tailoring through cluster analysis and classification. Knowledge discovery in database: PKDD 2006. *Lecture Notes in Computer Science,* 4213:395–406	2006	670 females and males	Cluster analysis and multi-relational classification
Faust, M.	Doctoral thesis: The use of standard sizes in women's ready to wear and consumer fit	2006	6310 females	Clustering using PCA
Ujevic, D.	Anthropometric measurements and adaptation of garment size system. Project: 117-1171879-1887 Faculty of Textile Technology, Prilaz baruna Filipovića 30, HR-10000 Zagreb, Croatia	2007 2011		
Honey, F. and Olds, T.	The Standards Australia sizing system: quantifying the mismatch. In M. Marfell-Jones and T. Olds (Eds.), *Kinanthropometry X*. Routledge: London: 97–112.	2008	294 women, 18–30 years old	L statistic
Chung, M., Lin, H. and Wang, M.	The development of sizing systems for Taiwanese elementary- and high-school students. *International Journal of Industrial Ergonomics*, 37(8): 707–716	2007	7800 children, 6–18 years old	PCA and cluster analysis

(*Continued*)

Table 1.1 Continued

Author	Title	Year	Samples	Method
Lin, H., Hsu, C., Wang, M. and Lin, Y.	An application of data mining techniques in developing a sizing system for army soldiers in Taiwan. *WSEAS Transactions on Computers* 7(4): 245–252	2007	610 adult male army soldiers	PCA and decision tree CART (classification and regression tree)
Ng, R., Ashdown, S. and Chan, A.	Intelligent size table generation. Sen'i Comfort Model, Project No. S01-AE32, *National Gakkaishi*, 63(11): 384–387	2007	1000 adult females	Genetic algorithm (artificial intelligence)
Hsu, C.	Applying a bust-to-waist ratio approach to develop body measurement charts for improving female clothing manufacture. *Journal of the Chinese Institute of Industrial Engineers*, 25(3): 215–222	2008	542 females, 18–24 years old	PCA and bust-to-waist ratio classification
Gupta, D.	Anthropometric data analysis and garment sizing system for Indian population. Presented at 86th Textile Institute Conference, Hong Kong	2008	1500 adult females	PCA and cluster analysis
Hsu, C.H.	Data mining to improve industrial standards and enhance production and marketing: an empirical study in apparel industry. *Expert Systems with Applications*, 36: 4185–4191	2009	956 females	Factor analysis and two-stage cluster
Hsu, C. H., Lee, T. Y. and Kuo, H. M.	Mining the body features to develop sizing systems to improve business logistics and marketing using fuzzy clustering data mining. *WSEAS Transactions on Computers* 8(7): 1215–1224	2009		

Ariadurai, A., Nilusha, T. and Dissanayake, M.	An anthropometric study on Sri Lankan school children for developing clothing sizes. *Journal of Social Sciences*, 19(1): 51–56	2009	160 children, 5–12 years old	Bivariate classification using body types (height and girth)
Kwon, O. Jung, K., You, H. and Kim, H. E.	Determination of key dimensions for a glove sizing system by analyzing the relationships between hand dimensions *Applied Ergonomics*, 40(4): 762–766	2009		
Hsu, C. H.	Developing accurate industrial standards to facilitate production in apparel manufacturing based on anthropometric data. *Human Factors and Ergonomics in Manufacturing and Services Industries*, 19(3): 199–211	2009	755 females	Factor analysis, girth ratio, figure types classification
Doustaneh, A.H., Gorji, M. and Varsei, M.	Using self organization method (SOM) to establish a nonlinear sizing system. *World Applied Sciences Journal*, 9(12): 1359–1364	2010	670 Iranian men	Self-organization method (SOM)
Jung, K., Kwon, O., You, H.C.	Evaluation of the mutivariate accommodation performance of the grid method. *Applied Ergonomics*, 42(1): 156–161	2010	1774 men	Regression R^2 and multivariate accommodation performance (MAP)
Bagherzadeh, R., Latifi, M. and Faramarzi, A.	Employing a three-stage data mining procedure to develop a sizing system. *World Applied Sciences Journal*, 8(8): 923–929	2010	1050 males, 16–22 years old	PCA, cluster analysis and decision tree technique
Mpampa, M.L., Azariadis, P.N. and Sapidis, N.S.	A new methodology for the development of sizing systems for the mass customization of garments. *International Journal of Clothing Science and Technology*, 22(1): 49–68	2010	12810 Greek men	Linear regression
Zakaria, N.	Doctoral thesis: The development of a children's sizing system using anthropometric data	2010	2035 children, 7–17 years old	PCA, cluster analysis and decision tree technique

(*Continued*)

Table 1.1 Continued

Author	Title	Year	Samples	Method
Ujevic, D., Zenjak, R.H., Dole, K., Mirko, Z. and Szirovicza, D.K.	Size designation system of clothes and footwear based on Croatian anthropometric system. *Journal of Fiber Bioengineering and Informatics*, 4(4): 311–319	2011		
Salehi, M., Esfandarani and Shahrabi, J.	Developing a new suit sizing system using data optimization techniques. *International Journal of Clothing Science and Technology*, 24(1): 27–35	2012		
Ujeviæ, D., Petrak, S., Hrastinski, M. and Mahniæ, M.	Development of the garment size system and computer-based body models. *Journal of Textiles and Engineering*, 19(85): 35–40	2012		
Jeyasingh, M.M. and Appavoo, K.	Mining the shirt sizes for Indian men by clustered classification. *International Journal of Information Technology and Computer Science*, 6: 12–17	2012		Clustering and classification

relationship for the sample studied, since it classified correctly 95% of subjects within less than 30 size categories.[5]

All the methods described above are based on a linear structure which has the advantages of easy grading and size labeling.[2] However, a new method of optimization was introduced by Tryfos[6] and McCulloch *et al.*[7] which they believed would yield a better sizing system. This method looked at aggregate loss efficiency, so that the sizes created would fit the wearer with minimum aggregate loss.

In Tryfos' study,[6] this distance is known as aggregate discomfort, and can help anticipate profit in clothing markets. He claimed that manufacturers are concerned with how many sizes should be created for clothing in order to maximize expected sales. He argued that consumers always resort to fit quality as an influence on their purchase decision, and that the concern of any sizing system is to ensure that the sizes created are as close as possible to the person's actual measurements for better fitting garments.

McCulloch *et al.*[7] made a breakthrough when they developed a method of calculating aggregate loss known as aggregate loss of fit, which means determining the fit of clothing by measuring the distance between actual sizes and assigned sizes (proposed sizes). Minimum aggregate loss means the distance between actual and assigned sizes is low and therefore the garment is expected to have a better fit.

Both studies used the same concept of optimization in a sizing system but Tryfos[6] is concerned with the viewpoint of customers and profitability whereas McCulloch[7] is concerned with the viewpoint of goodness of fit of the final product. Ashdown[8] also found the non-linear optimization technique to be the best for deriving an efficient sizing system from multidimensional anthropometric data. This method of calculating aggregate loss to validate the sizing system has been used extensively in apparel research.

Multivariate analysis – specifically the PCA technique – is still widely used by many researchers to detect the relationships between variables and in turn find key dimensions by which to classify a population.[1,2,5,9–11] Gupta and Gangadhar[11] used PCA to identify the key dimensions for their population. They classified each population according to these key dimensions using simple univariate analysis. The dimension of height resulted in three height ranges and bust girth gave six bust ranges. From that, 11 size charts were created for each size group for the target population. Finally, the size charts were validated using the aggregate loss method.

Later, a new method of clustering populations called linear programming (LP) was applied by Gupta *et al.*[12] to develop a sizing system. Using this technique, the key dimensions and the degree of fit desired for each target population can be easily changed. The strongest part of their research was that the system could give the exact number of people categorized under each size group, which allowed manufacturers to choose the best size for their target market and decide the quantity of each size to produce and keep in stock.

In recent years, apparel researchers have started to explore another method of classifying populations: data mining. This method is capable of analyzing huge amounts of data either by automatic or semi-automatic means. Data mining techniques include cluster analysis and decision trees. Cluster analysis is a data reduction technique used to solve classification problems. Chung and Wang[13] argued that little research has been done in the application of data mining techniques to the development of sizing systems.

The data mining technique known as clustering was utilized in 2007 to produce a good sizing system for school-age Taiwanese children.[14] This method proved to create a sizing system that has fewer sizes than the Korean sizing system, which was built from a similar appropriate own sizes. In another study by Viktor *et al*.,[15] clustering was used to classify body scan data resulting in five different sizes. The study showed that the interrelationships between different body measurements must be taken into account in order to create clothing sizes that will fit the body elegantly and hide obvious body flaws. To attain this goal, cluster analysis was used to characterize each size which yielded profiles of the population.

That same year, the decision tree technique was employed by Lin *et al*.[16] to classify a population for a sizing system for soldiers' uniforms. PCA was applied and important sizing variables were extracted. Next, the decision tree technique was applied to identify and classify significant patterns in the subjects' body shapes. The researchers showed that the decision tree technique was an advantageous choice because it results in a wider coverage of body shapes with a lesser number of sizes, gives sizing patterns and rules, and provides manufacturers with reference points by which to facilitate production.[16]

The difference between the cluster analysis technique and decision tree technique lies in the profile of the variables which are selected. The decision tree technique is able to predict the target and predictive variables, which means that the selection of the most important variables can be verified. Cluster analysis on the other hand uses centroid partitioning to divide the samples which only provides the range of the variables without the profiles. Nevertheless, both techniques have been shown by researchers to give good results in classifying a population for a sizing system.[13,14,17]

In 2010, both the cluster and decision tree techniques were employed to successfully develop sizing systems. According to Bagherzadeh *et al*.[18] a sizing system developed in this manner offered better accommodation. Futhermore, he stated that using the decision tree technique to profile the cluster groups seemed appropriate and effective in generating each size profile.

The most recent method applied to sizing system development is the artificial intelligence (AI) technique. So far, this technique has not been widely used for the development of sizing systems. However, Ng *et al*.[19] acknowledged the significance of this technique because its results offered more flexibility, a greater reduction in the number of sizes, and higher efficiencies compared to data mining. Artificial intelligence can greatly reduce the overall fit problems extant in sizing systems. Although intelligent sizing appears to be the best technique, it is still new and has not been widely applied; data mining techniques are more well-established among apparel experts.[10,13,14,20]

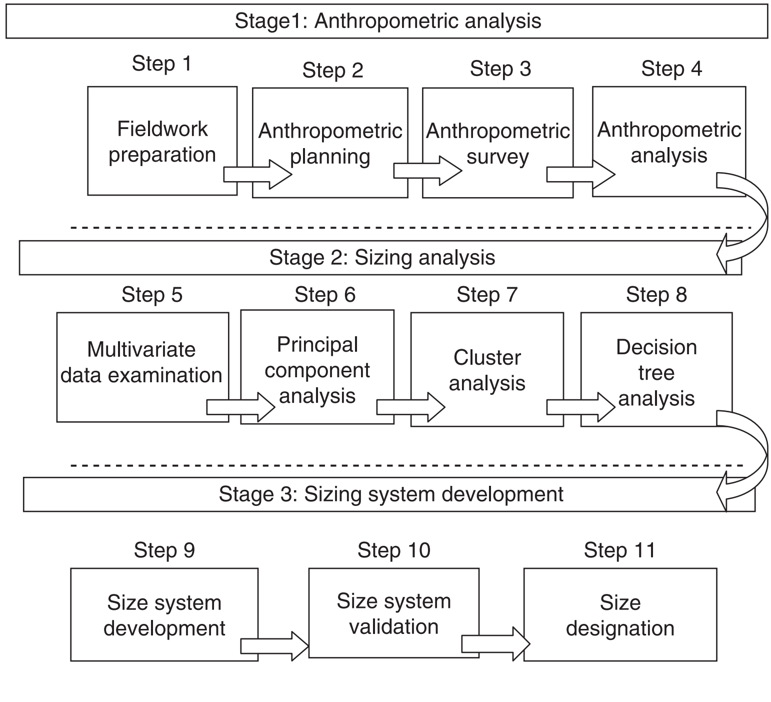
Since 2010, a few more techniques have been introduced and explored for the development of sizing systems. For instance, neural networks – a type of AI technique – has the capability to train itself on a sample population and then classify the population into their own groups. According to Chih *et al.* (2011), by applying a neural network-based data mining procedure, body types can be classified from an anthropometric database. The number of sizes produced for each size group can also be predicted correctly.[21]

This will enhance the accuracy of inventory control and production planning. Another promising method for predicting sizes for classified groups is the self-organizing method (SOM), which is a form of neural network. The SOM is highly efficient as it creates a nonlinear sizing system, results in a higher accommodation rate of population, and gives a smaller aggregate loss of fit compared to the statistical method.[22] Thus, by reducing the number of sizes, it yields manufacturing benefits since producing fewer sizes with a higher accommodation rate is the ideal goal.

The sizing studies that have been reviewed thus far demonstrate many different ways to develop a sizing system. Current sophisticated computer programs have proven to be more efficient when applied to the analysis and the classification of populations. Advanced AI techniques such as artificial neural networks (ANN) and genetic algorithms (GA) can accurately predict the sizes needed for a specific population and are less dependent on humans to make decisions about size classifications.[23] The AI process of designing the right sizes for different body types is more sophisticated and can be done more precisely and quickly. Sizing system development has been a continuous focus of garment research activities, and the necessary knowledge and techniques have been continuously developed and improved over time to ensure the satisfaction of clothing consumers and to produce a good fit for quality clothing. The concept of a garment sizing system has not only undergone many years of study in an attempt to improve the efficiencies of the system, but has been broken down into a comprehensive procedure made up of well-defined stages and steps. This procedure is discussed step by step in the following sections.

1.3 Sizing system development: Stage 1 – Anthropometric analysis

The detailed and comprehensive process of developing a sizing system is shown in Fig. 1.1. This diagram clearly shows how complex it is to develop a sizing system, encompassing three stages and eleven steps from beginning to end. Stage one is anthropometric analysis, stage two is sizing analysis and stage three is sizing system development. All 11 steps are explained in the following sections.



1.1 Methodology for sizing system development.

Stage 1 is anthropometric analysis. The goal of Stage 1 is to collect body measurements of the sample population and analyze those using simple statistical methods. The purpose of this analysis is to understand the body ranges and variations present in the sample population. This stage consists of four steps – fieldwork preparation, anthropometric planning, the anthropometric survey itself, and anthropometric analysis – each of which is described in the following sections.

1.3.1 Step 1: Fieldwork preparation

Paperwork

Fieldwork preparation refers to the preparation that must be done before conducting the anthropometric survey. Preparation activities could include getting permission from the authorities, developing the anthropometric protocol and training the measurers. When conducting an anthropometric survey, the process of preparing paperwork and getting the access from the authorities might involve asking formal permission from government bodies or agencies, various related ministries or even the Ministry of Education if one wants to deal with school-aged children. The paperwork granting permission to work with different target populations can be challenging which needs persistence and patience with the process of waiting for authorities to organize them. However, once the permission is granted it will be a really good experience to conduct the anthropometric survey meeting with many people of different walks of life.

Training the measurers

The next task is to prepare the measurers, if the anthropometry survey is conducted manually. If the survey is to be done using digital methods, such as a 3D body scanner, then training will be focused on using the sophisticated machine. The training for an anthropometric survey for clothing purposes is based on ISO 8559/1989, which defines the terms used for each different body dimension. Under this ISO standard, there are 49 body dimensions to be measured for a clothing system. These body dimensions are divided into three groups: vertical length, width and girth, as shown in Table 1.2. These dimensions are also divided

Table 1.2 List of body dimensions according to ISO 8559/1989

Length (vertical)	Width (vertical)	Girth (horizontal)
Height	1. *Shoulder length	*Weight*
1. *Under arm length	2. *Shoulder width	1. *Head girth
2. *Scye depth	3. *Back width	2. *Neck girth
3. *Neck shoulder point to breast point	4. *Upper arm length	3. *Neck base girth
4. *Cervical to breast point	5. *Arm length	4. *Chest girth
5. *Neck shoulder to waist	6. *7th cervical to wrist length	5. *Bust girth
6. *Cervical to waist (front)	7. *Hand length	6. *Upper arm girth
7. *Cervical to waist (back)	8. Foot length	7. *Armscye girth
8. *Cervical height (sitting)		8. *Elbow girth
9. *Trunk length		9. *Wrist girth
10. *Body rise		10. *Hand girth
11. *Cervical to knee hollow		11. Waist girth
12. *Cervical height		12. Hip girth
13. Waist height		13. Thigh girth
14. Outside leg length		14. Mid thigh girth
15. Waist to hips		15. Knee girth
16. Hip height		16. Lower knee girth
17. Crotch		17. Calf girth
18. Trunk circumference		18. Minimum leg girth
19. Thigh length		19. Ankle girth
20. Inside leg length/crotch		
21. Knee height		
22. Ankle height		

* Upper body dimensions. All others, lower body dimensions

into upper and lower body. The 29 dimensions suitable for upper body or whole body are marked with an asterisk (*), while the other 20 dimensions (not marked) are categorized as lower body dimensions.

First, the measurers have to be briefed about the objectives of the anthropometric survey. They can be introduced to the topic using a PowerPoint presentation and the objectives clearly explained laying emphasis on the consistency and precision of measurement process. Each of the trainees should be provided a copy of the anthropometric manual giving pictures of all the body dimensions. This is followed by a detailed explanation of each body dimension followed by a demonstration on a real body.

The measurers should ideally work in pairs and perform a hands-on practice on their partners for some days till they are comfortable and familiar with each body dimension. Each measurer uses a form, which lists all the body dimensions to record the measurements. The measurement practice should be continued until the measurers gain confidence and start getting consistent readings.

Anthropometric measurement protocols

Anthropometric protocols demonstrate how a manual anthropometric survey can be conducted. The measurement process starts with the subject changing into a tight-fitting garment for better and more accurate body measurements. In every anthropometric survey activity, a team of workers will attempt to finish the targeted number of measurements per day in order to achieve their daily goal. Manual measurement takes an average of 40 minutes per subject and the goal is to measure at least seven people daily. Using the 3D body scanner, it is much faster: the time from changing clothes to completion of measurement is about 5–10 minutes per person.

A consistent set of procedures should be employed for the manual measurement process, such as:

- Fill out demographic data (name, age, gender, ethnic group)
- Measure height
- Measure weight
- Measure upper body dimensions
- Measure lower body dimensions.

One member of the team can measure while the other records the measurements. All measurements should be taken from one side of the subject's body consistently. After completing the measurements of the day, the forms should be counted and the overall quality of anthropometric measurements checked. Forms with missing data are considered not valid and discarded. The number of subjects measured each day is recorded to ensure that the target number of samples has been achieved and that results are accurate.

1.3.2 Step 2: Anthropometric planning

Anthropometric planning comprises the preliminary study, sample size calculation and fieldwork coordination. The first purpose of the preliminary study is to test the whole process of measuring, to understand the nature of the survey and to solve any potential problems before undertaking the real anthropometric survey. The second purpose is to take the measurements needed to calculate the sample size for the anthropometric survey.

Preliminary survey

The preliminary survey can be conducted on a small scale and is usually called the pilot study. The sample size can range from 30 to 100 people. The main objective is to collect sufficient body measurements to calculate the sample size needed for the real anthropometric survey.

One common technique that can be used to calculate the sample size for a study is the proportionate stratified random sampling technique.[24,25] Proportionate stratified sampling refers to taking the same proportion (sample fraction) from each stratum.[26] For example, say there are three groups of students: Group A with 100 people, Group B with 50 people and Group C with 30 people. These groups are referred to as strata. The sample units are randomly selected from each stratum based on proportion. For example, a proportion of 10% from each group (strata) would mean that ten people were taken from Group A, five people from Group B and three people from Group C. The strata group for this study was based on two groups, age (7–17 years old) and gender (female and male).

A study can have for example, four demographic variables: age, gender, ethnic group and geographical area (rural and urban). If the study is focused on two factors such as age and gender, then the proportionate sample size will reflect the distribution of age and gender groups in the real population. The other two parameters, ethnic group and geographical area, can be selected according to simple random technique with the targeted number of subjects calculated from the proportionate sample size.

Data obtained from the preliminary study can be analyzed to calculate the total sample size using the stratified random sampling formula (Equation 1.1). Then, the number of subjects to be sampled from each gender and age group can be calculated using proportionate sampling based on the actual number of subjects present in the geographical area of interest. The steps are given in detail below.

Sample size determination

The sample size for a survey can be calculated using the stratified random sampling formula as shown in Equation 1.1[26]:

$$n = \frac{\Sigma_{i=1}^{l} N_i^2 \sigma_i^2 / \alpha_i}{N^2 D + \Sigma_{i=1}^{l} N_i^2 \sigma_i^2} \qquad [1.1]$$

where

N_i^2= sample size for stratum age group
σ_i^2 = standard deviation of variable
α_i = total population size in percentage
N^2= total population size for stratum age
D = can be calculated using Equation 1.3 below

The body dimensions used to calculate the sample size are the common key dimensions for a sizing system: height, chest girth, bust girth, waist girth and hip girth. After figuring the total sample size, the sample size for each of the strata can be calculated using Equation 1.2 and then the total number of subjects for each age range and gender can be calculated based on the proportionate method formula (Equation 1.3).

First step:

$$\bar{y}_{st} = \frac{1}{N}[N_1\bar{y}_1 + N_2\bar{y}_2 + ... + N_l\bar{y}_l] \qquad [1.2]$$

where

N = total population age 7–17
N_1= total population age 7–12
N_2= total population age 13–17
$\bar{y}$ = mean of variables for each age group

Second step:

$$D = \left(\frac{0.01 \times \bar{y}_{st}}{2.326}\right)^2 \qquad [1.3]$$

Third step: Calculating the sample size using stratified random sampling
To calculate the sample size, the age range for the sample population is calculated and then the total population in the geographical area is calculated. For example: The total population in one state is 823 071 [*N*]. The number of subjects in each age group is then tabulated. Each age group forms a stratum and the sample for each stratum is calculated using the proportionate method according to the ratio of the real population. Each stratum age [*h*] is given by:

$$n_h = (N_h/N) * n \qquad [1.4]$$

where n_h is the sample size for stratum, h, N_h is the population size for stratum h, N is total population size, and n is the sample size.

For example; the male-to-female ratio in the real population in one state is 51% male, 49% female. For each age range, the sample is divided into the corresponding ratio (n) of male and female.

$$n_m = N_h * n \qquad [1.5]$$

$$n_f = N_h * n \qquad [1.6]$$

Where n_m is the sample size for the male stratum and n_f is the sample size for the female stratum, N_h is the population size for stratum *h (age)*, and *n* is the total sample size.

1.3.3 Step 3: Anthropometric survey – manual method

A preliminary study is conducted before the main anthropometric survey in order to check the feasibility of the research approach and to improve the design of the research. ISO standard 8559:1989 (garment construction and anthropometric surveys – body dimension) can be used as a guideline for taking body measurements. In the traditional manual technique, measurement tools to be used include calibrated non-stretchable plastic measuring tapes, height scale with movable head piece, long ruler, elastic 5-meter tapes and digital weight scale. Since measuring a single subject can take from 20 to up to 40 minutes, provision for refreshments for measurers as well as the subjects should be made to incentivize them. The survey data collected in the form of categorical (demographic data) and continuous data were screened and stored in a standard format.

Data entry

All the collected data are keyed into software such as SPSS or MS Excel. The usual format is to key in the subject's name and data into a row, which is known as a case. The body variables are keyed into the columns. The demographic information (categorical data): gender, ethnic group, age and geographical area (urban or rural) comes first followed by columns containing numeric body measurements (continuous data).

Data screening

Data screening consists of examination for data entry errors, missing data or outliers. The entire data set is filtered to ensure that there are no errors or missing data. Errors can creep in due to mistakes in keying in the data; these can be rectified by cross-checking with the raw data.

The distribution of data can be tested using graphical as well as numerical methods. The graphical method makes use of histograms, while the numerical assessment is based on values of mean, median, skewness and kurtosis. Histograms provide a useful graphical representation of the data. Data are considered to be normally distributed if the histogram shows a Gaussian distribution. This involves evaluating the bell shape of the data distribution. When tabulating common key dimensions like height, chest girth, bust girth, waist girth and hip girth, the mean and median values should be the same while the skewness and kurtosis should show values of 0 and 3 respectively; this indicates that the data are normal.[26] Skewness refers to the asymmetry of the distribution. If the skew has a negative value, this means the data are skewed to the left; if positive; the skew is to the right. Kurtosis refers to the peakness or the flatness of the graph.

1.3.4 Step 4: Anthropometric analysis

The final step of Stage 1 is to analyze the data. The statistical method generally applied at this stage is the descriptive analysis also known as univariate analysis based on simple statistics. Categorical and continuous data can be analyzed as follows.

Categorical data

The categorical data are analyzed to understand the demographic profile of the sample population. The first classification to be made often is to divide the population into gender based subsets, namely male and female. Frequency distribution curves are plotted by quantity and percentage and results can be illustrated using tables and bar graphs.

Continuous data

Continuous data analysis based on descriptive statistics includes calculation of frequency distributions, range, mean, median, mode, standard deviation, coefficient of variation and Pearson correlation coefficients to determine the interrelationships between the various body dimensions.

The objective of anthropometric analysis is to profile the demographic data and the continuous data in such a way that the overall patterns of body dimensions are described and one can distinguish between genders and different age groups for selection of key dimensions.

The next section deals with Stage 2 – the sizing analysis.

1.4 Sizing system development: Stage 2 – Sizing analysis

In this stage, the objective is to divide the sample population into smaller groups composed of individuals who have similar key body dimensions. The center panel of Fig. 1.1 shows the phases of Stage 2, which consists of four steps (Steps 5 to 8). The analysis shown in Stage 2 is only one possible method of determining key dimensions and clustering the sample population. Besides the three methods shown here (PCA, cluster analysis and decision tree analysis), other methods like bivariate analysis, fuzzy logic, neural networks and artificial intelligence can also be used.

Step 5 is multivariate analysis, the purpose of which is to test the sampling adequacy of the collected data. In Step 6, PCA is employed to reduce all the variables into significant components. In Step 7, cluster analysis is used to segment the sample subjects into homogeneous groups with similar body shapes and sizes. In Step 8, the decision tree technique can be applied to classify sample subjects into groups based on profiles and to validate the cluster groups.

1.4.1 Step 5: Multivariate analysis

Prior to applying a PCA, a sampling adequacy test needs to be performed on the data to confirm the appropriateness of conducting PCA in order to ensure that the data can be factored well.[27,28] In addition, Bartlett's Test of Sphericity can also be used to add a significant value to support the factorability of the correlation matrix obtained from the items.[29]

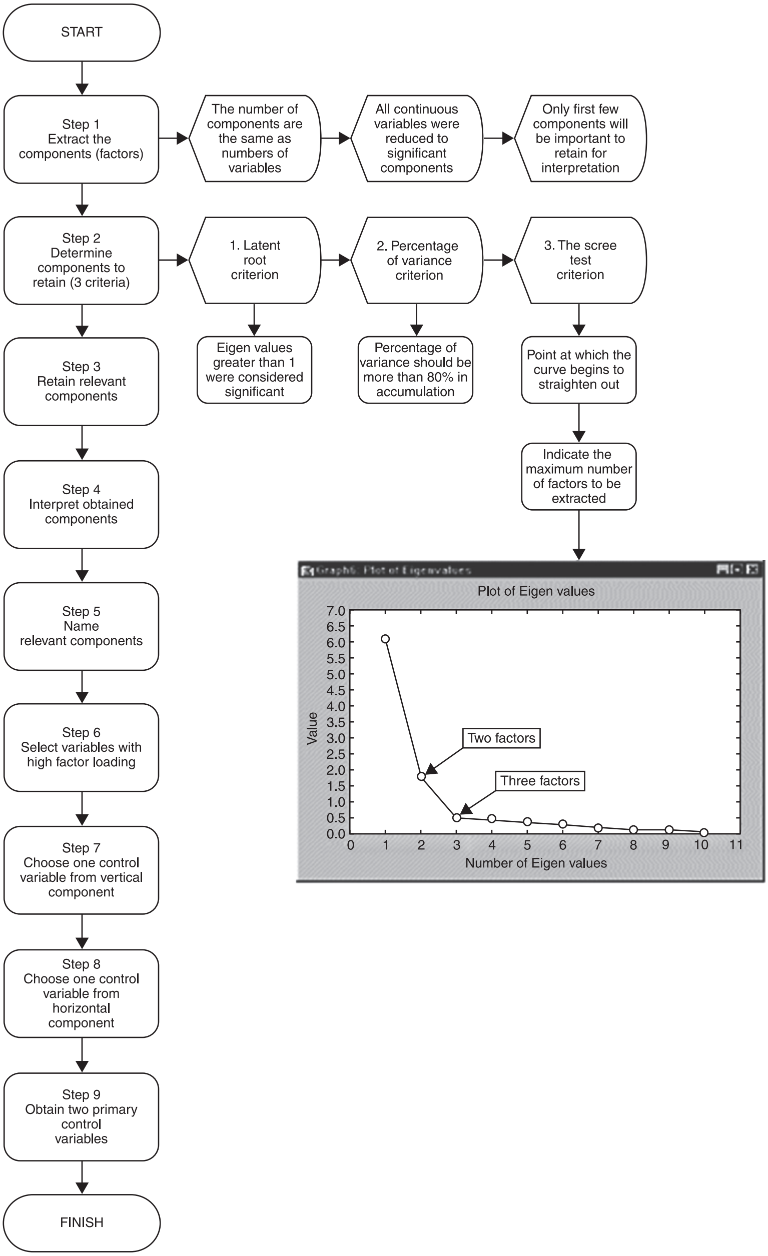
1.4.2 Step 6: Principal component analysis (PCA)

The objective of using PCA is to reduce the number of variables and to cluster these variables into a more parsimonious and manageable number of groups. Parsimonious means to summarize most of the original information (variance) in a minimum number of components for prediction purposes.[30] The process of PCA is shown in Fig. 1.2. The PCA technique is shown in nine steps whereby each step is explained in the diagram. In the first step, the variables are extracted using the orthogonal method called the Varimax technique. The Varimax technique is used as all factors are treated as independent and not correlated. In this step all variables are reduced into components.

Extract the variables

PCA uses an orthogonal method called the Varimax technique. This method is chosen as all the factors are to be treated as independent and are not correlated. In the first step, the variables are extracted and reduced. This is to transform all the data into components. The extracted numbers of components are usually the same number or about the same number with the variables that were chosen. Step 2 determined how many components were to be retained by using three criteria.

After extraction, the next step is to decide how many components need to be retained. In order to retain the most important components, three criteria are used:



1.2 PCA flow chart.

namely, the Kaiser criterion (also known as latent root criterion), the percentage of total variance and Scree plot evaluation.

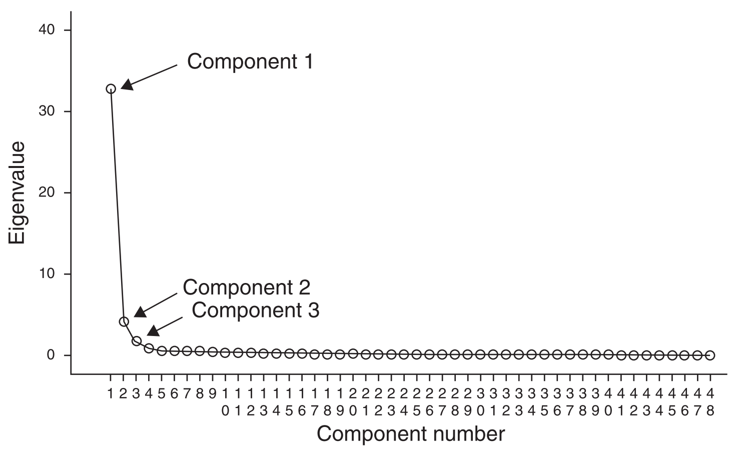
1. For the latent root criterion, the Kaiser rule ensures the Eigen value is greater than 1 which proves it is significant. Thus, all components more than 1 are extracted and retained.
2. Percentage of total variance
   All components should have a percentage of total variance of more than 80% for significant value as recommended.
3. Scree plot
   As shown in Fig. 1.3, for scree plot evaluation, the significant components are those curves that begin to straighten out. From Fig. 1.3, three points on the curve show three significant components. All the other steps from step 3 to step 9 are then illustrated as in Fig. 1.2.

1.4.3 Step 7: Cluster analysis

Cluster analysis is an exploratory data analysis tool used to segment a population into homogeneous subgroups. This means that each person in a group shares similar physical traits with others in the group and that people in one group differ from those in other groups.

1.4.4 Step 8: Classification analysis (decision tree)

Decision tree analysis is a data mining technique which is effective for classification.[17] The Classification and Regression Tree (CRT) technique can be



1.3 Scree plot.

used to verify and classify the sample population according to cluster groups; CRT is used where the data are continuous. The profile of the tree is useful when interpretation of the data set is required. By doing the classification analysis, important variables can be obtained and a simple profile can easily be extracted from the tree diagram.[31]

1.5 Sizing system development: Stage 3 – Developing and validating a sizing system

In this stage, the sizing system is developed based on the data analysis performed in the preceding steps. The process of sizing system development is shown in Fig. 1.4. This stage has three steps, namely: size system development, size system validation and size designation. Each step is described in detail in the following sections.

1.5.1 Step 9: Size system development

The purpose of developing the sizing system is to create sizes for each cluster group that are appropriate to the individual group's range. Two important decisions must be made. The first is to estimate the size roll which will accommodate most of the target population, and the second is to determine which samples go into the cluster groups obtained from the cluster analysis technique. The goal is to accommodate as many people from the target population as possible using one intersize interval.

For the development of the sizing system, the following elements have to be calculated: size range, size interval, size scale and size roll.

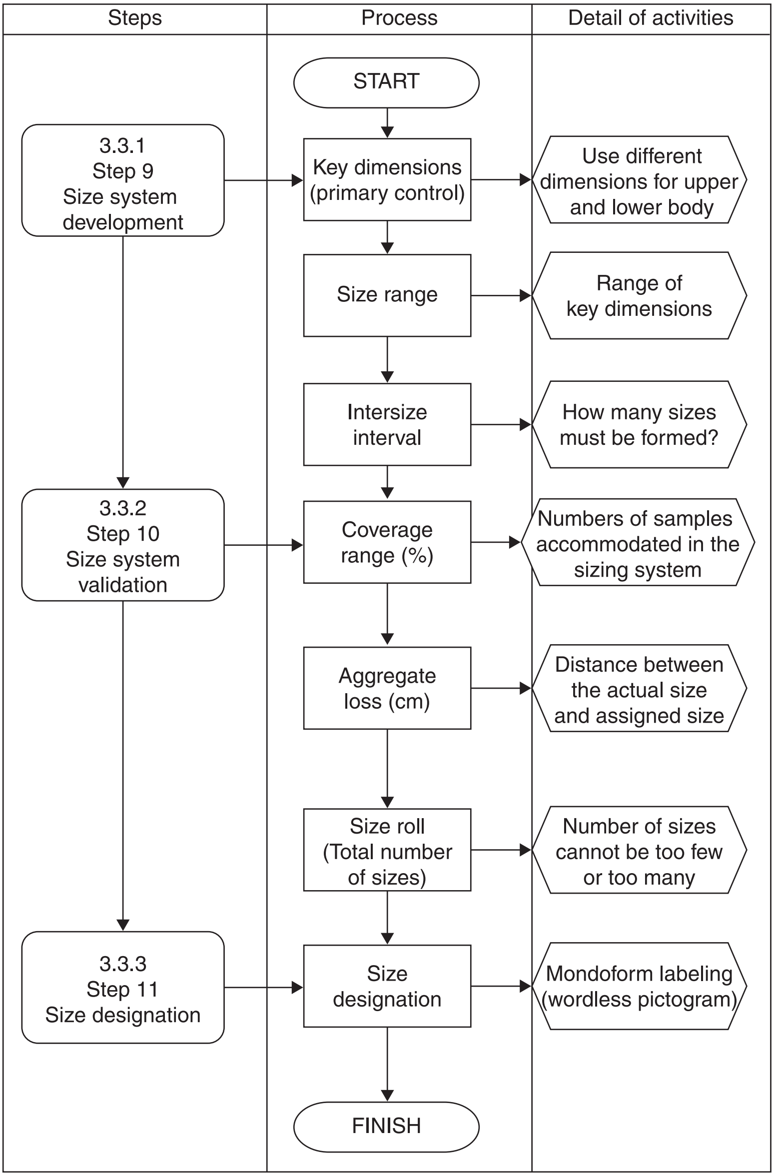
After the selection of the interval range, the classification profile obtained from the decision tree analysis is used as a guide to select samples matching the right body size and shapes. Using this profile, the samples are classified according to the body sizes and shapes. The last step is to validate the efficiency and accuracy of the sizing system thus developed.

1.5.2 Step 10: Size system validation

The aim of any sizing system is to enumerate a set of sizes that can accommodate most of the target population. Thus, the final step is to validate the sizing system based on cover factor (%), aggregate loss, and size roll.

Cover factor

For cover factor validation, the percentage of sample accommodated under each body type and each assigned size is calculated. Each assigned size is presented in the size table. The sizes that fall below 2% coverage are highlighted, as mentioned



1.4 Sizing development flow chart.

in previous studies.[32] Next, the percentages for each size are added together to give the total percentage covered by the system as a whole for each sample group. The cover factor should typically range from 65%–80%, meaning that the sizing system is able to accommodate 65%–80% of the population with the sizes proposed.[33]

Aggregate loss

The next item of validation for the sizing system is goodness of fit. For any sizing system, the sizes that are developed are based on measurements of the actual human body; therefore, the sizes developed must reflect the sizes of the measured bodies as closely as possible. In other words, the goal of any good sizing system is to produce sizes that are close to the wearer's actual body dimensions. This degree of closeness is referred to as goodness of fit. As much previous research has shown, aggregate loss is often employed as a measure of goodness of fit.[2,7,34,35] In aggregate loss, first the Euclidian distance (the distance between actual dimensions and assigned dimensions) is calculated. If the size fits the wearer well, then the distance from the assigned size to the actual size is said to be minimized. The average Euclidian distance is minimized when the aggregate loss value is low.

The formula for the distance between two points $X(X_1, X_2$, etc.) and $Y(Y_1, Y_2$, etc.) is calculated as follows: x_i and y_i are the coordinates of points where x is the actual size and y is the assigned size for the jth axis to represent the jth dimension. The distance is defined as:

$$d = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \qquad [1.7]$$

where:

x = assigned size
y = actual size

The ideal value of aggregate loss is calculated using the number of body dimensions used to segregate the population. Thus, the ideal value is calculated using Equation 1.8.

$$t = (n^{1/2}) \qquad [1.8]$$

where:

i = ideal aggregate loss
n = number of key dimensions used to divide the population into homogeneous groups.

If two control variables are used to cluster the population then the ideal aggregate loss is given as $2^{1/2} = 1.41$. This value is in inches. Since all measurements are taken in metric (cm), the aggregate loss is calculated as $1.41 * 2.54\,\text{cm} = 3.58\,\text{cm}$. This value is the ideal aggregate loss regarded as the benchmark for an accurate size. Using Equation 1.8, the aggregate loss can be calculated for each size developed in any sample population. The Euclidian distance is divided by the number of individuals in each size group. As a result, the distance between the two sizes can be calculated based on the ideal aggregate loss. If the actual aggregate loss is less than the ideal aggregate loss, then the fit is deemed to be good; if it is higher than the ideal aggregate loss, then the fit is deemed to be not so good.[7,11,36]

Size roll

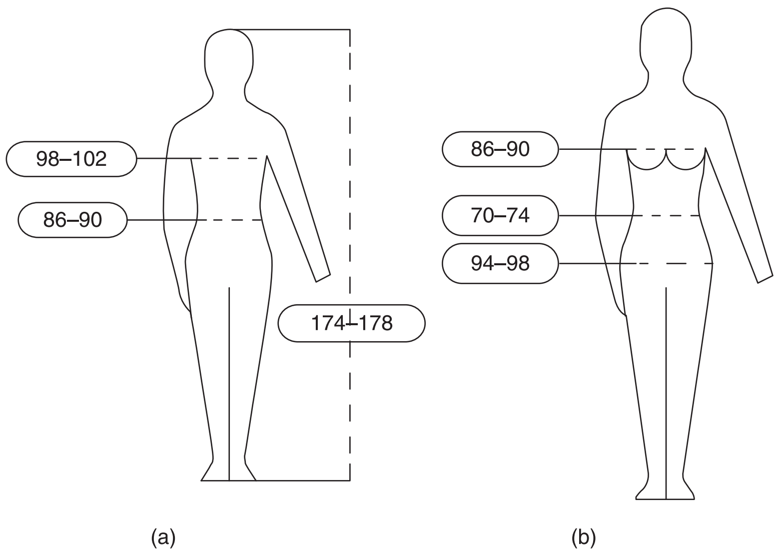
Size roll is simply the total number of sizes obtained for a sizing system, from the smallest to the largest, with fixed intervals between adjacent sizes. The size interval can be the same magnitude across all sizes or it can vary across the size range.[37] The more sizes, the better the fit, because the assigned sizes will be nearer to the actual sizes. Fewer sizes means the range of customers that fall into each size is wider and so some will be much farther than others from their actual size; fewer sizes therefore results in a less efficient sizing system. In terms of practicality and economics for the manufacturer, then, the optimum size roll should be neither too few nor too many.

1.5.3 Step 11: Size designation

Size designation refers to how each size is identified on the clothing or the tag. A size designation can be numeric, alphabetic or graphic. One such method is that of using the standard Mondoform labeling, which employs wordless picture of key dimensions, in conjunction with the numeric system used in the EN 13402-3 European standard for labeling clothing sizes.[38] The size labeling is based on key body dimensions used in segregating the population. The purpose of creating this type of sizing designation is to prevent confusion among consumers by clearly conveying the key measurements on a pictogram. Figure 1.5 illustrates one example of how a pictogram size designation might appear on male and female clothing.

1.6 Future trends

This chapter has successfully shown how important an accurate garment sizing system is to the RTW garment industry. The purpose of developing a sizing system is to produce garments in sizes that can accommodate a majority of customers within a set of fixed sizes. Without a sizing system that is able to generate an appropriate range of sizes for each size designation, producing good quality well-fitting garments is impossible and the overall objective of mass production cannot



1.5 Mondoform labeling of key dimensions for (a) male size labeling and (b) female size labeling. Units: cm.

be met. When a sizing system is introduced, researchers must relate it to the understanding of fit. An accurate sizing system must be built based on actual anthropometric data as the understanding of body sizes and shapes is the only way to cater to the needs of consumers. The method of producing a sizing system impacts the efficiency of that sizing system.

As can be seen from Table 1.1, the theory and practice of sizing system development has progressively evolved from 1940 to the present. This means that a sizing system needs a lot of improvement in order to be efficient. For mass production purposes, the sizing system must be flexible in nature; if there is a need to reduce the number of sizes to make mass production more efficient, the accommodation rate should not be negotiated. Every manufacturer understands that there is a need to accommodate a majority of their customers with a high-coverage sizing system.

Sizing system development began decades ago using only simple bivariate methods. As time went on, the sizing systems evolved to incorporate many highly intelligent methods such as data mining, neural networks and SOM. This was made possible by the experience of more than 70 years of exploring and understanding how to develop sizing systems that are efficient for manufacturers, customers and retailers. It is amazing that the study of sizing systems is still ongoing today – it seems that the study of anthropometric data, sizing systems and size designations never stops. Many discoveries have been made and the weaknesses of different sizing systems are being discussed in order to develop new methods as old methods become obsolete. Today, researchers are finding better ways of developing sizing systems by adopting different advanced machine learning methods like data mining and artificial intelligence methods. It is anticipated that newer sizing systems using newer advanced analysis techniques will produce better and better sizing systems resulting in a greater goodness of fit for clothing customers.

Today, researchers are still actively searching for ways in which to improve the efficiency of clothing sizing systems, many of which lie in the improvement of sizing validation. The key efficiencies lie between the accommodation rate and size roll. New advanced intelligent techniques are being applied to produce better sizing systems with higher accommodation rates and lower size rolls. New methodologies like artificial neural networks and genetic algorithms are some of the intelligent machine learning techniques that may prove useful in creating a predictive model for finding the right sizes for the right body shapes. This is very important to garment manufacturers, as a better model means that they can produce fewer sizes and still accommodate a majority of the population. This would yield tremendous benefits for both consumers and retailers, since such a model satisfies both parties.

1.7 Sources of further information and advice

Websites relating to sizing systems

TC 133 Sizing systems and designations for clothes

http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=52374

A Bibliography on Apparel Sizing and Related Issues

http://2011.fashion/networks.com/images/article_pdf/sizing%20for%20appareal%20(5).pdf

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2
Anthropometry and the design and production of apparel: an overview

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Abstract: Engineering anthropometry is a branch of ergonomics aimed at providing correct body dimensions for obtaining a good fit of a product to the user. Even though body measurements are integral to design of clothing, designers, in most cases, are not familiar with the principles and application of anthropometry in this field. Traditional systems of data collection, interpretation and applications in designing and grading of patterns are unscientific in nature and therefore fail to provide a good fit of clothing for users. This chapter highlights some of these problems and strives to bridge the communication gap between ergonomists and designers, by interpreting and applying the principles of ergonomics and anthropometry to the specific problem of design of clothing.

Key words: anthropometry, clothing, design, human body, size.

2.1 Introduction

Clothing forms a close shell over the human body thus creating an intimate environment around it. People move and perform tasks of various kinds as part of their personal as well as professional routine. During these activities, clothes move and interact with the body. The pleasantness or unpleasantness of this interaction, as experienced by the user, is determined by several factors. Among these, an important factor is the way in which the clothing fits or conforms to the shape and size of the wearer. The fit of a garment affects the appearance as well as performance of the user.

Under extreme circumstances, garment dimensions can become critically important determinants of the safety and performance of the design. For example, industrial clothing which is loose can get caught in machinery and cause accidents. Recognizing the potential of such a hazard, Occupational Safety and Health Administration (OSHA) (1992) issued safety guidelines and regulations to address the subject of loose clothing worn by workers. On the other hand, there is little information available on the effects of clothing which is tight for the user. Anders *et al*. (2005), showed that pants that are tight or smaller than the actual size of the user may restrict hip movement and alter trunk muscle activity during work as well as leisure activities. Subsequently, Yoo and Yoo (2012) report that any restriction in one of the multiple joints in the lumbo-pelvic and hip regions can lead to altered movement and biomechanics of the remaining unrestricted joints.

Taking the work further: Eungpinichpong *et al.* (2013) show that the common practice of wearing tight pants among young workers while performing specific manual tasks, leads to restricted and altered movement patterns of the hip and lumbar spine, respectively. These in turn, may be a cause of increasing complaints for low-back pain and disability among the younger workers. Other problems reportedly caused by the wearing of very tight pants include neurological problems like *Meralgia Paresthetica*, digestion related problems like heartburn and reflux as well as bladder problems for both men and women. However, as of now, there are no standards or directives to control the tightness of clothing.

In order to design clothing that truly fits the bodies it is intended for, a thorough understanding of body shapes and sizes existing in the target population is required. The first step in this process is to systematically measure the bodies of a representative sample of the population, also known as anthropometry. Anthropometry, in turn, is a branch of ergonomics which is defined as a study of the ways in which people work and act. Thus it can be said that the objective of anthropometry is to study and analyse the shape and size of human bodies, and use this knowledge to design products that fit the requirements of users. In case of clothing, users' requirements must be fulfilled with respect to appearance and comfort, while at the same time allowing them to perform their tasks without any impedance or restriction. The task of finding a good fit for all users is complicated by the fact that human beings vary significantly not only in the dimensions, proportions and shape of their bodies, but also in their perception of what comprises a 'good fit' or more often what 'looks good'. Ergonomic design requires an understanding of this variability in human bodies as well as human preferences, and its incorporation into the design process (Pheasant and Haslegrave, 2006).

One of the earliest commercial applications of anthropometry was in sizing of clothing. All historical large scale surveys were carried out to facilitate the sizing of mass produced, ready to wear clothing and equipment for military personnel. It is thus ironical to note that the application of anthropometry to the sizing of clothing continues to be the most flawed to date. This has been established by studies conducted across the world which have repeatedly shown that a large number of members in a population are dissatisfied by the degree of fit provided by ready to wear clothing (Goldsberry *et al*., 1996). Lack of good fit is also the reason given by consumers for deciding not to purchase clothing, and as much as 35% of clothing purchased from catalogs is returned because of problems with fit (Ashdown *et al*., 2007). The root of these problems can be traced to a lack of communication between ergonomics and designers of clothing. It is important that ergonomists collect and present their scientific data in a suitable format while the designers should be ready to interpret and apply it to design of products.

This chapter aims to bridge this communication gap between ergonomists and designers, by interpreting and applying the principles of ergonomics and anthropometry to the specific problem of design of clothing. It discusses the ergonomic aspects of clothing design and factors affecting the same.

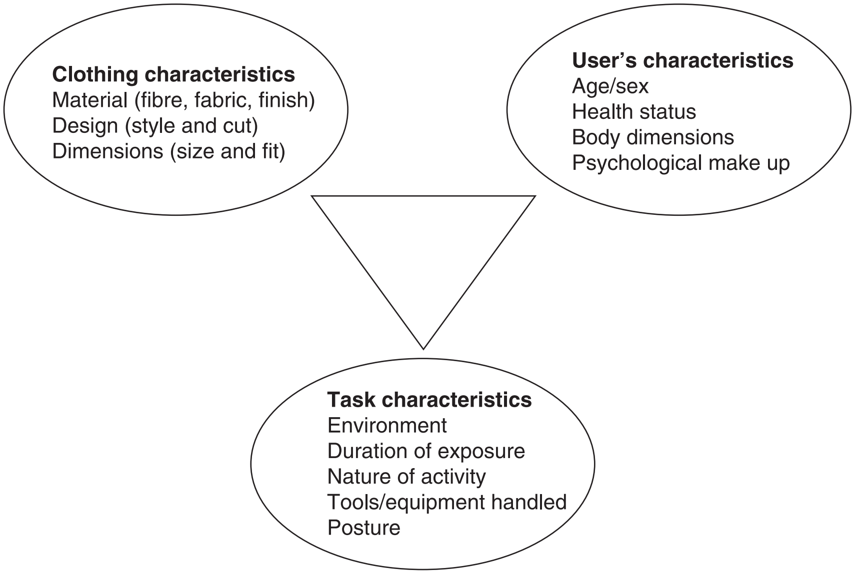
Anthropometric variables and landmarks, as well as methods of generating anthropometric data, right from the classical linear measures to the futuristic three and four dimensional measures have been discussed. Static and functional anthropometry, and its application to design of clothing have been covered. Considerations in selection of data sets for a specific design application, problems in interpretation of data by designers, sources of errors in data and factors causing variability in anthropometric measures have also been discussed. The chapter ends by discussing the futuristic methods by which the fit of clothing can be tested in a precise and scientific manner.

2.2 Ergonomics and design of clothing

This section deals with the application of the principles of anthropometry and ergonomic design to the problem of design of clothing. The term clothing refers to a covering for the human body. Typically, a garment is made from tubular sections, which when joined together, form one sheath for the trunk and two each to cover the limbs. In common practice, more than one such layer is worn in the form of inner wear or outer wear at any given time. The fundamental requirements of clothing include:

- Protection from external environment – heat, cold, wind, rain, etc.
- Maintaining the micro-environment – allow heat and moisture transport from the body.
- Exerting minimal inhibition – allow free movement and accomplishment of tasks.
- Ease of use – donning and doffing of garment.

During daily activities, people perform various actions like sitting, standing, walking, bending, lying down, climbing, lifting or reaching up or driving and so on. Other than these, some special groups may be involved in digging, running, swimming, cycling or sewing as part of their work or recreational activities. Clothing, by its very nature, has an inhibitory effect on the movement and activities of the user. Severity of inhibition depends on the nature of activity. During simple actions like walking or bending, clothes move with the body and cause some slight impedance. However, while performing actions like donning and doffing, the movement of clothing is controlled by the movement of limbs but clothes do not exactly follow the movement of body parts. This causes a huge impedance on the user. Depending on the age, health and strength of users, as well as the type of clothing in use, the task of handling clothing can be rated from simple to quite complex. Clothing design varies with the type of task and activity that the wearer is engaged in. It may thus be said that performance of clothing depends on several interrelated factors, such as the clothing characteristics, user characteristics and task characteristics, as shown in Fig. 2.1.



2.1 Determinants of garment design.

2.2.1 Clothing characteristics

Design of a garment is dictated by the requirements of aesthetics, performance and comfort. An infinite choice of textile materials is available to the designer of clothing. Fabrics can vary in appearance, weight, stretch, strength, stiffness, softness, compressibility and deformation characteristics, depending on the fibre, yarn or fabric parameters used in their production. Application of colour and finishes for enhancing appearance or performance can further change the fabric properties. Dimensions of a garment can be dictated by fashion or performance requirements. As per individual preferences, fabric characteristics can be selected to provide a loose, regular or close fit on the body. But for specialised applications such as clothing required for body monitoring (wearable electronics) or for rehabilitation purposes such as compression clothing, fit is critical to the function and is often the only consideration in design.

2.2.2 User characteristics

Clothing has a very intimate relationship with the user, and clothing preferences vary greatly with age, sex, health, psychology, ethnicity and nationality of user. At this time, when human centred design is becoming very important, designers must give due consideration to the needs and preferences of a diverse group of users. For example, while young users prefer body hugging clothes, older people have a common preference for comfort fits. Fabric, colour and style preferences are also different for people belonging to different subsets of the population. All these must be given due consideration to make the design activity inclusive.

2.2.3 Task characteristics

People involved in different tasks require different types of clothing. Study of body motions while performing certain tasks can be used to design clothing to improve the quality of life of people involved in extreme activities like firefighting, mining or construction work. The performance of clothing under a given set of conditions depends on its interaction with other elements in the environment such as military clothing and its interaction with the helmet, mask, weaponry and other protective equipment that the personnel may be carrying. Ergonomics of clothing are also influenced by the number, size and location of pockets that enable easy access of tools, the closing systems used and the ease of dressing and undressing for the user.

2.3 Anthropometry

2.3.1 Definition and history

The term 'Anthropometry' is derived from a combination of Greek words ***anthrop*** (meaning human) and ***metricos*** (meaning measurement). It refers to the scientific measurement and collection of data about human physical characteristics such as body dimensions, body volumes, masses of body segments, centre of gravity, and inertial properties. According to Hrdlička (1920), one of the earliest anthropologists, anthropometric measurements may be taken for use in industrial design, art and sculpture, military purposes, medical, surgical and dental research and procedures, detection of body defects and their correction and forensic identification.

In its initial stages, the field of physical anthropology was only concerned with body measurements, but thereafter it changed to studies of the human evolutionary processes. Subsequently, a lot of managers in developed countries realised the importance of well designed workplaces and equipment in enhancing the productivity and lowering of worker fatigue. Anthropometry is aimed at providing the correct body dimensions required to provide a good fit of the product to the user. It helps the designers to understand and appreciate the variability that exists in human body dimensions, proportions and shape (Pheasant and Haslegrave, 2006). In the 1930s and 1940s a large amount of military anthropological research was carried out in the USA and Europe which was used in the design of military equipment including apparel, aircraft, battleships and tanks.

All this body of knowledge helped bring data from psychology, physiology, anthropology and medicine together into the domain of engineering and came to be known as the field of ergonomics or human engineering. Since the Second World War, research has continued in the area of anthropometry for applications in workplace and product design. Its most extensive use by far has been in the design of automobiles. Today, engineering anthropometry plays an important role in industrial design, clothing design and architecture, where these data are applied in the design and evaluation of user-centric systems, equipment, manufactured products, work spaces and facilities (Ahlstrom *et al.*, 2003).

2.3.2 Anthropometric variables

An anthropometric variable is defined as a quantifiable characteristic of the body that can be defined, standardised and referred to a unit of measurement. Up to 2000 different anthropometric variables have been used to define the human body for various applications. The number and nature of anthropometric variables to be used for each product has to be critically selected and standardised for each application. For example, while design of work spaces can be carried out by using 33 measured dimensions and 20 derived ones, the Italian fashion board (*Ente Italiano della Moda*) prescribes a set of 32 general purpose and 28 technical measures for clothing design.

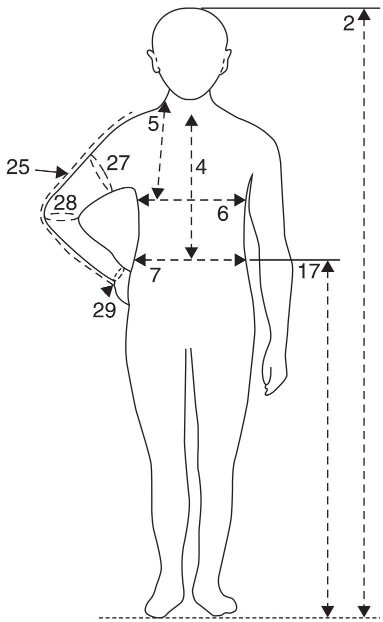
Landmarks are defined as sites on the body that serve as endpoints for measurements. They are specifically located on a bony prominence or other physically definable point on the human body (detected by feeling the bones beneath the skin) and marked on the body to identify anchor points for the measuring tools and to ensure that measurements are taken consistently and accurately.

2.3.3 Static or structural anthropometry

This is the traditional and simplest method of collecting anthropometric data. Body circumferences, lengths of body parts and volumetric measurements are recorded while the body is held still in fixed, standard positions. Tools and methods for collecting these measures have been discussed in an exhaustive review by Bye *et al.* (2006) who have classified them under:

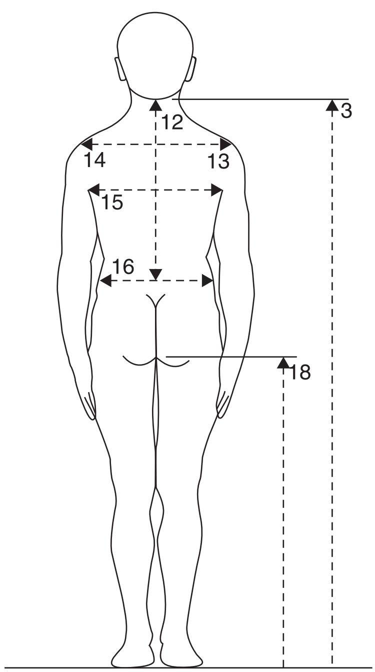
- **Linear measures** which yield data in the form of distance between two points. Figures 2.2–2.5 show some typical linear measures collected for design of clothing.
- **Multiprobe methods** which use a combination of linear methods with other tools to map the body's contours.
- **Body form methods** which give information about the surface, shape and volume of the body.

Standard measures are shown in Figs 2.2–2.5 and are classified below.



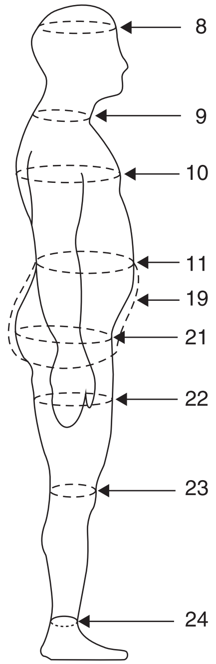
Code	Attribute
2	Height (Ht)
4	Centre front waist length (CFWL)
5	Highest shoulder to chest (HSC)
6	Front chest width (FCW)
7	Front waist (FW)
17	Waist height (WHt)
25	Arm length (ArL)
27	Upper arm girth (UArG)
28	Elbow girth (EG)
29	Wrist girth (WG)

2.2 Measures recorded from the front of the body.



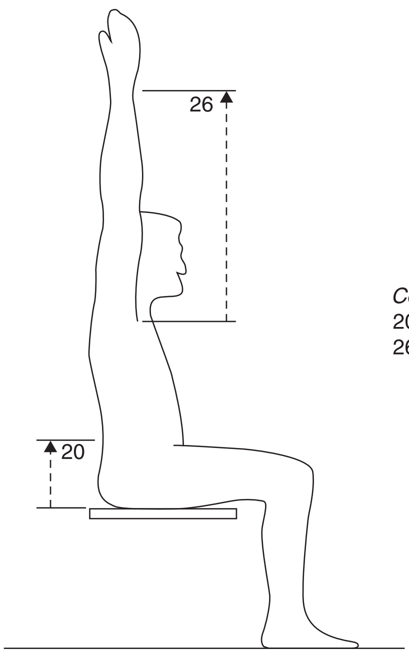
Code	Attribute
3	Cervical height (CerHt)
12	Centre back waist length (CBWL)
13	Arm hole depth (Ar.H.D)
14	Across back shoulder width (ABSW)
15	Across back width (ABW)
16	Back waist (BW)
18	Crotch height (CrHt)

2.3 Measures recorded from the back of the body.



Code	*Attribute*
8	Head circumference (HC)
9	Mid-neck girth (MNG)
10	Chest girth (CG)
11	Waist girth (WG)
19	Crotch length (CrL)
21	Hip girth (HG)
22	Thigh girth (TG)
23	Knee girth (KG)
24	Ankle girth (AG)

2.4 Body girths or circumferences.



Code	*Attribute*
20	Crotch depth (CrD)
26	Under arm length (UArL)

2.5 Measures recorded in sitting posture.

Linear measurements

The traditional tape measure, developed around 1820, was the first scientific tool to be used for recording length and circumferential body measurements in a consistent and accurate manner. It is still the most commonly used tool for linear measures. In 1941, O'Brien and Shelton conducted the first reported anthropometric survey of American women where the circumference measures were captured with a tape measure while the heights and widths of the body were captured with the help of anthropometers and calipers respectively. An anthropometer consists of a calibrated, vertical rod to which are attached two horizontal arms, one of which is fixed and the other is movable, for measuring the length of human trunk and limbs. The caliper, on the other hand is a device with curved arms that are pivoted in the centre, and is used for measuring the breadths and depths of the trunk (Roebuck, 1995). It has not changed much since it was first used by Richer in 1890.

Linear measures are easy to capture, but difficult to translate into 3D measures for the garment pattern pieces. Some dimensions which are critical to the fit of clothing, but are particularly difficult to determine by linear measures include the slope of shoulder, curve of the armhole (arm scye), width and depth of the neck and the final contour of the side seam. All these measures are empirically derived or approximated by pattern makers. Linear measures suffer from the limitation that neither the reference points nor the path of linear measures strictly follow the path of the garment plane as it moulds over the 3D body. According to Gazzuolo (1992), the cumulative effect of several linear dimensions cannot reproduce the 3D configuration of body planes and prominences nor do they reflect the planes of the garment as it drapes over the double curvature of the human body.

Photographic measurements

The next development in measurement techniques was the use of photographic techniques to capture the dimensions of the body. Sheldon *et al.* (1940) showed that circumferential measures recorded on photographs, with the help of calipers, showed lower variance than the same measures recorded directly on the body. Douty (1968) proposed a process called 'graphic somatometry' in which silhouettes of subjects were projected through a grid screen. The somatographs were used to gain information about the proportions of body segments, for contour analysis and angle measurements. Farrel-Beck and Pouliot (1983) used the data points from somatographs to plot full body contours of female subjects. Heisey *et al.* (1986) extended the technique by applying mathematical analysis to determine the angles of darts and seams directly from the silhouettes on the somatographs. The technique works well for those areas of the garment that can be modelled as cones. In a recent paper, Lin and Wang (2010) used an automated body feature extraction method to identify 60 feature points from the front and side photographs of subjects. Their technique showed improved performance over other photographic techniques used by Seo *et al.* (2006) and Meunier and Yin (2000).

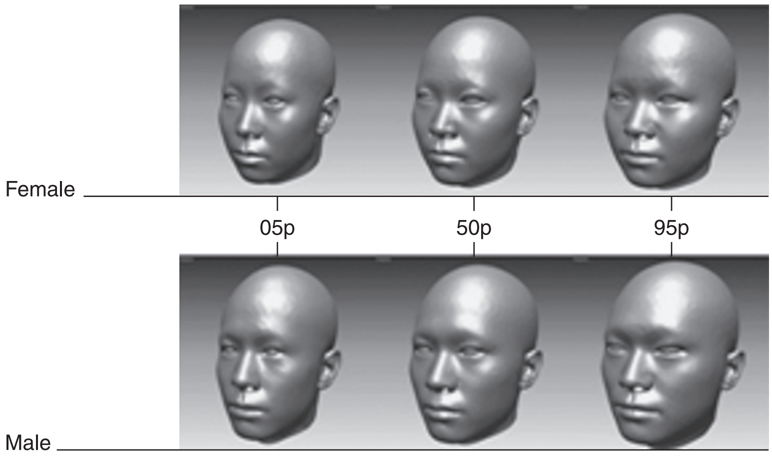
To capture more information about body contours, postures and body angles, Beazley (1997) used a multiprobe method, involving the use of a ‘harness’-like device, while Woodson used a similar device called a ‘Body Graph’ (Gazzuolo, 1985). The device, when placed on the body, allowed direct capturing of multiple measurements. Gazzuolo (1985) was the first researcher to propose the use of a planar method to correlate the dimensions of a human body lying in a 3D plane to those of a 2D fabric. In this method, a non-woven textile marked with a grid was draped on the subject. Dimensions were recorded as a series of points marked on planar devices, rather than a series of linear dimensions. The method gives accurate patterns since it describes the body contours by relating the points and lines around a 3D surface. Gazzuolo (1992) went on to use photographic measures to predict the planar as well as linear measurements with good accuracy. This photographic method was found to give better estimates for body angles, as compared to linear methods. The method has been further adapted for application to 3D body scans for predicting pattern shapes and sizing data for garments (Gazzuolo, 2004).

Body form methods

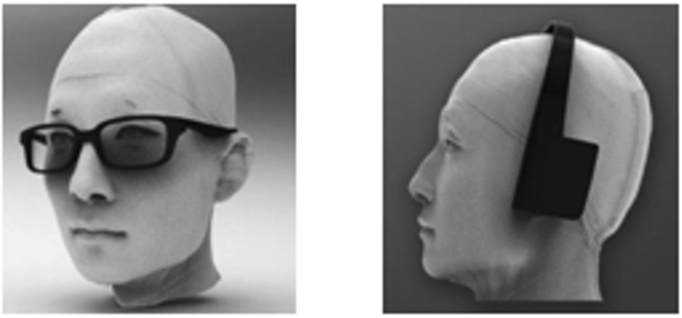
In certain applications, such as design of protective equipment or clothing, an efficient product-user fit can be best obtained only when a complete 3D profile of representative subjects is available from the target population. Several techniques have been used to obtain data of the body in 3D. The first such method was ‘draping’ where the fabric was draped directly on the body to capture the form in 3D. Currently, dress forms or mannequins are used for the same purpose. Dress forms moulded directly from the scans of fit models can also be obtained by manufacturers. With advances in 3D scanning technologies, additional data about the body such as volume, surface area and curvature of the body can be extracted using shape quantification technologies. The technology has matured in the last decade and a variety of software is now available for translating these data and for extracting point, line, surface, shape and volume data from the scans. This is the most accurate method of taking measurements, besides being faster and less invasive than the earlier methods.

There are certain limitations in use of 3D methods for body measurement, which must be known to a designer. The first relates to the fact that all data obtained from a 3D scanner are not necessarily 3D in nature. In some earlier studies, 3D scans were used to extract 1D data, similar to the linear measures obtained from traditional anthropometry, either because of the limitations of technology or due to a lack of awareness about the potential of technology. Even when the data are available in 3D format, like the digital 3D point cloud models, they cannot be used directly by designers. The presence of a large number of measured points and a lack of consistent representations between various scans present challenges in their use. Progress in the field of 3D image analysis techniques, during the last two decades, has made it possible to record and access high resolution 3D scans with a large amount of detailed geometric information about the human body shape. Azouz *et al.* (2006) applied principal component analysis to determine the variations in height, weight, posture and muscularity between bodies so as to bring all models into correspondence with each other. Large scale scan databases have been created through projects such as Civilian American and European Surface Anthropometry Resource (CAESAR), Size UK, Size USA and National Institute of Occupational Safety and Health (NIOSH) head and face database (Robinette *et al.* (1999)).

It is now possible to obtain realistic 3D models of human bodies, faces or heads representative of the generic shapes present in a given population (Blanz and Vetter, 1999; Bradtmiller and Freiss, 2004; Haar and Veltkamp, 2008). Luximon *et al.* (2011) used 3D point cloud data from the scanned heads of Chinese people to create highly detailed and accurate Chinese heads and faces with complete anatomical features and textures. The research output has been commercialised and it is possible to purchase, (off the net) a series of head shapes of the Chinese population from Certiform.org. Heads of six males and six females representing the 5th, 50th and 95th percentiles of the Chinese population are available on a DVD in several formats such as IGES (surface) and VRML (mesh) that are compatible with most CAD systems (Fig. 2.6). Corresponding physical models of the heads are also available. Availability of 3D head data in this form has opened



2.6 3D anthropometric models of Chinese males and females at 5th, 50th and 95th percentile. Image courtesy: http://www.sizechina.com/products.php.

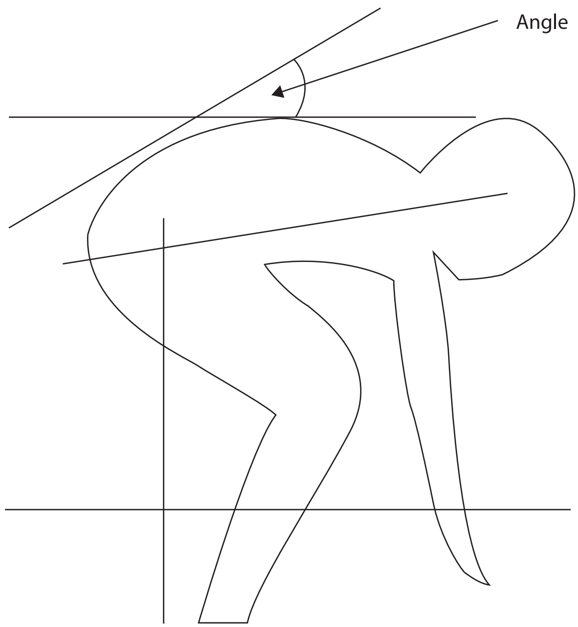


2.7 3D scan of a head being used as a reference to design eyewear and an audio headset. Image courtesy: http://www.sizechina.com/designlab_headset.php.

up a whole lot of opportunities for designers to design a variety of eyewear, facewear and headwear for the Chinese population with very high precision and accuracy (Fig. 2.7). It is expected that in future, more and more organizations will be moving towards establishing 3D digital human databases of their target population and using them directly for their design problems.

2.3.4 Dynamic or functional anthropometry

During use, the user interacts with the product in an intimate manner and while doing so the body moves and changes with time. Introducing the element of motion of bodies, through time and space, adds the fourth dimension to the field of anthropometry and is known as dynamic or functional anthropometry. Functional anthropometry involves the measuring of body while it is in motion or engaged in various actions or tasks (Todd and Norton, 1996). It is often task specific: for example, to design a swimsuit, the motions of a swimmer will be studied, while for designing workwear, the motions of the worker will be studied. The process involves selection of body joints and muscle movements involved in the task, adjustment of the measured dimensions to reflect actual conditions of use, such as forward bending stance, reaching out and presence of accessories like a helmet or mask, etc. This is followed by selection of the appropriate motion ranges in body joints, e.g. knee angle at 60 or 90 degrees. Several variants of the product are then tried by the subject. Finally a 3D motion analysis system, equipped with multiple cameras, is used to record the measurements in various postures in static as well as video mode. Standard photos can be taken with an anthropometric rod placed in the sagittal plane of the subject (Fig. 2.8). Placing markers on the subject further facilitates the process of tracking joint movements. The effect of posture (sitting$<$standing) or weight in hands (heavy weight decreases reach) on the body dimensions is also studied.



2.8 Dynamic anthropometry – recording measurements in specific postures.

Dynamic anthropometrics, though difficult and cumbersome to conduct, can be applied directly in the design process. The most successful application of dynamic measures, so far, has been in design of sportswear for world champions. Swimwear and other sport garments designed using such data have been shown to reduce muscle fatigue, enhance body comfort, reduce impedance and even lead to enhanced performance. It is generally not possible to measure the body in motion with the same kind of accuracy as when it is held in a static pose because of the variation in the way in which a task is performed even by the same individual. Also, it is quite complicated to track the location of body landmarks while the body is in motion. Even though dynamic anthropometry lends a lot of precision and versatility to the process of design, the process, as of now, is time consuming and expensive as only a few measuring systems are available.

2.4 Selection of anthropometric data for clothing design

Clothing differs from other consumer products in many ways. While most products such as workspaces, workstations, switches and automobile interiors are based on the combined anthropometric data of men and women, this approach cannot be applied to design of clothing. Body shape is different for men and women, boys and girls and each data set has to be treated independently. Age is often not as important a consideration in general product design as it is in design of clothing. Change in body shape, size, posture, strength and mobility of joints with age leads to change in clothing preferences. As clothing follows the complex double curvature of the body forming an intimate covering for the same, the measures must correspond to the specific group for which it is being designed. Additionally, the accuracy of fit desired by the users in their garments is much higher than the fit needed in, for example, the height of a dining table or depth of an office chair. This is what makes the task of designing clothes that offer a good fit for most people, highly challenging. Clothing designers must take all these aspects into consideration while designing for various applications. Hsiao and Halperin (1998) suggest a six-step guideline for anthropometric design. The same can be adapted to design of clothing as well, to maximise the well-being, comfort, satisfaction and performance of the user.

1. Determine the body dimensions that are critical to the design of a particular clothing (bust girth for shirt, hip girth for trousers, hand width for gloves, etc.).
2. Determine the target population (men, women, infants, fire fighters, swimmers, etc.).
3. Determine the percentage of the population to be accommodated (stock keeping units, retail space, cost-benefit ratio, etc.).
4. Collect or access necessary data for the target population.
5. Analyse the data using any of the techniques such as univariate (mean, mode, percentiles, histograms, variance analysis, etc.), bivariate (correlation, regression), multivariate (multiple correlation and regression, factor analysis, etc.), 3D shape analysis methods.
6. Select the correct anthropometric design approach for developing a sizing system.

While points 1–3 are relatively obvious and simple decisions to make, identification or collection of relevant data, nature of data to be used and selection of the design approach are challenging decisions for most designers of clothing products. These are discussed below.

In the last decade, several countries and organisations have been involved in conducting anthropometric surveys of their populations. Data sets from these are now available to designers. However, the accessibility of a variety of data sets has by no means simplified the task of product designers who continue to face problems with their use. Problems relate to the anthropometric procedures employed for collecting or processing of data. In some cases, the required information is missing or too hard to find or there are problems with the population covered or the variability in the population is high (Robinette, 2008). Other issues relate to the relationship between the measures and the product or the relationship between the product and user. Selection of an appropriate data set from what is on offer, suitable interpretation and analysis of data relevant to the design problem as well as the selection of correct design approach are decisions that have to be made by the designer for each product.

2.4.1 Data set for target population

Anthropometric measures that accurately represent the target population are essential for designing of products. However, it is rare to find such data in most cases. Often, the available anthropometric data are drawn from populations that are markedly different from the target populations (Parkinson and Reed, 2010). Surveys vary in terms of the size of population, age group of subjects, time of collection of data as well as the procedures used. In most countries extensive data are available for military populations and products for civilian use are often designed on the basis of these measures. Even data collected from civilian populations may not be truly representative of the typical user populations. This leads to a mismatch in the dimensions of the product and the user. To combat this problem, statisticians have employed techniques such as 'down sampling' and 'weighting' to modify existing data sets to make them represent the target population better. Parkinson and Reed (2010) have discussed and reviewed these techniques in detail. They then go on to propose an improved weighting procedure, that can be used on existing anthropometric data sets, to synthesize new data sets that correlate better with the target population. Their method exploits the correlations among measures to produce better estimates of the distributions of variables than are obtained by typical weighting procedures.

To standardise the process of conducting anthropometric surveys in future and make them compatible, a new international standard ISO 15535:2012 (ISO, 2003) has been set up. It lays down the general requirements for establishing anthropometric databases that contain measurements taken as per ISO 7250–1, such as characteristics of the user population, sampling methods, measurement items, database format, anthropometric data sheets and statistics. With this new standard in place, it is expected that in future all anthropometric databases and their associated reports would be available in a standard format and that these various data sets would be fully comparable.

2.4.2 Selecting appropriate measures for a design problem

Anthropometry can provide designers with statistical information about dimensions of the human body, but this information still cannot be translated directly into product dimensions (Ashdown *et al.*, 2007), since the number as well as the type of anthropometric measures required for each design problem is different. Depending on the application, the designer may need a single measurement to design a product (1D) or they may need 2D, 3D or 4D measures. The decision of the designer in this matter can vary with their maturity and understanding of the design problem, awareness regarding the availability of data as well as time and money at their disposal (DINED.nl).

One-dimensional anthropometry

In some design problems, only a single body dimension or univariate data are required for sizing the product; which dimension to select and how much population to cover depends on the relation between the product and the nature of dimension (Dirken, 1999). 1D data are generally used for the anthropometric approach called 'design for extremes'. For example, 'design for the tall' (tall interpreted as 95th percentile man) is a good strategy to decide the height of a doorway, so that even the tallest person does not have to bend to pass and for shorter people, obviously there would be no problem. On the other hand, to decide the height of an emergency switch, 'design for the small' (small being the 5th percentile woman), would be appropriate so that even the shortest person in the population can reach it conveniently. While designing the forward leg space in a car driver's seat, 'design for adjustability' is the best option. The range of leg lengths to be accommodated can be calculated using the mean and standard deviation of the population, so as to allow people with varying heights to fit in. Several databases which share this type of data are available from online as well as offline sources and can be used for design of consumer products. Some examples include Human body dimensions (DIN 33 402), measurements on USA Flying Personnel from 1954, online databases like ERGODATA or Anthrokids and offline databases like People Size, Childata or Olderadult (DINED.nl).

One dimensional data sets, which report only the mean, percentiles and standard deviations of measures, are the most widely available for various populations across the world. They are also relatively easy to use. However, their use is limited by the fact that they do not give any information about the relationship that one anthropometric variable has with another and that they assume that all data are normally distributed (DINED.nl). Such data sets are suitable for certain broad design applications but deficient in applications which require more detailed information regarding the shape and size in the population.

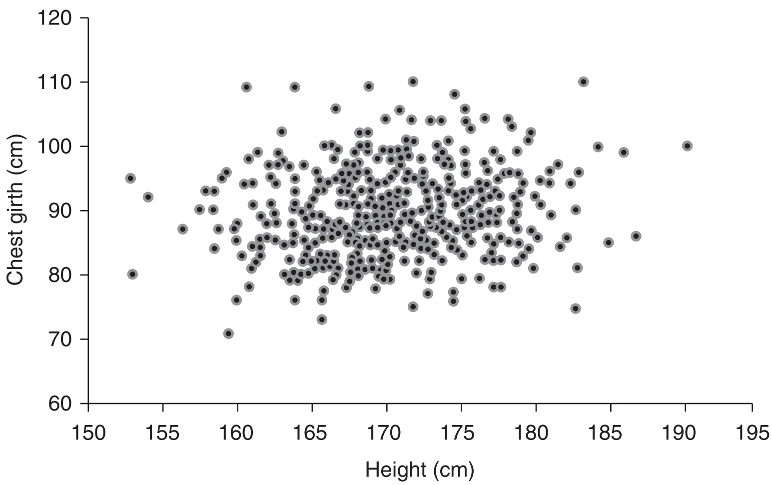
Two-dimensional anthropometry

Two-dimensional (2D) anthropometry or bivariate analysis is used for products which can be designed accurately by using any two key body dimensions. A casual T shirt for boys can be designed based on two measures: namely, height and chest girth. A scatter plot, showing the correlation between the two measures for a set of 18–24 year old men, is shown in Fig. 2.9 (Gupta, 2010). The plot clearly demonstrates that these two factors are not correlated ($R^2 = 0.17$) to each other for this population and thus justifies the selection of one length and one girth variable. Hongwei Hsiao (2013) applied bivariate analysis to design of respirators, where face length and face width are the only two measures required to obtain a good fit for 95% of population. They provide a complete methodology for developing a sizing system and testing the fit of respirators. Another application of 2D anthropometry is in sizing of shoes.

Even though the same data set as is used for 1D anthropometry can be used for 2D anthropometry, in order to derive the correlations between different dimensions, all individual measurements of subjects are required. Two dimensional anthropometry is useful for selecting dimensions for a particular application and also for comparing populations. It is, however, limited to two dimensions at a time. In applications where more than two linear dimensions or information regarding shape or size is required to obtain a good fit for the user, 3D anthropometry is required.

Multivariate anthropometry

The concept of applying multivariate analysis to design problems was first introduced in the 1980s to solve more complex design problems. The most commonly applied technique has been principal component analysis (PCA) which is used to identify the most critical measures and their relationships. Garment sizing systems based on this analysis have been proposed by several researchers and are discussed elsewhere in this book. PCA, though effective in showing relationships between variables, does not describe the 3D shape of an individual.



2.9 Scatter plot for height and chest measurements of Indian males, aged 18–24 years.

Three-dimensional anthropometry

Human body data from 3D scanners are now available for designers to use. Advanced shape quantification technologies have been applied to these data to obtain detailed information about the human body size and shape, human–product interface assessment and determination of the size scheme for products. Though these developments have opened up huge opportunities, the availability of systematic procedures giving information about the application of such data for design of products is as yet limited. Three dimensional data are most suited to applications such as design of clothing and protective equipment including helmets or harnesses, where a good fit is critical at several points on the body for the safety or performance of the user. In a recent paper, Hsiao (2013) proposes a step by step approach for selection and application of 3D shape data to design of fall arrest harness equipment. Through user trials, the critical measures associated with the fit of harness were found to be associated with sizes and shapes of several body segments such as back, chest, trunk, thigh, crotch and hip. They applied the elliptic fourier analysis (EFA) approach developed by Hsiao *et al*. (2009) to quantify the variations in body configuration (size and shape) and to establish correlations between shape and size of the body and the fit of harness. Based on the findings, they propose a size roll comprising three sizes for men and three for women, along with the adjustments possible for each strap length, to cover the target population.

2.5 Errors and variability in anthropometric data

Whatever the source or nature of a data set, the designer must be aware of factors that affect the accuracy and precision of anthropometric dimensions, sources of variability and sources of errors in any data set; at all times, while working with body measures it must be known that the human body is highly unpredictable, both as a static and as a dynamic structure. With time, the same person can change in muscularity and fatness; may undergo skeletal changes due to ageing, disease or accidents or change in posture due to training or sports activities. It must be known that people differ in dimensions as well as proportions or in other words, tall people are not proportionate enlargements of short ones. Some of the key factors that affect the accuracy of body measures and which should be known to the designer are discussed here.

2.5.1 Measurement conditions

Errors in data can creep in from several sources. Some of them can be attributed to the **measurer** (key landmarks misrepresented, instruments used incorrectly), others may be **instrumental** (instruments not calibrated before use, measurements are imprecise), or related to the **subject** (changes posture during measurement). A stoop or an extra stiff stance can yield significantly varying results. **Time of day** when the measurements are recorded can also introduce variability as body dimensions can change with the time of day. Dimensions can be different if recorded just before or after a meal. The body tends to be shorter by up to 2 cm in the evening because the cartilaginous discs of the spinal column get compressed by body weight throughout the day. Additionally, extremities (like feet) swell throughout the day. **Clothing worn** at the time of measuring the body can affect the dimensions significantly. Different types of clothing can have different effects. Measurements recorded on a nude or minimally clad body are the most accurate but may not always be possible in conservative societies. Suitable adjustment for clothing has to be made in each case.

2.5.2 Variability in human dimensions

Anthropometric dimensions are specific to the population they represent. People differ significantly in shape, size and proportions and this variability has important ergonomic consequences (Pheasant and Haslegrave, 2006). Data specific to a population are usually used for designing products for those populations only. Some factors known to introduce variability in data are discussed below.

2.5.3 Age

Age is the most significant factor affecting body dimensions. Dimensions increase with age and then start decreasing around 40 years. Average height of adults steadily declines after 20 years of age. Around 40 years of age most people start to shrink in stature, the extent of shrinkage being greater in women as compared to men. This shrinkage can be attributed to changes occurring in the intervertebral discs of the spine, which cause a stooping of the back. Reduction in height may also result from shrinkage of lower limbs around the joints (Hedge, 2007). Similarly, the average weight of adults increases from ages 20–45 and starts to decline from age 50 for men and age 60 onwards for women. Until 55 years of age, weight increases and there is an increase in hip breadth. Fat redistribution takes place especially around the abdominal region while lean body weight decreases with age due to wasting of muscles.

Moon and Nam (2003) propose a classification and a sizing system for the lower part of the figure in elderly women in their study while Ashdown and Na (2008) compared upper-body measurements of women aged 19–35 to those of women aged 55+ using a 3-D body scanner. Of the 36 body measurements taken, 21 measurements were found to be significantly different between the two age groups. Bilateral asymmetry increased in bodies of older women. Due to redistribution of fat, the bust, waist, abdomen and hip become larger, while the face and legs become thinner. In addition, bust line is lowered and back becomes rounded. Fit problems faced by older women with respect to clothing have been the topic of research by various people for more than fifty years (Bartley and Warden, 1962; Hogge and Baer, 1986; Miller and Petrich, 1986). In fact, the change in the way the clothing fits is sometimes the first indicator of the changes in the body of a woman with age.

A better understanding of the changes occurring in body proportions or posture of women due to age induced anatomical and physiological changes can lead to development of products that fit their needs better. What is of interest to the clothing designer is the finding that this change in body shape is usually accompanied by a change in psychological make up of women, which is reflected in their style and fit preferences. There is no consideration given to these facts and most clothing styles currently available in the market are based on the body shapes and style preferences of younger women, thus causing great dissatisfaction and frustration among the women in the middle and higher age groups.

2.5.4 Ethnicity and nationality

Different ethnic groups have different physical characteristics. As compared to Europeans, African populations have proportionately longer legs while Asians have proportionately shorter legs. Recent surveys have shown that the Dutch people are now the tallest ethnic group in the world. A study conducted on Korean women by Fernandez *et al.* (1989) concluded that the body dimensions of Korean females are different from the Western and Japanese females. Interestingly enough, relative body proportions of the Korean female were found to be closer to those of the Western female as compared to the Japanese female. A clothing designer must be aware of these differences and know their target population and its characteristics. In a metropolis, where a lot of mixed ethnic groups are living, their distribution in the population and their anthropometric characteristics must be known to the designer so as to provide a good fit to the customers.

2.5.5 Occupation

Prolonged practice or involvement in any one type of activity can affect the development of muscles in a particular manner. This has long been known and expected. However, the only conclusive study which compares several occupational groups in the USA and provides detailed data has been conducted by Hsiao (2002). The data show that body measurements of specific occupational groups are different from those of the general population. Male agricultural workers are on an average 2.5 cm shorter in height, and have wider wrist breadths compared to other workers, while female agricultural workers have larger waist circumferences than other workers. Firefighters and police were 7–10 kg heavier than those in other occupations. These findings have an important bearing for the designers of work wear or uniforms by allowing them to modify the designs to accommodate the dimensions of their specific target group. Correct sizing and fit of work wear in industrial and protective services can prevent accidents and enhance the efficiency and performance of users. There is a need to conduct similar studies for other occupational groups such as nurses, teachers and people employed in the hospitality sector or people involved in various sports activities such as swimming, basketball, golf, etc. This would open up a whole new sector for designing occupation specific clothing for populations.

2.5.6 Special conditions

Special health conditions such as pregnancy or disability change the body shape and dimensions. Anthropometric surveys of pregnant women and wheelchair users are being conducted now to develop products especially suited to their requirements. Design standards, such as ANSI A1171.1-1980, are available to assist with designs for wheelchair users.

2.6 Selection of anthropometric design approach

The design approach is a method by which the anthropometric data of a population are applied to a product design, so that a desired portion of the population can be accommodated. Universal operability is 90–95% of the population. Depending on the nature of the clothing being produced and the population for which it is being produced, the designer has to take appropriate design decisions about which anthropometric approach to adopt. In most products, any one approach is employed such as design for extremes or design for the average. However, there is no one approach that can be applied to all categories of clothing. The choice depends on the type and nature of the product and several approaches may have to be used. Ergonomic considerations may sometimes require that more than one approach be used in a single product. In this sense, the decision making process is much more complex for design of clothing as compared to other products. Design approaches that can be used for design of clothing are discussed below.

2.6.1 Design for all

Since clothing is needed by everyone, 'Design for all' is the broad guideline to be followed – designing for the 95th or *n*th percentile is not a choice. The population has to be classified into target groups on the basis of sex, age, ethnicity, nationality or economic strata. Within each of these groups further classification of measures is done on the basis of type or 'style' of garment such as top wear, bottom wear, inner or outer wear. However, given the diversity inherent in the shape and size of human bodies no one system can cover the entire population in any of the groups. Thus 'Design for more types' is the preferable approach.

2.6.2 Design for several sizes

Most standard size charts used across the world for production of ready to wear garments are based on this approach. In this approach, the data set for each population group is statistically analysed to produce a set of size charts or a 'size roll' which serves as a reference point for designers of clothing. Since the size roll covers a wide range of body measurements (such as chest size from 87 cm to 132 cm), the anthropometric design approach is assumed to be one of 'Design for more types'. However, there is a major fallacy inherent in this design approach. Around six anthropometric dimensions are required to give a good fit of a shirt (Table 2.1).

Raw anthropometric data for all these variables for the target population are taken. The key dimension for the garment is identified, e.g. chest girth. The complete range of 45 cm in chest girth is divided into ten sizes, giving 5 cm intervals. Anthropometric data of each of these population groups divided on the basis of chest measures are segregated. The average value for the population for each of the other five dimensions is taken for the medium size to complete the size chart. Then these measures are graded up and down for other sizes. Such a chart has no basis in anthropometric data. Thus it can be said that though the design approach sets out to 'design for more types', in the real sense the design approach is that of 'design for the mean' since proportions are taken to be constant across all sizes and most other values are distorted averages of the actual data measures. The 'mean' in this case refers to the assumed common shape of the body. Clothing designed based on these systems provides a satisfactory fit to only 20% of the target group. Several recent studies corroborate this observation and the size rolls being developed now cater to more shapes as well as sizes for men, women, infants, elderly, etc. The obvious fallout of this approach is that the number of size variants has become much larger, thus making it difficult for the manufacturer to take a decision on how many pieces to produce in how many sizes.

2.6.3 Made-to-measure bespoke tailoring

This anthropometric approach is rarely used in design of common products but is common in design of clothing. Also known as bespoke tailoring, it is prevalent in

Table 2.1 Body measurements (cm) required in sizing of a shirt

Measure	Small		Medium		Large		X-Large		XX-Large	
Chest	87	92	97	102	107	112	117	122	127	132
Waist	71	76	81	87	92	97	107	112	117	122
Hip	89	94	99	104	109	114	119	124	130	135
Neck	35.5	37	38	39.5	40.5	42	43	44.5	46	47
Sleeve	81	81	84	84	87	87	89	89	91	91
Stature	178	178	178	178	178	178	178	178	178	178

Source: Winks (1997).

the clothing industry in various avatars. This was the only form of clothing production available before industrialisation. Tailors would measure every client and create clothes for the individual. The process continues to be prevalent in countries such as India, where the penetration of ready to wear clothing is still not complete. However, in developing countries it had become an absolute luxury until it was reborn in a high tech version a few years ago. Levi Strauss and Co. was the first large company to offer mass customisation, followed by Land's End and Brooks Brothers who offer mass customised suits at their New York City retail store. Several such systems are now available where it is possible to get a single piece of clothing made as per specifications of the individual using advanced CAD and CAM tools. Some specialised clothing products such as space suits for astronauts and performance wear for sports champions are made for a single user. This approach is expensive and has limited applicability but gives best results where fit is crucial for the safety or performance of the user and cost is not a consideration. The approach can be used in a wide range of applications from fashion to functional wear. As users become more discerning and demanding in their choices, made to measure presents the solution that meets the needs of the customer in terms of fit, lifestyle, and individuality (Kay, 2013). As the use and accessibility of 3D scanners increases, it is envisaged that this approach will become more and more popular in the high end fashion wear as well as in performance clothing such as sports garments, workwear, electronic clothing used for monitoring body parameters, clothing for special groups such as patients or disabled having unusual body shapes or posture.

2.6.4 One size fits all

Clothing items such as raincoats, gloves and socks may sometimes be designed in the one size fits all mode. The stretchability and adjustability provided in the design allows the same product to be used by a large number of people.

2.6.5 Design for adjustability

The principle of adjustability is used in products like caps, where providing multiple grooves can allow the user to adjust the cap circumference to fit the head dimensions of 5th to 95th percentile population. Some adjustability at waist, wrist and/or ankle, particularly in high-performance wear, can be provided by elastication or use of buttons or hook and loop fasteners.

2.7 Anthropometry and clothing production

Principles used commonly in engineering anthropometry cannot be applied directly to the design of clothing. People are made up of a variety of uncorrelated dimensions such that each human is shaped differently and any sizing approach covers only a range of users (Harrison and Robinette, 2005). Some of these users are fitted well by the size while others are not fitted so well. Body measurement standards based on anthropometric data, known as size charts in the industry, are used throughout the process of apparel design and production (Hsu, 2009). These standards are intended to guide the designers into making clothes that fit their customers, and at the same time help the producer to decide the quantities to be manufactured in each size. If the selection of anthropometric data set corresponds closely to the target population and if the correct anthropometric design approach has been applied at each step then it can result in enhanced production, material savings and better production planning for the manufacturing units (LaBat and Delong, 1990).

2.7.1 Steps in clothing production

Steps in clothing design include: (a) development of a garment style; (b) which is translated into its constituent patterns in the medium size; (c) patterns are then scaled up and down to create larger and smaller sizes; and (d) these pieces finally go into production. If the principles of anthropometry and ergonomics, as discussed in the previous paragraphs, are applied suitably through steps (a) to (c) then products that provide a satisfactory fit for the users can be produced. Currently, however, step (a) is driven only by design, style and fashion preferences, and that too of only the young and fit age group. There is no consideration either for functional requirements or for population groups whose body shape, proportions or strength may vary from those of the 'normal'. Similarly, pattern shapes in step (b) are based on the assumed and empirical 'standard body shapes' with no consideration for changes brought in by age, disability, activity or occupation. Critical body measurements, as obtained from a classical anthropometric survey, have no direct correlation with the critical body landmarks on the pattern. Thus, pattern development activity is essentially based on empirical knowledge. For example, while the shoulder length is measured on the body, the slope of shoulder in the pattern is arrived at empirically. Also, some measurements recorded during a survey are not body measurements at all, but are garment measurements such as 'arm scye' or 'inner leg seam'.

It has been shown that body measurements and proportions in women undergo significant changes with age (Ashdown and Na, 2008). Differences between the measurements such as shoulder slope, waist height, and bust point and cross-shoulder measurement, taken on the left and right sides of the body are higher among the older women indicating an increasing asymmetry of the body configuration with age. Such anatomical changes in the proportions and symmetry of the body call for analogous changes in geometry of patterns, in order to be able to provide flattering, well-fitting clothing for the elderly. For example, asymmetries in the body can be covered by choice of suitable styles, such as avoiding strong centre line features in the designs, avoiding close fitting styles and choice of removable shoulder pads, etc. Older women prefer longer sleeves, higher necklines and softer collars on their dresses. These and similar considerations can lead to the creation of clothing products which fit the anthropometric as well as psychological requirements of any given subset of a population.

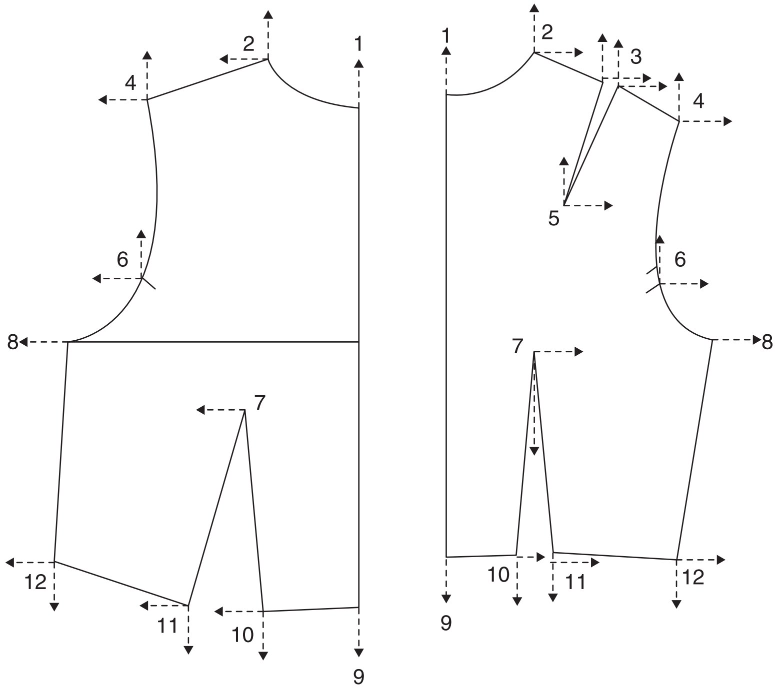
2.7.2 Sizing and grading practices

Pattern makers refer to a set of size charts which contain key body measurements for a range of body sizes, each chart created to serve one body type (Table 2.1). Grading begins with a garment pattern developed for a fit model or dress form in the manufacturer's 'base' size. Increments and decrements are applied at given points (cardinal points) on the base pattern to make the pattern larger or smaller to produce garments in a range of sizes. Figure 2.10 shows the location of cardinal points on a bodice.

In order to create grade rules that accurately reflect body measurements and proportions of users, an understanding of how bodies are shaped and how they grow from one size to another is a prerequisite. However, grading has long remained a neglected area of research in the clothing industry and the classical size charts used by the industry have evolved over the years by a trial and error method (Kunick, 1967). Though some anthropometric surveys were conducted at the beginning of the twentieth century, they did not influence the sizing systems of the world in any significant manner (Cooklin, 1990: 8). This could be because the practices used to develop size charts were already in existence before any anthropometric data became available and perhaps there were possible advantages in continuing with the empirical practices rather than switching over to research data (Staples, 1995). It is therefore not surprising, that traditional grading rules do not yield clothing that fits well on the user, because they follow a proportional grading system based on the following unscientific assumptions:

(a) bodies grow at constant intervals at each cardinal point;
(b) all vertical measurements increase with increase in girth measures;
(c) difference between principal girths remains constant for all sizes;
(d) increase in measures from one size to another is a constant (linear grades); and
(e) bust point remains at a stationary level for all sizes.

These fallacies are reflected in the data in Table 2.1, where the size increment is based on a single measurement and all other measurements are graded proportionately. With increasing availability of real and updated anthropometric data, research needs to be undertaken to study how bodies grow in real populations. Based on this systematic understanding, new body landmarks need to be defined and fresh grading rules need to be established based on anthropometric surveys of the target population (Moore *et al.*, 2001). For effective translation of anthropometric data of a body into patterns, selected landmarks should have direct correlation to the cardinal points on a 2D pattern. Using this approach, Schofield



2.10 Location of cardinal points on a bodice.

and LaBat (2005) identified seven new measurements on the upper torso of American women which can become the basis of developing a new and accurate grading system. They developed a set of patterns which were based on real body measurements, as compared to the proportional grading system, which fitted the users much better (Fig. 2.10). Similar studies need to be done with all populations, in order to develop a complete system which can become the basis for design of well fitting, ready to wear products for a large majority of the population.

2.8 Testing the fit of clothing

Fit of a garment is defined by the relationship between its dimensions and those of the human body. Perfect fit for people has always been a target for design of clothing. However, given the complexity of human body shapes, finding a cost-effective method to provide quality fit in apparel continues to be a challenge for this industry. Testing of clothing is often carried out by one or both of the following methods: **Subjective fit trials** and **Objective fit trials**. Both these trials can be conducted either in the static, quasi-static or dynamic mode (Wagner *et al.*, 2007). The static analysis is based on testing the product under any one posture considered to be the most critical during the task, e.g. testing of skiing gloves in the skiing position. The quasi-static analysis employs a static analysis at multiple time steps of a motion, e.g., testing the fit of pants in standing, sitting and bending position. The dynamic mode of analysis includes all aspects of motion in calculating the stresses, e.g. movement of clothing *vis-á vis* the body, during actions such as running or putting on and taking off of a garment, and also the restraining effect of clothing on the actions of user.

In **subjective fit** trials, subjects from the target population are asked to try on the test garments. Assessment of the garment, with respect to comfort, fit and usability of the product can be done either by the user or by fit experts. Ergonomic aspects, such as interaction with other environmental elements, for example the compatibility of a firefighter's suit with gas mask, gloves, boots and oxygen cylinder, etc. can also be evaluated (Alemany, 2008). Often several variants are tried by the users and a comparative rating given for the trial garments so that the best option can be selected for the given application. Feedback is collected on a structured questionnaire and analysed.

Depending on the requirement and availability of time and resources, **objective fit trials** can assume several forms. For example, tests are conducted to assess the performance of compression wear for use in medical or sports applications. These are special clothing items engineered to apply a specific amount of pressure on certain body parts. Pressure sensors are used at the body–garment interface to measure the pressure exerted by the garment. An optimum balance between the requirement of pressure and the comfort and tolerance of user has to be established for each application. While use of digital human models is well established for several applications such as job safety evaluations including biomechanical, postural and strength analysis, reach/space accommodation and task analysis, their use is relatively infrequent as yet, in testing the fit of clothing. Viktor and Paquet (2007) applied clustering algorithms to divide 3D body scans obtained from the CAESAR survey, into five clusters representing small, medium, large, extra large and extra extra large sizes in clothing. These clusters were subsequently used to create a database of virtual mannequins corresponding closely to real human body shapes. Such a database of virtual mannequins can be used by customers to conduct realistic fit trials, during electronic purchases of clothing. Ashdown *et al.*, 2007 demonstrated the use of a virtual sizing technique for fit trials. A combination of objective and subjective tests was used to compare the measurements of a pair of pants for women, created virtually from body measures, with those of the scanned 3D measurements of the target population. Analysis in the functional test mode showed that the body dimensions of women, whether normal, overweight or obese, change when they sit or stand. Circumferences and breadths increase and crotch length decreases while sitting, with significant differences occurring at hip circumference, waist breadth and thigh breadth during sitting. This leads to a corresponding change in the fit of pants for individuals. Interestingly, the change in measurements was found to be different for the three health groups. As part of the subjective assessment, visual assessment of fit of pants (on the virtual bodies) was done by experts. Comparison data thus obtained were used to modify the shape and size of the 2D patterns to provide a better fit for each of the three groups having different body shapes.

In future, use of such methods will become more and more common for conducting fit trials. Realistic 3D visualisation of bodies as well as clothing in digital form can be used to provide a better fit of garments for a larger section of the population. Testing can be carried out on a wide range of human body scans without the need to produce even a single physical prototype of the test garment or having a single human model available for testing, thus leading to large savings in cost, time as well as the dependence on human subjects. The next step will be to carry out dynamic fit analyses using human models. This would require capturing of motion data and integrating it with movement and flow of garments. Currently available software is not capable of simulating complex human motions with sufficient accuracy. But research is going on in the field.

2.9 Conclusions

This chapter has highlighted the principles of ergonomics and anthropometry as applied to the design of clothing and related products. The complexity and diversity of human body shapes makes creation of perfectly fitting clothing a highly challenging task for the designer. The last two decades have seen momentous developments in the field of anthropometry and its application to the design of clothing. On one hand, advanced statistical methods have been developed to extract and synthesise data of relevant target groups from large scale existing data sets collected using classical measuring techniques. A standard for collecting anthropometric data in a standardised and internationally compatible format has been proposed, thus improving the efficiency of the design process significantly. Tremendous developments have occurred in the field of hardware, that can be used to scan and measure bodies in a fast, accurate and non-intrusive manner. Citing the unique nature of clothing as a product, the chapter explains the process of selecting an appropriate anthropometric design approach for sizing of clothing and related products. The challenging relationship between anthropometry and the process of clothing design has been discussed. It is shown how traditional methods of measuring, pattern development and grading have no scientific basis and no relation to real body measures. They do not cater to the diversity inherent in any given population and therefore fail to provide a satisfactory fit to the majority of users. A case is made out for designers to use recent and accurate data of their target populations to develop new pattern-making and grading systems. The need to identify and design for all subsets in the population – principle of inclusive design – has been emphasised. The impact of current and future developments in technologies and systems, on the way clothes will be produced, tried, sold and purchased by people in future has also been discussed.

2.10 Future trends

The past decade saw the development and fine tuning of shape analysis technologies which can be used to interpret the 3D scan data and obtain meaningful and detailed output about the volume, surface, geometry and anatomical details of the body. It is therefore expected that the exciting developments of the past two decades in the field will continue at the same pace through the next decade. As these technologies go mainstream and become cheaper and more accessible, measuring, designing as well as fit testing will move away from the traditional physical methods into the virtual domain. As more and more powerful image analysis techniques for handling shape and size data of bodies become available and are applied to the ever growing number of 3D body scan data, the field of anthropometry is poised on the brink of a revolution. Large clothing manufacturers will create and maintain databases of 3D anthropometric data of their target populations. These would be fully compatible and capable of being combined with any other data set from another source. It will be possible to categorise these data sets into sub-sets on the basis of age, sex, occupation, ethnicity and nationality, as well as social status, to create products suited to the size as well as the style and fit preferences of each one of these groups. With these developments, the utopian idea of creating a product matching the size and requirements of each individual customer does not appear to be impossible to attain.

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3

Anthropometric methods for apparel design: body measurement devices and techniques

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Abstract: This chapter gives details on how anthropometry is being carried out for both traditional methods and three-dimensional (3D) anthropometry. Methods of the quality control of anthropometric data and related international standards are introduced

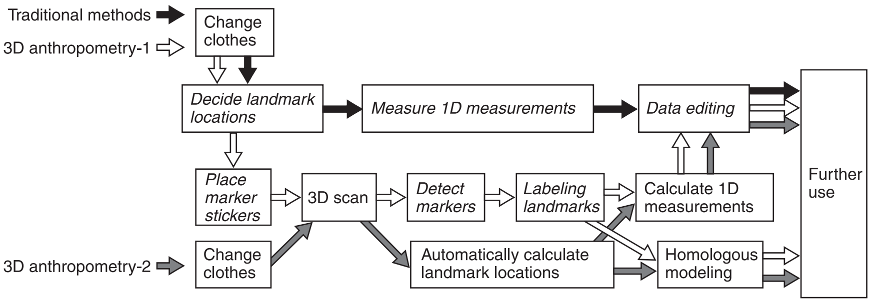
Key words: traditional anthropometry methods, 3D anthropometry, quality control, measurement error, landmarking, posture, scanning attire, accuracy.

3.1 Introduction

Anthropometric methods are intended to ensure the comparability of measurements obtained by different measurers and repeated measurements by the same measurer. For this purpose, postures for measurement, points on the body used to define measurements (known as landmarks), instruments, measurement procedure and measurement attire are standardized. Anthropometry started in the field of anthropology and dates back more than one hundred years. In traditional anthropometrical methods, human measurers decide the landmark locations and take measurements manually using traditional tools such as calipers and a tape measure. These instruments are not very expensive, but such traditional methods require time to complete the measurements for each person and are prone to error.

In recent decades, non-contact human body measuring systems (hereafter, three-dimensional (3D) body scanners) have been available and used in sizing surveys. Using 3D body scanners, the 3D body surface shape and landmark locations can be obtained, and one-dimensional (1D) measurements can be calculated from these data. Body scanners are much more expensive than traditional tools, but more people can be measured in a limited time compared to the traditional methods. It may require time after the scan, and scan-derived 1D measurements are not always comparable with those obtained by traditional methods.

Figure 3.1 shows a flow diagram of anthropometry. In the traditional methods, landmarking and measurement are conducted by measurer(s). In 3D anthropometry, landmarking must still be done by a measurer (3D anthropometry-1), or landmark locations can be calculated from body surface data (3D anthropometry-2). Landmarking is the most important process for ensuring that anatomical locations



3.1 Flow diagram of anthropometry. Manual procedures are shown in italics.

correspond between subjects and defining body dimensions and homologous body models.

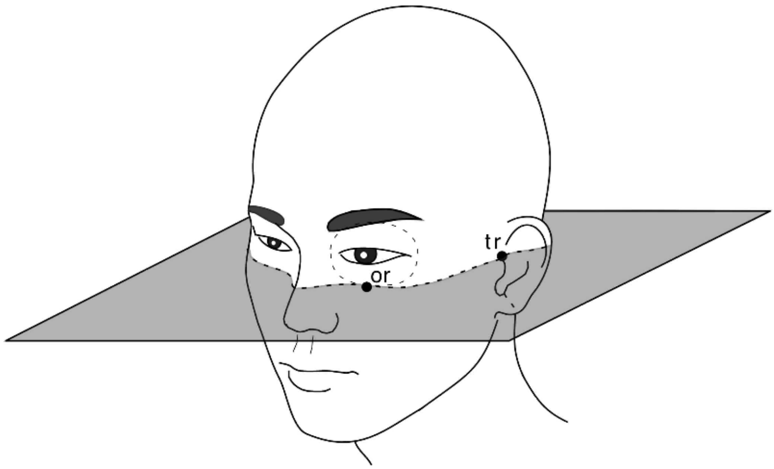
The anthropometry method used depends on the purpose of the measurement. Specifically, the chosen method will depend on which type(s) of data are required (1D measurements, 3D landmark locations, or 3D surface shape) and how the obtained data will be applied. The required accuracy of measurements and measuring attire also depend on the purpose of the anthropometry. Measurements for a sizing survey for establishing national standards should be more accurate than measurements for selecting the proper size of clothes for individual customers. The proper measurement attire may be different for designing underwear and designing outerwear. If measurements are compared with existing data obtained by traditional methods, scan-derived 1D measurements need to be comparable with those obtained by traditional methods. If measurements are used only within a company, they need not be comparable with measurements obtained by other methods.

Users of anthropometric data expect three different types of quality: validity of data, comparability of measurement items, and accuracy and precision of measurements. The validity of data means that the subject population of an anthropometric survey meets the target population of the user. Comparability of measurement items means that 1D measurements with the same name are measured using exactly the same method. In this chapter, anthropometric methods are described with special attention on the quality of obtained data. Individual measurement items are not described. Please see anthropometry textbooks introduced in section 3.7 for descriptions of individual measurement items.

3.2 Traditional anthropometric methods

3.2.1 Basic postures

In the basic standing posture, the subject stands erect with feet together (see Fig. 3.7(a)). The shoulders are relaxed and the arms are hanging down naturally.



3.2 Frankfurt plane (or: orbitale, tr: tragion).

The head is oriented in the Frankfurt plane; that is, the Frankfurt plane of the subject is horizontal. The Frankfurt plane is defined using three landmarks of the head, the right tragion, left tragion, and left orbitale (Fig. 3.2). The orientation of the head affects the accuracy of measurements such as the height and neck circumference. The tragion is the notch just above the tragus. The orbitale is the lowest point on the lower edge of the orbit (eye socket), which can only be located by palpation. The three landmarks should be marked in advance, and the measurer should confirm that the line connecting the left tragion and the left orbitale is horizontal just before taking a measurement. In the basic sitting posture, the subject sits erect with thighs fully supported by a hard horizontal plane. The head is oriented in the Frankfurt plane. Proper instructions are necessary to ensure that the subject maintains the proper posture during the measurement.

3.2.2 Measuring instruments

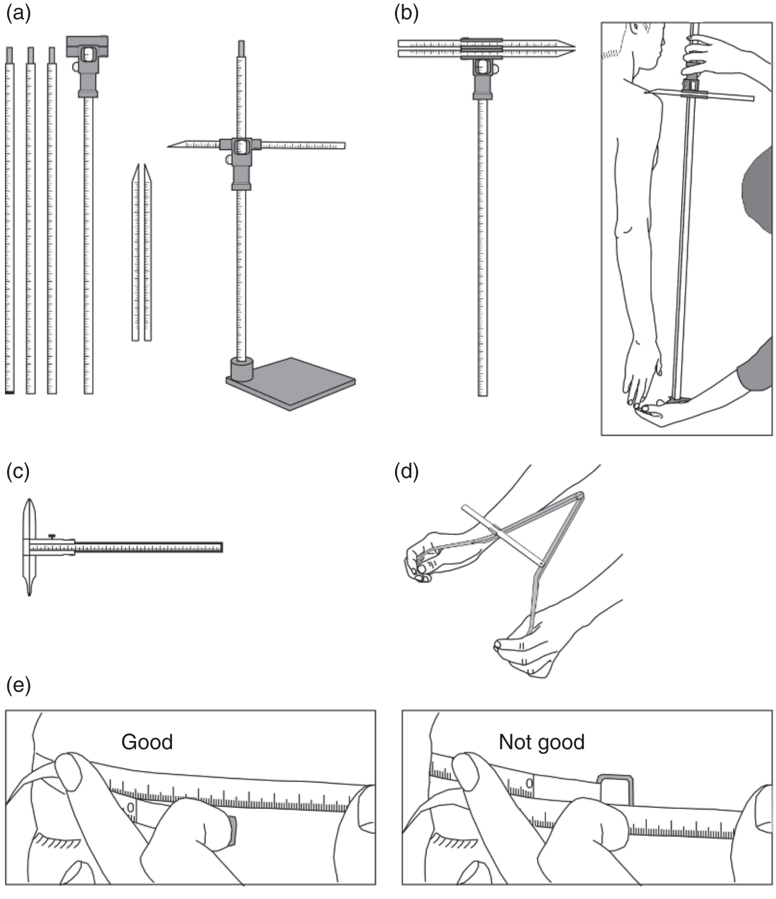
The instruments that are used in traditional anthropometry are calibrated in millimeters. Measurements are read to the nearest millimeter except small measurements of the head, hand, or foot. Figure 3.3 shows the main instruments used in traditional methods.

The anthropometer and tape measure are usually used in anthropometry for garment design. The anthropometer is used to measure a vertical distance from the floor to a specific landmark. Four rods are put together to make an anthropometer (Fig. 3.3(a)), and a straight arm is inserted into the cursor. The measurer holds the rod of the anthropometer vertical, slides the cursor, and places the tip of the arm on the target landmark. The measurer should keep the tip of the arm away from the eyes of the subject.

A large sliding caliper consists of one or two rod(s) of the anthropometer and two arms (Fig. 3.3(b), left). It is used for measuring large distances between two landmarks and for breadth and depth measurements. Curved arms are used instead of straight arms when necessary (e.g. measuring the chest depth in the mid-sagittal plane). The length of the two arms must be the same except when the projected distance between two landmarks is measured.

A sliding caliper is used to measure small breadth measurements and the distance between two landmarks (Fig. 3.3(c)). Pointed-tip-jaws should not be used to measure living people.

A spreading caliper is used to measure the distance between two landmarks when two tips of a sliding caliper cannot touch the landmarks because a part of the body is



3.3 Traditional instruments. (a) Anthropometer, (b) large sliding caliper, (c) sliding caliper, (d) spreading caliper, (e) tape measure. (a) and (b) are from Mochimaru and Kouchi, 2005.

in the way, such as chest depth in the mid-sagittal plane and head length (Fig. 3.3(d)). The large sliding caliper with curved arms can be used for the same purpose.

A tape measure is used for measuring the circumference and surface distance. The material of a tape measure should not stretch by tension or by wetting. The tape measure should be cleaned with alcohol as necessary. When a tape measure is wrapped around a subject, the zero point of the tape measure should overlap the scale on the tape measure as shown in the left image in Fig. 3.3(e).

An inclinometer is used to measure the shoulder slope. Place the inclinometer on the shoulder line (see 'Armscye line' in section 3.5.5) with an end of it at the neck shoulder point, and read the angle. Prepare two inclinometers, and measure the right and left sides simultaneously when both sides are measured.

3.2.3 Role of the measurer

In traditional methods, a measurer and an assistant work together to take measurements. The measurer and assistant must be female when the subject is a female. When the subject is a male, a measurer of the same sex is preferable. Measurers should be properly trained before starting a survey to obtain accurate measurements in minimal time. The training includes lectures on basic anatomy for understanding landmark locations, definitions of landmarks and measurement items, measurement errors, and physical training of landmarking and measurements with several subjects with different body shapes.

The measurer is in charge of the measurement process. She/he must decide and mark the locations of landmarks, give proper instructions to the subject for maintaining the correct posture, give proper instructions to the assistant, and take actual measurements.

3.2.4 Role of the assistant

The assistant records the measured value in the correct cell of a data sheet. She/he should repeat the value aloud before writing it down in order to avoid mistakes. If the assistant realizes that the value is unusual, she/he must ask the measurer to take another measurement. The assistant helps the measurer by checking the posture of the subject that is not visible to the measurer (orientation of the head, rotation of the torso, etc.), checking the orientation of the anthropometer (the anthropometer should be vertical), holding the tape measure at the back of the subject, and passing the small articles necessary for landmarking or measurement to the measurer (Fig. 3.4). To minimize the time for measurement, the assistant should be aware of what she/he should do without instruction from the measurer.

3.2.5 Measurement errors

The accuracy of measurements is affected by factors related to the instrument, the measurer, and the subject. In traditional methods, the instruments are simple and

3.4 Possible roles of the assistant: check the posture of the subject and orientation of the instrument, record measurements, and hold the tape measure.

easy to calibrate. The accuracy in landmarking and measurements depends on the skill of the measurer. A proper measuring posture and its repeatability are subject-related factors. However, posture is a part of the definition of a measurement item, and can be controlled by proper instruction form the measurer. Because measurements are taken quickly, the effect of body sway is negligible. Therefore, the skill of the measurer is the main cause of errors in traditional methods.

Suppose a measurer performed a 1D measurement x of N subjects. The measurement of the i-th subject, x_i, is described as Equation 3.1, where M is the mean of N subjects, s_i is the characteristic of the ith subject, o is the effect of the measurer, and e_i is the random error.

$$x_i = M + s_i + o + e_i \qquad [3.1]$$

Since the mean of the random error is 0, the mean of the subject population will be $M+o$; that is, the effects of random errors are canceled out, but the effect of the observer remains as a bias. On the other hand, the variance of random errors is not 0. Therefore, the variance of x is larger than the between-subject variance. One of the purposes of training measurers is to reduce the random error of each measurer. The variance of random errors by a specific measurer can be calculated from two repeated measurements of N subjects using Equation 3.2, where x_1 and x_2 are the first and the second measurements of each subject, respectively.

$$V[e] = V[x_1 - x_2]/2 = \Sigma(x_1 - x_2)^2/2N \qquad [3.2]$$

The square root of the random error variance is called the technical error of measurement, and is one of the indicators of the degree of repeatability of measurements by a measurer.

When multiple measurers participate in an anthropometric survey, systematic differences (or biases) between measurers also increase the variance. Inter-observer error, the difference between measurements taken by two different measurers, depends on the magnitude of the bias as well as the magnitude of the random error by each measurer. The inter-observer error is larger than the intra-observer error due to the systematic bias between the two measurers. Another purpose of training is to reduce the bias between measurers to an allowable range when plural measurers participate in an anthropometric survey. A common understanding of locations of landmarks on the body between measurers is most important for reducing the bias. A practical protocol for locating a landmark helps to reduce both bias between measurers and random error within a measurer. A protocol established in ISO 20685 (see section 3.5) can be used for evaluating if the differences between measurements taken by two measurers are within an acceptable range.

3.3 Three-dimensional anthropometry

3.3.1 Basics of 3D measurement

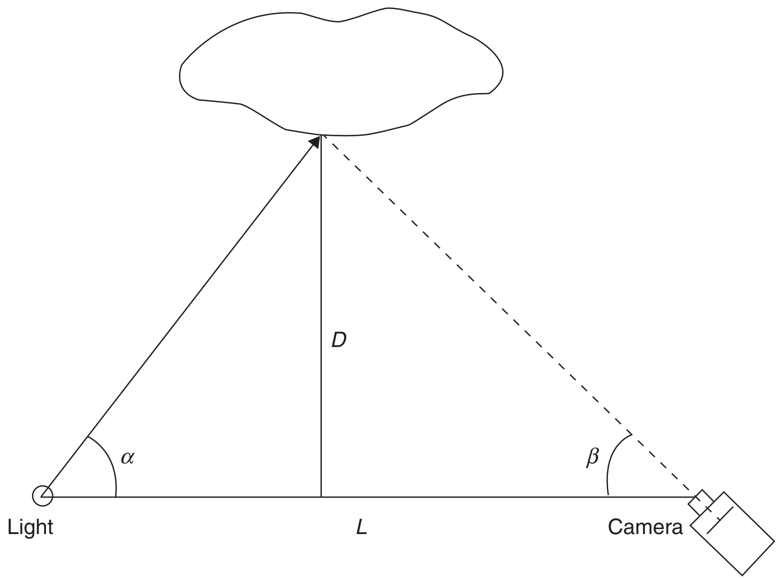
Triangulation is used for obtaining the depth information in 3D body scanners (Fig. 3.5). In one type of body scanner, a single slit light is projected on the body surface, which is observed by a camera from a different angle. The length between the light source and the camera (L in Fig. 3.5) as well as angles between the line connecting the light source and camera and the line connecting a point on the body surface and the light source or the camera (α and β in Fig. 3.5) are known. Therefore, the depth can be calculated. The time required for scanning the entire body by slit light ranges from several seconds to over 10 seconds according to the system used.

In another type of body scanner, structured patterns are projected on the body surface, which are observed by a camera from a different angle. In this method, the body can be measured within one second, in principle. However, plural cameras and plural projectors are often used to minimize the occluded area, and the time for a scan is several seconds to nearly 10 seconds according to the number and the arrangement of cameras and projectors for avoiding the interference of patterns from different projectors.

There are several different methods for obtaining 3D coordinates of landmark locations (Table 3.1). Important points that affect the throughput are: (1) the method to decide landmark locations on the body: a measurer decides landmark

Table 3.1 Different methods to obtain landmark coordinates in 3D anthropometry

Decision of landmark location	Detection of marker location	Labeling
Manual	Manual	Manual
	Automatic	Automatic
Automatic	Automatic	Automatic



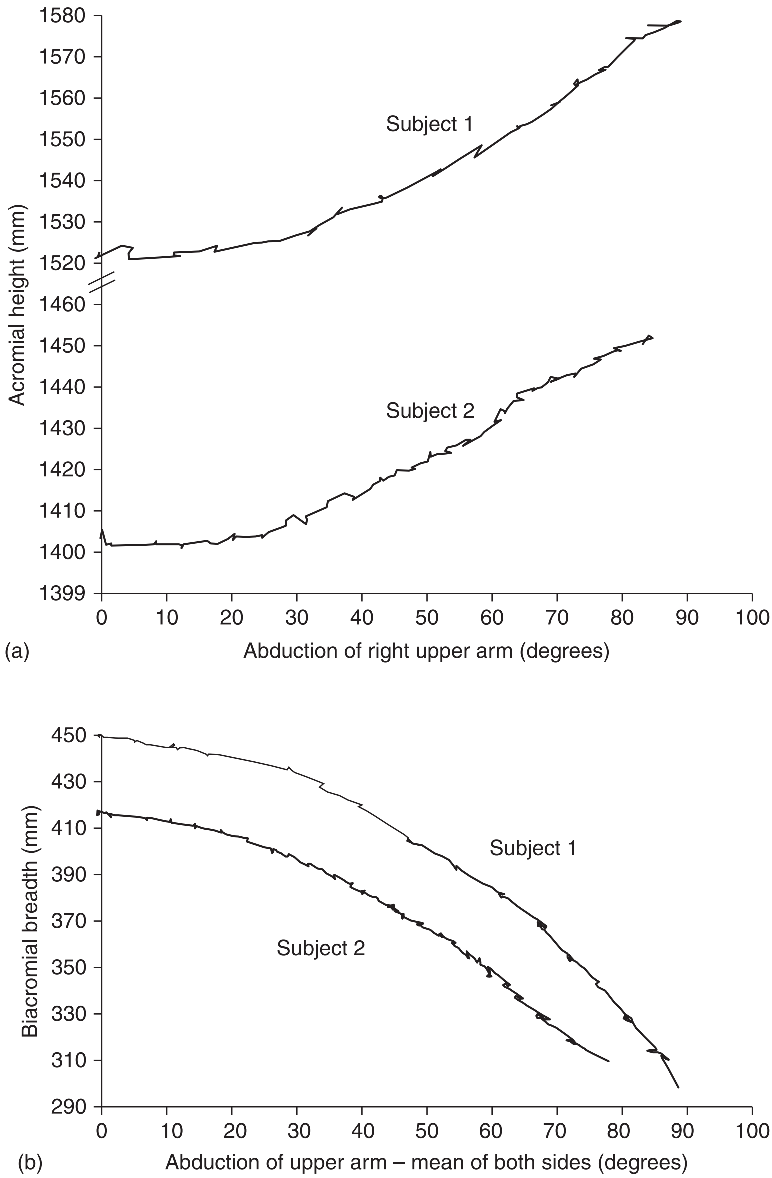
3.5 Principle of 3D measurement.

locations manually or a system calculates landmark locations automatically; (2) the method to obtain 3D coordinates of marker stickers: an operator manually picks the centers of marker stickers or a system automatically recognizes marker stickers and calculates 3D coordinates; and (3) the method to name landmarks (labeling): an operator or a system automatically names each marker. Deciding landmark locations on the human body and placing marker stickers on them are time consuming. However, picking marker centers and naming markers are also time consuming. Automatic calculations of landmark locations save time, but the calculated landmark locations do not always match with landmark locations chosen by skilled anthropometrists. The difference can actually be very large.

There are systems in which all three processes are manual, or process (1) is manual but processes (2) and (3) are automatic, or all three processes are automatic (Table 3.1). It is very important to confirm the time necessary for scanning as well as for obtaining the 3D coordinates of landmarks and 1D measurements before purchasing a 3D body scanner.

3.3.2 Scanning posture

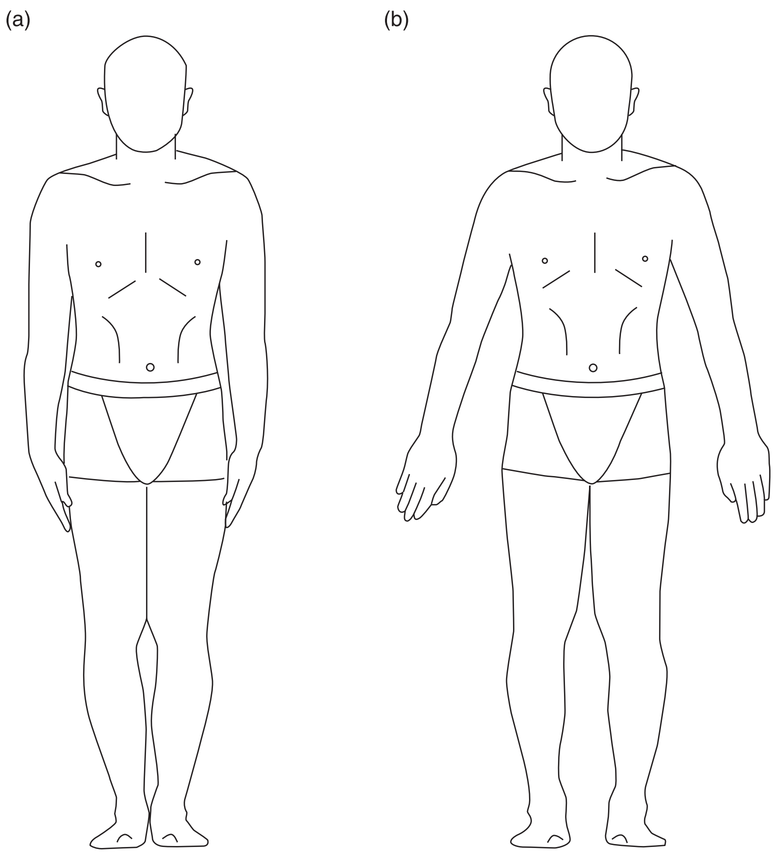
A basic standing posture used in traditional methods may not be suitable for body scanning due to larger occluded areas at the axillae and the crotch. Occluded areas are smaller when arms and legs are abducted, but the shape of the shoulders and body dimensions around the shoulders and hips change (Kouchi and Mochimaru, 2005). Figure 3.6 shows the relationships between the arm abduction angle and



3.6 Relationships between the arm abduction angle and right acromial height (a) or biacromial breadth (b). The body height is 168 cm for subject 1 and 181 cm for subject 2. The abduction angle in the basic standing posture is 0°. From Kouchi and Mochimaru, 2005.

acromial height or biacromial breadth measured for two subjects using a motion capture system (Vicon MX) when their arms are slowly abducted from a basic standing posture. The acromial height (Fig. 3.6(a)) remains stable as long as the abduction angle is smaller than approximately 20°, but the biacromial breadth (Fig. 3.6(b)) becomes smaller when the abduction angle is over approximately 5°. Kouchi and Mochimaru (2005) compared body dimensions of 40 subjects in several different postures using the traditional methods. They found significant differences in measurements defined using the acromion and anterior axilla point as well as the maximum hip breadth and hip circumference between a basic standing posture and a posture recommended in ISO 20685 in which the arms are abducted 20° and the distance between the foot axes of both feet is 20 cm (Fig. 3.7(b)).

The scanning posture is a compromise between the occluded area and shape deformation. It should be noted that many scan-derived 1D measurements



3.7 Scanning postures recommended in ISO 20685. (a) Posture for height measurements. (b) Posture for circumference measurements.

obtained from a scan with a posture with arms and legs abducted are not comparable with traditional measurements because the postures are different. ISO 20685 recommends two standing postures for scanning: one is the basic standing posture for height measurements (Fig. 3.7(a)), and the other is a posture with arms and legs abducted for circumference measurements (Fig. 3.7(b)). In the latter posture, the head is oriented in the Frankfurt plane, the long axes of the feet are parallel to one another and 20 cm apart, the upper arms are abducted to form a 20° angle with the side of the torso, the elbows are straight, the palms face backward, and the subject is breathing quietly. Lu *et al.* (2010) examined the relationships between the arm posture and differences between scan-derived and traditional measurements. They found that when the palms faced backward rather than forward or to the side of the body, the space between the arm and body was larger and the differences between the scan-derived and traditional measurements were smaller.

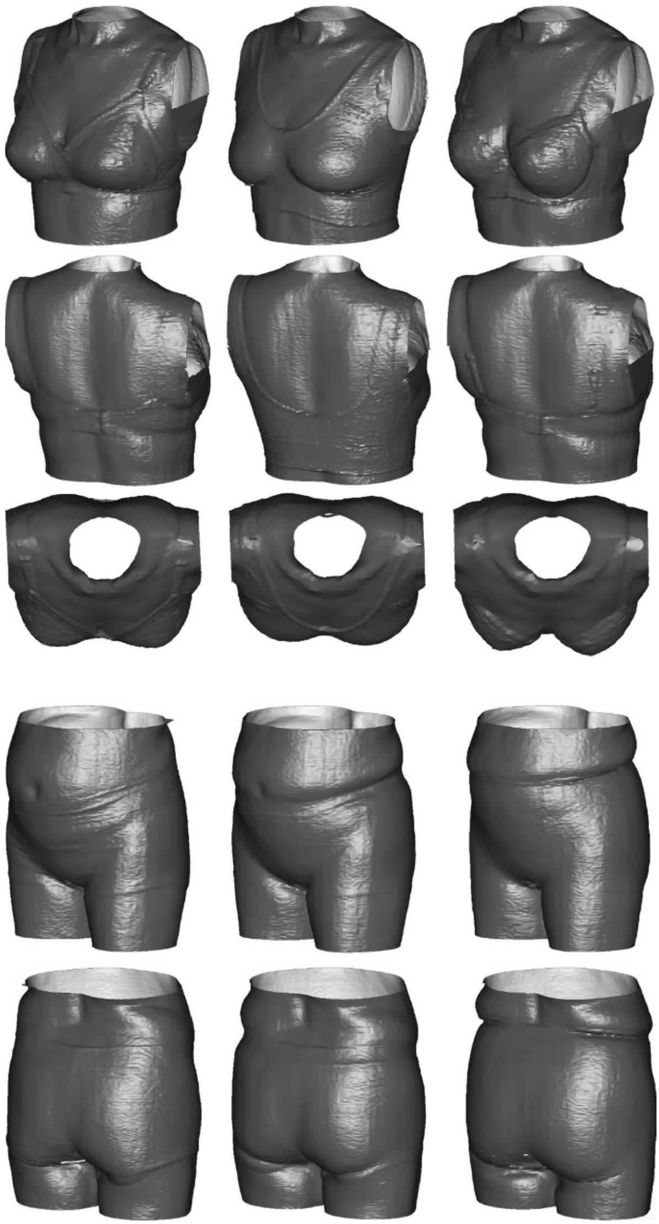
3.3.3 Scanning attire

Scanning attire should be neither too loose nor too tight, and should be appropriate for the purpose of the measurement. Figure 3.8 shows the scan results of the same person wearing three different garments. It is clear that the shape changes according to the garment. ISO 20685 recommends that the subject being measured wears garments that expose landmarks, and a pattern that results in no side seams on the thigh. We recommend a seam on the center back of the lower garment.

In most 3D body scanners, dark colors cannot be captured. Long hair should be pulled up using a rubber band and/or cap so that it does not hide the neck and shoulders of the subject.

3.3.4 Comparability of scan-derived and traditional 1D measurements

The quality of scan-derived measurements depends on the accuracy of the machine and the performance of software for detecting and calculating the coordinates of the center of marker stickers, and for calculating body dimensions using landmark locations. It also depends on the skill of the measurer to decide landmarks if the system uses manually chosen landmark locations, and on the skill of the operator to pick the center of marker stickers using a mouse if the system uses manually chosen marker locations. The quality of scan also depends on the body sway of the subject during the scan because a human cannot stand completely still for 10 seconds. The effects of body sway are smaller when the scan time is shorter and the scan direction is from the top down rather than from side to side. Many more factors affect the accuracy of scan-derived 1D measurements compared to traditional 1D measurements, in which the skill of measure(s) is the dominant factor.



3.8 Shapes of the same person in different garments. Left: garment used in Digital Human Research Center, National Institute of Advanced Industrial Science and Technology; center: garment used in Size *JPN* project, right: commercially available lift up bras and soft girdle.

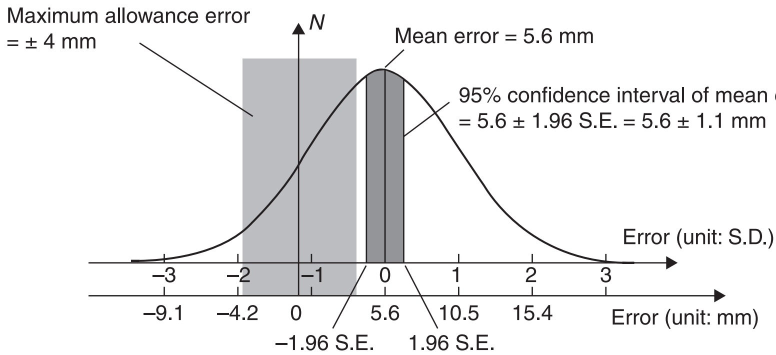
Scan-derived and traditional measurements have been compared in several studies (e.g., Bougourd *et al.*, 2000; Paquette *et al.*, 2000; Han *et al.*, 2010), but the criterion of judging comparability is not always clear. ISO 20685 published in 2006 establishes a protocol for evaluating the comparability between the scan-derived and traditional 1D measurements. In ISO 20685, the criterion of judgment is based on inter-observer differences of experienced anthropometrists in traditional 1D measurements. The procedure for evaluation is described below. See the original document for details:

1. Measure N subjects ($N \geq 40$) by traditional methods (measurer should be a skilled anthropometrist) and by a 3D body scanner.
2. Calculate the error for all subjects. The error is defined as the difference between the scan-derived measurement and the measurement by the skilled anthropometrist.
3. Calculate the 95% confidence interval of the mean error. The lower and upper limits of the 95% confidence interval are calculated as the mean error $\pm 1.96 \times$ the standard error. The standard error is calculated as the standard deviation divided by the square root of N.
4. When the following equations are satisfied, the two types of measurements are considered sufficiently similar: −the maximum allowable error < lower limit of the 95% confidence interval of the mean error, and the upper limit of the 95% confidence interval of the mean error < +the maximum allowable error. The maximum allowable error is 4 mm for height, small circumference, and body breadth measurements, 5 mm for segment length and body depth measurements, 9 mm for large circumference measurements, 2 mm for foot measurements and head measurements including the hair, and 1 mm for hand measurements and head measurements not including the hair.

The procedure is explained using an example of cervical height. Cervical height was measured for 74 subjects (39 females and 35 males) by a bodyline scanner (Hamamatsu Photonics K.K., Hamamatsu, Japan) and by a skilled anthropometrist. The error was calculated as the difference between the scan-derived measurement and the traditional measurement for the 74 subjects. Means and standard deviations are shown in Table 3.2. The lower limit of the 95% confidence interval is

Table 3.2 Comparison of scan-derived and traditional measurements of cervical height (N=74) (units: mm)

	Scan-derived measurement	Traditional measurement	Error
Mean	1388.2	1382.6	5.6
SD	76.9	76.1	4.9



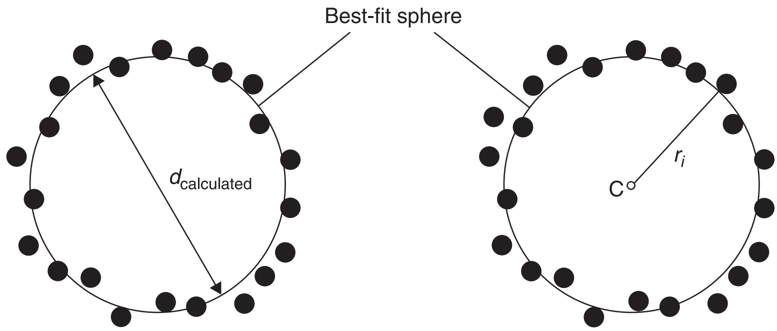
3.9 Distribution of the error and the relationship between the 95% confidence interval of the mean error and the maximum allowable error using the data of Table 3.2. S.E.: standard error.

calculated as mean error $-$ 1.96S.E. $=$ mean error $-$ 1.96S.D./$\sqrt{N}$ $=$ 5.6 $-$ 1.96 $\times$ 4.9 /$\sqrt{74}$ $=$ 4.48 [mm]. The upper limit of the 95% confidence interval is calculated as mean error $+$ 1.96 S.E. $=$ 5.6 $+$ 1.96 $\times$ 4.9/$\sqrt{74}$ $=$ 6.72 [mm]. The maximum allowable error of height measurements is 4 mm. As the upper limit of the 95% confidence interval is larger than the maximum allowable error, the results do not satisfy the condition, and we conclude that the scan-derived and traditional measurements are not comparable in this example; this bodyline scanner systematically gives larger values. Figure 3.9 shows the relationship between the 95% confidence interval of the mean error and the maximum allowable error in this example.

3.3.5 Accuracy of scan-derived 3D measurements

An international standard for establishing a protocol for the acceptance test of 3D scanners is now under discussion in ISO TC213/WG10 (ISO/DIS 10360-8). National standards of similar contents have been published in Germany (VDI/VDE 2634 Part 1 – Part 3) and in Japan (JIS B 7441). The basic idea is to measure an object with known shape and size, and compare the measured results with the actual values. In these standards, an artifact (ball or ball-bar) calibrated using a coordinate measuring machine (CMM) that is traceable to the international standard of the length is used as a test object. The test object is first measured by a 3D scanner to be evaluated. The diameter of the ball or distance between the two balls of a ball-bar is then calculated from the scanned data points and is compared with the actual value given by a CMM.

A ball is also used as the test object in JIS B 7441. The ball is calibrated by a CMM, and the actual value is given. The ball is then measured at several different locations of a scanner to be evaluated. A function of the sphere is fitted to the scanned point cloud, and the diameter is calculated. The error of the diameter measurement is calculated as the difference between the measured diameter ($d_{calculated}$ in Fig. 3.10, left) and the actual diameter. The distance between the center



3.10 Evaluation of 3D body scanners. Left: the error of the diameter measurement is calculated as the difference between the diameter of the best-fit sphere ($d_{calculated}$) and the actual diameter given by a coordinate measuring machine. Right: the error of the surface shape measurement is calculated as the difference between the maximum and the minimum of the distances (r_i) from the center of the best-fit sphere (C) to each of the measured data points.

of the best-fit sphere and each of the measured data points are calculated (r_i in Fig. 3.10, right). The error of the spherical form measurement is calculated as the difference between the maximum and the minimum of these distances. The worst case is reported among the results from measurements at several locations. These standards are intended to provide the basis for an agreement between scanner providers and scanner purchasers. When the test result is as good as or better than the value described in a specification, then both parties agree on the accuracy of the scanner.

Though these standards are not for 3D body scanners, this protocol is useful for evaluating the performance of 3D body scanners. Moreover, only by using a test object with actual values can we evaluate the accuracy of the measured shape. This procedure may provide a basis for the agreement on the quality of scan-derived surface shape between the data providers and data users.

Occluded areas due to the complicated body shape and quality of scan-derived landmark locations are issues specific to anthropometry. ISO TC 159/SC3/WG1 has started a new work item for establishing a protocol for evaluating the quality of scan-derived measurements other than 1D measurements (Kouchi *et al.*, 2012).

It may not be easy to access an artifact calibrated using a CMM. A hard and nondeformable ball of appropriate surface treatment and size can be used for daily verification. This can be done by measuring the test object using a 3D body scanner to be evaluated and comparing the measured diameter with the diameter measured with a calibrated vernier caliper.

The following information should be considered when selecting a 3D body scanner: scan volume, time necessary for one scan, scan direction, resolution, accuracy, function to capture the texture, function to capture premarked landmark locations and its method (manual or automatic), number of cameras arranged in different directions, function to merge data obtained by different cameras, function to calculate 1D measurements, and function to generate a homologous model. The final decision depends on the required type(s) of data (1D measurements, landmark location, and surface shape), accuracy of data, and funds (time and space allowed to obtain required data, price of a 3D body scanner, and running cost).

3.4 International standards related to anthropometric methods

It is implicitly assumed that measurements from different surveys are taken using exactly the same method when the measurement name is identical. Unfortunately, this is not always true. Measurement items named identically but defined differently or named differently but defined identically cause confusion. To avoid such unnecessary confusion, textbooks and standards are used as references. The most frequently used reference is an anthropometry textbook, Martin's textbook of anthropology (Martin and Knußmann, 1988), but this textbook does not focus on anthropometry for garment design. There are several international standards related to anthropometry, ISO 7250 series, ISO 8559, ISO 15535, and ISO 20685. ISO 20685 was already introduced in section 3.3.4. ISO 7250-1, ISO 8559, and ISO 15535 are introduced below. ISO/TR 7250-2 is a data book of body dimensions measured according to ISO 7250-1. Standards, however, are not intended to be a manual for anthropometry. For details of measurement items and measurement procedures, please refer to the textbooks and manuals described in section 3.7.

3.4.1 ISO 7250-1 and ISO 8599: definitions of measurement items

ISO 7250-1:2008 and ISO 8559:1989 describe measurement items for technological design and garment design, respectively. At present, both standards are being revised.

Fifty-six measurement items for technological design are described in ISO 7250-1. ISO 7250-1 was published in 1996, followed by ISO 20685, and there are several disagreements in landmark descriptions between the two standards. Harmonization between ISO 7250-1 and ISO 20685 on landmark descriptions is the main purpose of revising ISO 7250-1. Another purpose is to update definitions of several landmarks to be valid in 3D anthropometry. Traditionally, landmarks are defined and used for manual anthropometry. Present definitions of several landmarks are not sufficient for deciding a 3D position on the body surface. For example, the acromiale (acromion in ISO 7250-1) is the most lateral point on the lateral edge of the acromial process of the scapula. This definition may be sufficient for measuring biacromial breadth or acromial height. However, the antero-posterior location of the most lateral point depends on the shape of the acromial process. Sometimes it is very difficult to determine the location of the most lateral point. Adding a procedure for determining a point in such a case will help to reduce both intra- and inter-measurer errors.

Fifty-five measurement items for garment design are described in ISO 8559. Forty-five items are measured using a tape measure, and eight items are measured using an anthropometer. One item is measured using a scale, and one item by an inclinometer.

Table 3.3 compares 14 pairs of measurement items from ISO 7250-1 and ISO 8559 with the same or similar names. Only three pairs (body mass, chest circumference, and thigh circumference) are considered identical. Another three pairs (stature, cervical height, sitting, and calf circumference) are technically not identical, but are very similar. One more pair (tibial height) can be identical, but clarity of the definition in ISO 8559 does not warrant comparison. The other eight pairs have the same or very similar names but the definitions are different. ISO 8559 is now in revision, with harmonization with ISO 7250-1 as a target. It is hoped that confusions with names and definitions will be solved in the near future.

3.4.2 ISO 15535 and how to eliminate irregular values

ISO 15535:2006 specifies the general requirements for establishing anthropometric databases, such as the number of subjects to be measured and a protocol for eliminating irregular values from measured data.

In traditional methods, irregular values are inevitable due to mistakes. The effects of these irregular values on statistics such as the standard deviation, skewness, maximum and minimum can be very large. ISO 15535 establishes a protocol for eliminating these irregular values.

In this protocol, measured values smaller than or larger than the range of the mean $\pm$ 3 standard deviations are reviewed individually. This way, very large or very small irregular values (caused by, for example, the wrong measurement unit) can be identified. Most of the irregular values are, however, not extreme values. These irregular values can have effects on correlations rather than univariate statistics. To eliminate such irregular values, draw a scattergram using two measurement items highly correlated with each other, and review outliers identified by visual inspection. If the outliers are due to mistakes in data input, correct the values. If the cause is unknown, delete the values.

In the example shown in Fig. 3.11, 217 male subjects are plotted using body height and iliospinal height. It is easy to locate an outlier by visual inspection though both measurements of the outlier are within the range of the mean $\pm$ 3 standard deviations. Unfortunately, it is unknown which of the two measurements is incorrect only from this scattergram. In this situation, choose another measurement item highly correlated with both iliospinal height and body height (for example, acromial height). Draw a scattergram using the iliospinal height and acromial

Table 3.3 Comparison of measurement definitions in ISO 7250–1 and ISO 8559

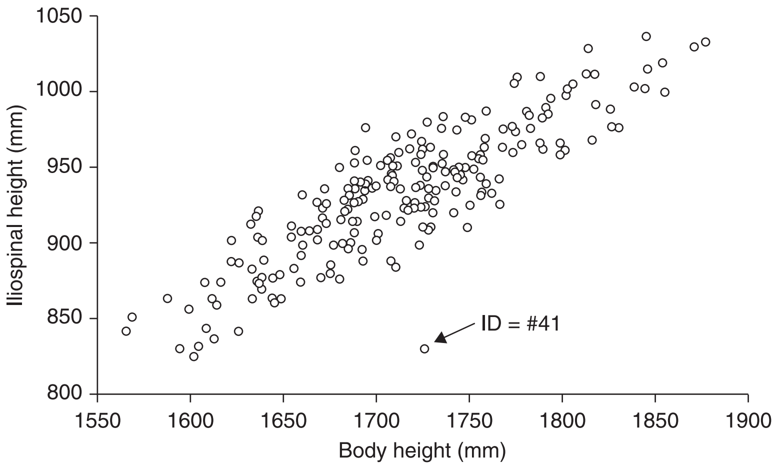
Measurement	ISO 7250–1	ISO 8559	Comparison
Body mass	4.1.1 Body mass (weight)	2.3.2 Body mass	Identical
Stature	4.1.2 Stature (body height)	2.2.1 Height	Slightly different: ISO 7250–1 specifies head orientation.
Crotch height	4.1.7 Crotch height	2.2.27 Inside leg length; crotch height	Different: ISO 7250–1 measures the vertical distance from the floor to the crotch (top of the inner surface of the thigh) using an anthropometer with subject standing with feet together. ISO 8559 measures the distance from the floor to the crotch using a tape measure with the subject standing with feet slightly apart.
Tibial height	4.1.8 Tibial height	2.2.6 Knee height	Unclear: ISO 7250–1 measures the vertical distance from the floor to the tibiale. ISO 8559 measures the vertical distance from the floor to the knee (tibial) level.
Cervicale height, sitting	4.2.3 Cervicale height, sitting	2.2.8 Cervicale height (sitting)	Slightly different: ISO 7250–1 specifies head orientation and describes the posture in more detail.
Hand length	4.3.1 Hand length	2.1.17 Hand length	Different: ISO 7250–1 measures the distance from a line drawn between the styloid processes using a sliding caliper. ISO 8559 measures the distance from the first crease at the base of the hand using a tape measure.
Foot length	4.3.7 Foot length	2.1.25 Foot length	Different: ISO 7250–1 measures the maximum distance from rear of the heel to tip of the longest toe parallel to the longitudinal axis of the foot using a large sliding caliper. ISO 8559 measures the horizontal distance between perpendiculars in contact with the rearmost point of the heel and longest toe using a tape measure.
Head circumference	4.3.12 Head circumference	2.1.1 Head girth	Different: in ISO 7250–1, the tape measure passes above the glabella and the rearmost point of the skull. ISO 8559 measures the maximum horizontal girth of the head above the ears. Head orientation is not specified.

Neck circumference	4.4.8 Neck circumference	2.1.2 Neck girth	Different: ISO 7250–1 specifies the orientation of the head, and measures the circumference at the level just below the Adam's apple (perpendicular to the longitudinal axis of the neck). In ISO 8559, the tape measure passes below the Adam's apple and the level of the 7th cervical vertebra.
Chest circumference	4.4.9 Chest circumference	2.1.7 Chest girth, 2.1.8 Bust girth	Identical
Waist circumference	4.4.10 Waist circumference	2.1.11 Waist girth	Different: ISO 7250–1 measures the horizontal circumference at a level midway between the lowest ribs and the upper iliac crest. ISO 8559 measures the natural waist line, which may not be horizontal, between the top of the iliac crest and the lower ribs.
Wrist circumference	4.4.11 Wrist circumference	2.1.15 Wrist girth	Different: ISO 7250–1 takes the measurement at the level of styloid processes of the radius and ulna; it is not clear if bones are included or not. ISO 8559 measures the girth over the wrist-bone.
Thigh circumference	4.4.12 Thigh circumference	2.1.18 Thigh girth	Identical: ISO 7250–1 takes the measurement at the level immediately below the gluteal fold. ISO 8559 measures at the highest thigh position.
Calf circumference	4.4.13 Calf circumference	2.1.22 Calf girth	Different: ISO 7250–1 specifies that the measurement is a horizontal circumference. ISO 8559 does not specify that the girth is a horizotal circumference, and measures the calf girth of a subject standing with legs slightly apart.

height, and another scattergram using the body height and acromial height. The measurement item with the outlier in two scattergrams has the incorrect value.

3.5 Landmarking

Landmark locations decided by measurers are used for defining anatomical correspondence between individuals. Many of these landmarks are defined on



3.11 Find outliers in a scattergram by visual inspection.

specific locations of bones or easily defined features of soft tissues such as nipples and the navel. Landmarks and imaginary lines on the body specific to anthropometry for garment design are defined using anatomical features as well as small articles such as a neck chain. In the following sections, main lines and landmarks are described using several manuals and standards as references (Clauser *et al.*, 1988; JIS L0111:2006; National Institute of Bioscience and Human Technology, 1994; O'Brien and Shelton, 1941).

3.5.1 Small articles for landmarking

Landmark locations should be marked on the skin when one landmark is used for measuring several measurement items in traditional anthropometry, during the training of anthropometry, or for body scanning. An eyeliner pencil is useful for marking the skin. The mark can be easily removed by makeup remover, and it is easier to mark the skin compared with an eyebrow pencil.

A neck chain is used to define the neck base line and neck shoulder point (Fig. 3.13). A small ruler is used to define the posterior axilla point (Fig. 3.15). A waist belt is used to define the natural waistline (see Fig. 3.17).

3.5.2 Posture and measurement attire

When marking landmark locations, the marking must always be done for a subject in the correct posture for the measurement. Otherwise, the actual landmark location and the mark on the skin can be very different. For example, the tip of the spinous process of the seventh cervical vertebra can be easily palpated at the back of the base of the neck when the subject bends his/her neck forward (Fig. 3.12(b)).

Suppose that the tip of the spinous process is marked in this posture. The mark on the skin slides away from the tip of the spinous process while the subject lifts his/her head to be oriented in the Frankfurt plane.

When a landmark is covered by a garment (e.g., trochanterion), it is desirable to mark the skin directly rather than on the garment to avoid effects of relative movement between the skin and garment. When taking a measurement, use the mark on the skin. When the body is scanned, place a marker sticker on the garment immediately before scanning.

When a subject is wearing a brassiere, use the bust point (or breast point) rather than the therion (the center of the nipple). The bust point is the most anterior point of the bust for subjects wearing bras.

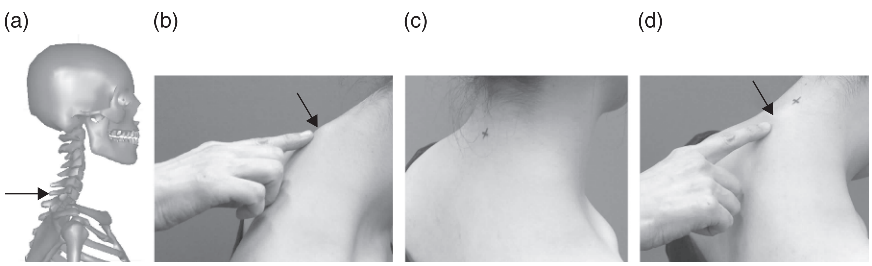
3.5.3 Size and shape of marks

Marks on the skin should be clear and visibly large enough to avoid confusing them with moles. When a marker sticker attached on a mark for 3D body scanning falls off, the paste removes the mark made with the eyeliner pencil. Putting another marker sticker at the same location is easy if the mark is a cross that is larger than the marker stickers.

3.5.4 Neck base line and related landmarks

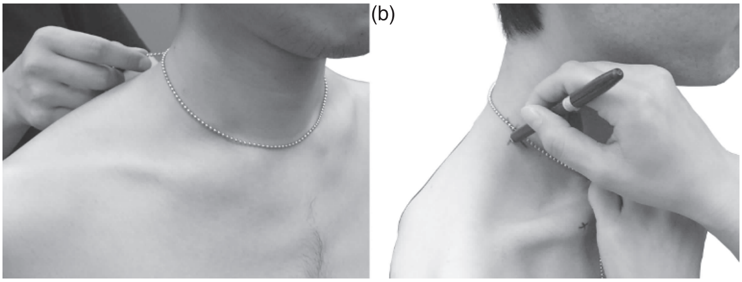
Cervicale

The cervicale is the tip of the spinous process of the seventh cervical vertebra (Fig. 3.12(a)). The tip of the spinous process of the seventh cervical vertebra is visible and easily palpated when the subject bends the head forward (Fig. 3.12(b)). The cervicale must be marked with the subject holding his/her head in the Frankfurt plane (Fig. 3.12(c)). The location of the marked cervicale while the



3.12 Cervicale. The arrow indicates the tip of the spinous process of the 7th cervical vertebra. The cross mark indicates the location of the cervicale marked on the subject in the basic standing posture. Note the difference between the location of the cross mark and the protrusion of the spinous process of the 7th cervical vertebra.

(a) (b)



3.13 Neck base line (a) and neck shoulder point (b).

head of the subject is oriented in the Frankfurt plane is considerably different from the position of the tip of the spinous process of the seventh cervical vertebra while the subject bends the head forward (Fig. 3.12(d)). In a few subjects, the spinous processes of two or three vertebrae are equally prominent. In such cases, select the one that makes the most natural neck base line.

Front neck point

The front neck point is the crossing point of the median line and a line tangent to the highest points of the medial (or sternal) extremities of the right and left claviculae.

Neck shoulder point

The neck shoulder point is the crossing point of the neck base line and the anterior border of the trapezius muscle. The neck base line is defined using a neck chain (Fig. 3.13(a)). The neck chain is placed around the neck so that it passes the cervicale and the highest points of the medial extremities of the right and left claviculae. The anterior border of the trapezius muscle can be easier to palpate by asking the subject to place his/her hand on his/her opposite shoulder. Find the anterior border of the trapezius muscle, and draw a line along the anterior border with the subject hanging both arms naturally downward (Fig. 3.13(b)). Draw a line along the neck chain to make a cross at the neck shoulder point.

3.5.5 Armscye line and related landmarks

Acromiale (acromion)

The acromiale is the most lateral point of the lateral edge of the acromial process of the scapula (Fig. 3.14(a), point a). The measurer stands at the back of the subject, and palpates the lateral borders of the right and left acromial processes with the balls of the index fingers (Fig. 3.14(b)). By moving the ball of the index finger in the medio-lateral direction, locate the edge between the superior and lateral aspects of the acromial process. Draw a line along the edge. Draw a short line perpendicular to this line at the most lateral point of the lateral edge (Fig. 3.14(c), point a). (See also section 3.4.1.)

Armscye line

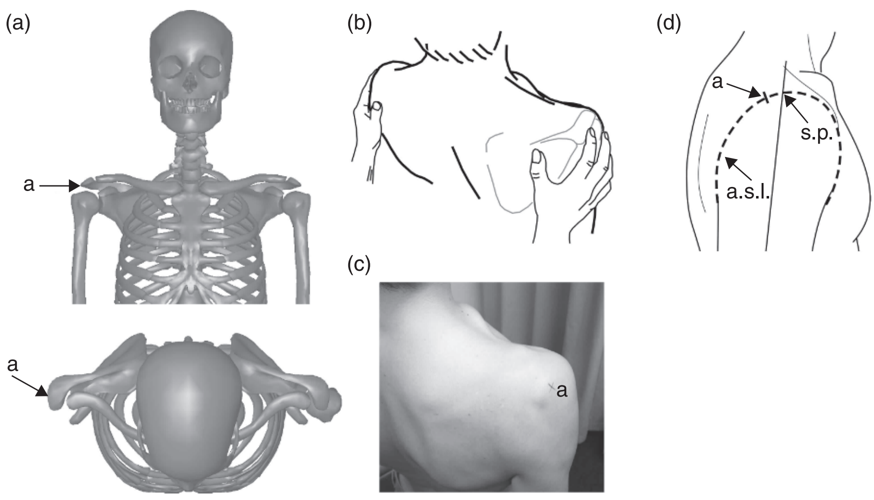
The armscye line is defined using a string. A string is placed under the arm of the subject abducting his/her arm approximately 30°. The subject hangs down his/her arms naturally. The both ends of the string are brought up and crossed over the acromiale (Fig. 3.14(d)).

Shoulder point

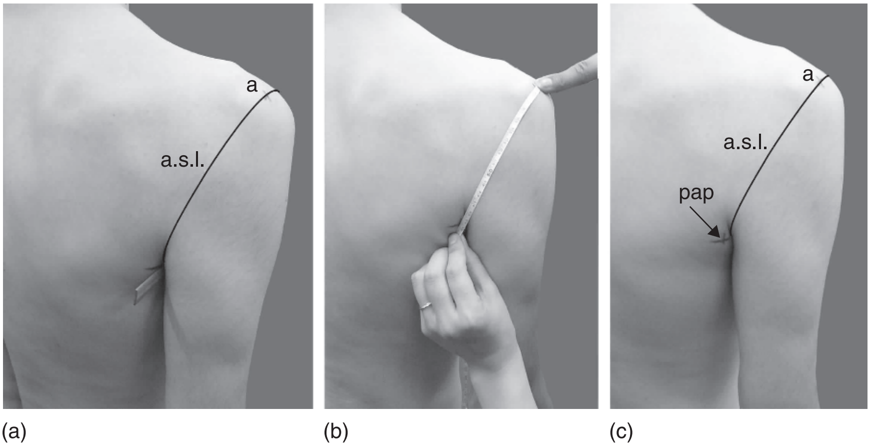
The shoulder point is the crossing point of the armscye line and a line that bisects the antero-posterior diameter of the upper part of the upper arm (Fig. 3.14(d)). Usually, the shoulder point is located anterior to the acromiale. The shoulder point is used to define the shoulder line, a line connecting the shoulder point and neck shoulder point.

Posterior axilla point

The posterior axilla point is the highest point of the axilla in the posterior aspect of the trunk. The posterior axilla point is defined using a ruler and a tape-measure. The subject abducts the arm approximately 30°. Place the edge of the ruler firmly



3.14 Armscye line and related landmarks (a: acromiale, a.s.l.: armscye line, s.p.: shoulder point). Panel (b) is from Mochimaru and Kouchi, 2005.



3.15 Posterior axilla point (a: acromiale, a.s.l.: armscye line, pap: posterior axilla point).

into the axilla in a horizontal position and ask the subject to carefully lower the arm to the side. Make sure that the ruler is level. Draw a short horizontal line on the trunk at the top of the ruler on the posterior side (Fig. 3.15(a)). Remove the ruler, and place a tape measure along the armscye line to extend the armscye line below while the arm of the subject is hanging down naturally (Fig. 3.15(b)). The posterior axilla point is the crossing point of the tape measure and the horizontal line indicating the top edge of the ruler (Fig. 3.15(c)).

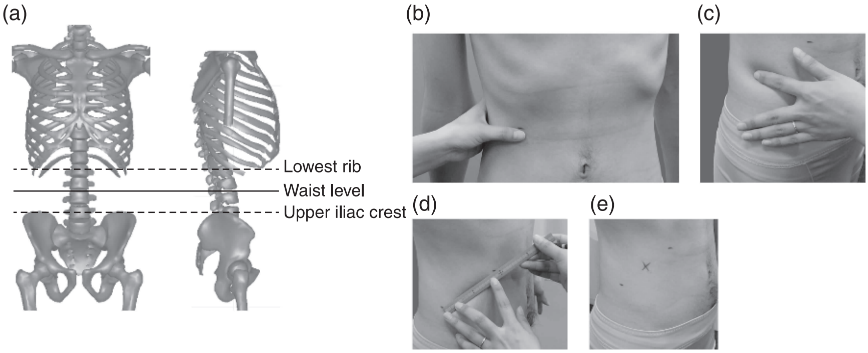
3.5.6 Waist circumference and different definitions

Waist level in ISO 7250-1

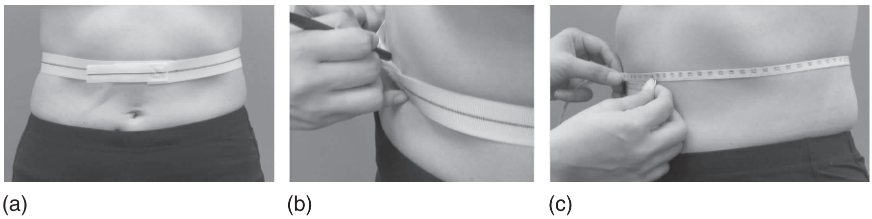
The waist circumference in ISO 7250-1 is a horizontal circumference measured midway between the lowest rib and the upper iliac crest (Fig. 3.16(a)). The lower part of the rib cage is visible when the subject inhales deeply (Fig. 3.16(b)). Palpate to find the lowest point of the rib cage (lowest point of the tenth rib). The mark should be made while the subject relaxes his/her muscles and breathes normally. Palpate to find the upper edge of the iliac crest (Fig. 3.16(c)). Locate the midpoint of the lowest point of the tenth rib and the upper edge of the iliac crest (Fig. 3.16(d)), and mark (Fig. 3.16(e)).

Natural waist circumference

The waist girth in ISO 8559 is the length of the natural waistline between the top of the iliac crest and the lower ribs. The natural waistline may not be horizontal. The natural waistline is defined using a waist belt. Ask the subject to wrap a waist



3.16 Waist level in ISO 7250-1.



3.17 Natural waist circumference.

belt around his/her waist where it settles naturally (Fig. 3.17(a)). Draw a short horizontal line at the center front, center back, right and left sides at the level of the midline of the waist belt (Fig. 3.17(b)). Remove the waist belt. The waist circumference is measured by passing the tape measure along the four marks on the natural waistline. The four marks may not be on the same horizontal plane.

3.6 Future trends

The main focus of this chapter is to introduce methods to obtain high-quality anthropometric data. When measuring the human body for designing garments that fit the shape of the body and conform to changes in shape due to body movements, anatomical landmarks are the basis for defining inter-individual correspondence or homology. In this sense, traditional methods are still the basics of anthropometry, and at present no software can replace a skilled anthropometrist. Unfortunately, there are not many educational institutes that provide training courses for anthropometry. The best and only way to learn anthropometric methods is through one-on-one training. It is especially important to teach the same methodologies at all institutes through national and international networks to harmonize the methods. Furthermore, a protocol for evaluating the skills of measurers needs to be established. For example, a method developed by Kouchi and Mochimaru (2010) can be used to evaluate the skill of landmarking.

There are two trends in 3D anthropometry. One is high-quality scanning for a national sizing survey using a high-end scanning system. The other is in-shop or in-house scanning for retail use using an inexpensive scanning system or a smart-phone. Only a few high-end scanning systems are now available. Unfortunately, two manufacturers of high-quality whole-body scanners discontinued scanner production due to the small market size. An ISO standard for quality assessment of scanners will be established, and users (institutes) can select a suitable scanner for their sizing surveys based on a standard quality assessment report. Moreover, institutes should conduct quality control for their sizing surveys.

On the other hand, inexpensive whole-body scanners are available for use in shops. Recently released, very inexpensive sensors may have accelerated the general trend for a lower price. Distributed scanners can accumulate a large amount of scan data in a short time. Individual data are used for the individual, whereas representative data based on statistics of a large amount of scan data will be used for different purposes. In the future, those representative data will be distributed from the company that collected data in retail shops. In such cases, data providers are responsible for the quality control of data, and an ISO standard on the quality assessment of scanners is required.

3.7 Sources of further information and advice

Definitions of landmarks and measurement items are described in textbooks of anthropometry. Several manuals of anthropometry are available through the Internet. Manuals for a specific survey provide practical information on procedures to decide landmark locations and to take measurements, though measurement items specific to garment design are not included in most of these textbooks and manuals.

Martin's textbook (Martin and Knußmann, 1988) is the most frequently used reference. Landmarks and measurement items for physical anthropology and ergonomics are briefly described. Sometimes it is unclear how to handle the instrument to take a measurement as described. A book by Cameron (1984) describes measurement items used for the study of child growth using photos. A textbook by Norton and Olds (1996) describes measurement items used for sports and health sciences.

A reference manual by Lohman *et al.* (1988) describes a measurement technique as well as information on literature and the reliability for several measurement items. This book also includes chapters on measurement errors and which side to measure.

A measurer handbook used in the anthropometric survey by the US Army (Clauser *et al.*, 1988) describes over 100 measurements including some for garment design. Each landmark and measurement item is described in detail in a practical way using a photo and a figure.

The following manuals of the National Health and Nutrition Examination Survey III conducted in the United States are available on the Internet. Though the number of measurement items is small and measurements for garment design are not included, the descriptions are practical and detailed, and provide a general idea of an anthropometry survey techniques:

- Westat Inc. (1988) National Health and Nutrition Examination Survey III. Body Measurements (Anthropometry). http://www.cdc.gov/nchs/data/nhanes/nhanes3/cdrom/nchs/manuals/anthro.pdf
- Catholic Relief Services (2004) National Health and Nutrition Examination Survey. Anthropometry Procedures Manual. Revised. http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/BM.pdf

A color atlas by van Sint Jan (2007) describes bones and how to palpate bones to find landmarks. Though most of these landmarks are not used in anthropometry for garment design, it provides useful anatomical information. Errors in landmarking in traditional methods are quantified in Kouchi and Mochimaru (2010).

For the quality control of 1D measurements, ISO 15535 establishes a protocol for eliminating irregular values as described in section 3.4.2. For the quality control of scan-derived 1D measurements, ISO 20685 establishes a protocol for evaluating comparability with traditional measurements as described in section 3.3.4. At present German (VDI/VDE 2634-1, -2, -3) and Japanese (JIS B 7441) standards are the only standards that establish a protocol for evaluating the accuracy of 3D scanners.

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ISO/TR 7250-2: 2010 Basic human body measurements for technological design – Part 2: Statistical summaries of body measurements from individual ISO populations.

ISO 8559: 1989 Garment construction and anthropometric surveys – Body dimensions.

ISO 20685: 2010 3-D scanning methodologies for internationally compatible anthropometric databases.

ISO/DIS 10360-8: 2012 Geometrical product specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 8: CMMs with optical distance sensors.

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VDI/VDE 2634 Part 1: 2002 Optical 3-D measuring systems Imaging systems with point-by-point probing.

VDI/VDE 2634 Part 2: 2002 Optical 3-D measuring systems Optical systems based on area scanning.

VDI/VDE 2634 part 3: 2008 Optical 3D-measuring systems – Multiple view systems based on area scanning.

4

Body shape analysis and identification of key dimensions for apparel sizing systems

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Abstract: This chapter deals with body shape analysis and identification of key body dimensions. It demonstrates, through a case study, the process of establishing the key dimensions for a sizing system and its application in clothing design. It further discusses the primary and secondary dimensions required for the development of a sizing system. Two distinct techniques – bivariate analysis and multivariate analysis – based on the principal component analysis, have been used to identify key dimensions. The last two sections of this chapter discuss the future trends and provide sources of further information and advice.

Key words: anthropometric data, key body dimensions, correlation coeficient, principal component analysis (PCA), machine learning technique.

4.1 Introduction

Anthropometric data are obtained from a comprehensive anthropometric survey to understand the body shapes and sizes in a certain population. Once the body shapes and sizes have been analyzed and understood, it is easy to develop a sizing system that enables production of correctly sized clothing for the population under consideration. An accurate sizing system becomes especially significant when garments are mass produced to cater to a large and diverse population. These garments are mainly known as ready to wear (RTW) in that the sizes are pre-set for certain body shapes and sizes.

Analysis of anthropometric data can be used to extract important information about:

1. the body sizes and shapes existing in a particular population;
2. the important key body dimensions;
3. clusters with similar key body dimensions;
4. what size designation can be used for better fitting choice.

In this chapter, the anthropometric data have been analyzed to gain information about body sizes and shapes and the selection of important key body dimensions. The rest of the topics have been dealt with in other chapters of this book.

4.2 Key dimensions and control dimensions

During an anthropometric survey, many different body dimensions are measured on each person, resulting in thousands of data points. These data are statistically analyzed to identify the significant dimensions which can be used to divide the sample population into clusters having similar body dimensions.[1] These significant body dimensions are known as *key dimensions*. Key dimensions can be different for different sample population and for different types of garments. These are also used as control dimensions to assign the size of garment best suited for an individual for good fitting.

Control dimensions can be classified into primary control dimensions, secondary control dimensions or tertiary control dimensions and so forth. Primary control dimensions are those that affect the goodness of fit in the garment and are the dimensions that are measured on a customer to match them with the right size garment. According to Winks (1997), primary body dimensions are the body dimensions that are fundamental to body size.[1] These dimensions define the body size of a person and thus are the dimensions in which the sizing system is developed.

Secondary dimensions are dimensions which are used together with the primary dimensions to define the body size of one person as a whole. For practicality, primary control dimensions need to be very familiar to the consumers; if consumers are familiar with the primary control dimensions, it will be easier for them to find their correct clothing size as the sizes are based on those key dimensions. To illustrate – for an upper body garment, if height is taken as the primary dimension, the population is first divided according to height and then further divided according to bust girth, if that is taken to be the secondary control dimension. After division, the size range of each population is obtained which consists of the range of the two body dimensions used as key dimensions, range being defined as the upper and lower limit of the said dimensions. Researchers recommend the use of two or three control dimensions depending on garment type – most common being the bust girth, waist girth, hip girth and stature.[2,3]

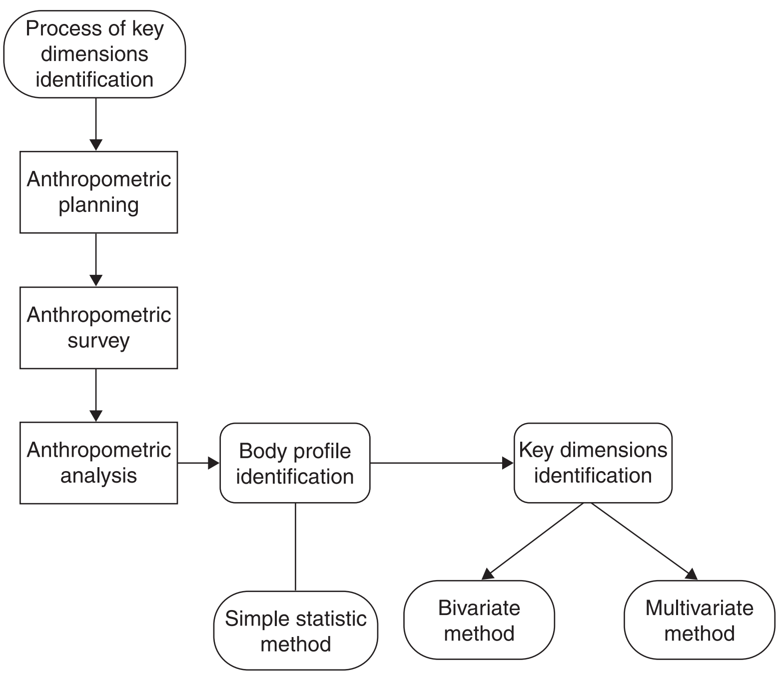
A combination of vertical and horizontal measurements must be used if the other measurements are to be predicted accurately.[4] Height seems most suitable as the predictor for vertical measurements. Weight, on the other hand, is the best predictor for girth measurements. Height and weight demonstrate the most variance within body length and thickness components, respectively. In other words, height and weight offer the best combination for accurately classifying adult female body size and shape.[5] However, researchers have consistently chosen bust girth (female) and chest girth (male) instead of weight for upper body, and hip and waist for lower body.[6] Choosing these two dimensions for upper and lower body can provide better fit for garments.[7]

4.3 Sizing systems and identification of key dimensions

The identification of key dimensions can be done using the process flow indicated in Fig. 4.1. The first step is anthropometric planning which includes the development of anthropometric measurement protocols, training of measurers, the selection of targeted sample population and lastly the calculation of targeted sample population needed for the study. One of the ways to calculate the sample size can be done by using the stratified random sampling.

The second step is to conduct the anthropometric survey. The process for conducting the survey includes measurement of population, collection and validation of the anthropometric data, entering the data in the system and examining the data. The next step is to perform the anthropometric analysis which includes the identification of key dimensions. This involves the process of understanding the body shapes and sizes existing in the sample population followed by identification of key dimensions.

Two different techniques for identifying the key dimensions are discussed in this chapter – the bivariate technique and the multivariate technique. Bivariate analysis helps to identify visual patterns of the dimensions, as it looks only at the relationships of two dimensions at a time and thus will only give correlational



4.1 The process of key dimensions identification.

relations between two variables. On the other hand, multivariate technique using PCA gives the relative importance of each of the body dimensions. Both methods will be demonstrated using the anthropometric data collected for schoolchildren in Malaysia.

4.3.1 Bivariate statistical techniques

Bivariate statistical techniques are the most common and popular method of determining the strength of relationship between two variables. The two variables are commonly associated in one of three ways, namely: unrelated, linear or nonlinear. Unrelated means these variables have no systematic relationship. The pattern of change in one is not related to the change in the other variable. Linear relationship means that two variables are related in the changes and can be explained by a straight line on a scatter plot. These changes can be observed by the direction of covariance, which may be either positive or negative. If one variable changes as the other variable changes, this means there is covariance. Positive covariance means that both variables increase together in the same direction (either both increase, or both decrease). Negative covariance means that one variable increases as the other decreases. And the third change is called nonlinear which shows relationships between variables that are not straight but related in some other way.

Statistical relationship between variables is known as correlation. A correlation between two variables is called simple correlation and can be calculated from the correlation coefficient. Determining key dimensions using the correlation coefficient measurement seems to be the most common method used by researchers to identify the key dimensions for the development of size tables.

According to Petrova,[8] the ‘first scientific study of body measurements used in the construction of women’s clothing’ was conducted in 1941 by O’Brien and Shelton, who used a bivariate distribution technique to develop their sizes based on bust and hip girth.[9] Thirty years later, other researchers applied the same technique to develop sizing systems for different target populations,[10] In her studies, Otieno[11] classified children into sizes, first according to the primary key dimension of height and then according to the secondary dimension of bust girth for upper body garments and hip girth for lower body garments.

4.3.2 Multivariate data techniques

The multivariate technique application that is discussed in this chapter is the principal component analysis (PCA) which is used to reduce the original set of variables into new significant variables called principal components (PC). In 1985, Salusso *et al.*[6] developed a sizing system known as PCSS (principal component sizing system) using the PCA technique. However, their application of PCA differed from that of O’Brien and Shelton.[9]

In previous studies, PCA was applied to the anthropometric data in order to reduce the data into significant components. Next, the components were analyzed for the selection of only one key dimension from each component. But in Salusso's research, PCA components were applied to the classification of the population.[6] Here, the relationship of variables (body dimensions) was looked upon in terms of the loading of factors of those variables on each component (i.e., correlation between a body dimension and a component). If the loading is high, it means that the variable is strongly associated with the component. In Salusso's study, the data showed that two components were most important, namely PC1 as laterality associated mainly with body girth, arcs and widths, and PC 2 as linearity associated with heights and lengths. PCCS is based on partitioning PC1 and PC2 geometrically.[6]

PC1 and PC2 behave like control dimensions in conventional sizing system construction. The height and weight distribution are used to identify the PCCS sizes. In this section, data for 13–17 years old male and female children is used to show how key dimensions can be selected using the PCA method.

4.4 Body dimensions profile

After completing the anthropometric survey, the first process is the anthropometric analysis shown in the flow chart (Fig. 4.1). The data obtained are based on the measured body dimensions shown in Table 4.1. The descriptive statistics of selected measurements – namely height, weight, chest girth, waist girth and hip girth – are shown in Table 4.2.

Table 4.1 List of body dimensions according to ISO 8559/1989

Height	Shoulder length	Lower knee girth
Under arm length	Shoulder width	Calf girth
Scye depth	Back width	Minimum leg girth
Neck shoulder point to breast point	Upper arm length	Ankle girth
Cervical to breast point	Arm length	Knee girth
Neck shoulder to waist	7th cervical height	Hip girth
Cervical to waist (front)	Hand length	Thigh girth
Cervical to waist (back)	Foot length	Mid-thigh girth
Cervical height sitting	Weight	Inside leg length/crotch
Trunk length	Head girth	Knee height
Body rise	Neck girth	Ankle height
Cervical to knee hollow	Neck base girth	Knee girth
Cervical height	Chest girth	Upper arm girth
Waist height	Bust girth	Armscye girth
Outside leg length	Waist to hips	Elbow girth
Trunk circumference	Hip height	Wrist girth
Thigh length	Waist girth	Hand girth

Table 4.2 Descriptive statistics of selected body dimensions for the whole sample size (n=2035; units, cm)

Body dimension	Mean	SD	CV (%)	Min	Max
Height (cm)	141.9	16.8	11.8	101.1	184.4
Weight (kg)	32.8	17.5	42.9	13.4	126.7
Chest girth (cm)	74.1	12.3	16.6	35.3	134.1
Waist girth (cm)	63.8	11.9	18.7	23.5	124.5
Hip girth (cm)	78.2	13.6	17.4	32.5	131.2

Table 4.2 gives a descriptive overview of the sample population. Simple statistics of these body dimensions are determined by calculating the mean, standard deviation and extremes which give the range of sizes for the key dimensions. The analysis of the anthropometric data will define the physical sizes of the sample population. Thus, the distribution of body dimensions as shown in Table 4.2 can be used to generalize the size range of body dimensions useful for garment making. For example: the tallest person measured in this sample height is 184.4 cm and the shortest is only 101.1 cm. As for weight, the heaviest is 126.7.3 kg and the smallest weight 13.4 kg only.

For the upper body, the size range for chest girth is 98.8 cm. For the lower body, waist and hip girth measurements indicate size range of 101.0 cm and 98.7 cm respectively. These extreme values seem high compared to the size range of Sri Lankan children, reported recently.[12] For Sri Lankan schoolchildren, the height range is 32.5 cm, while for chest, waist and hip girth the size ranges are 43.2 cm, 44.5 cm and 39.4 cm respectively. This indicates that the extreme values are different for different sample populations and that the body sizes cannot be compared for different countries. Extreme values are worth looking at to understand the overall range of body dimensions of one particular sample population.

4.5 Correlation coefficient

Correlation coefficient is the statistical measurement of relationship between two different variables. It ranges from +1 to −1. The measurement is r. If $r=+1$ then it is showing positive covariance, wherein if one body measurement increases then the other also increases. If $r=0$ it means that two dimensions are not changing together, meaning there is no covariance. If $r=-1$ it means that there is negative covariance, wherein if one body dimension increases then the other decreases. The correlational values adopted from BS 7231 (BSI, 1990) were assigned as follows: If $r<0.5$ then there is no relationship between the two variables. If $0.5\leq r\leq 0.75$, it indicates that there is a mild relationship and if $r\geq 0.76$, it indicates that the two variables have a strong relationship.[12]

4.5.1 Body dimensions correlation

In order to develop a good sizing system, the key dimensions should take one measurement from the set of horizontal body dimensions (e.g., girth) and one from the set of vertical body dimensions (e.g., height or length). Bivariate classification using these two key dimensions was employed to divide the population into size groups. Individuals with two similar body measurements were classified into the same size group. In another earlier study, Staples and De Lury[14] used multiple correlation coefficients to establish interrelationships between the various body dimensions and to select the key dimensions.

A Pearson product-moment correlation test was conducted to understand the relationship between various body dimensions. All variables were found to be significant at $p=0.05$ or less ($n=2035$). From the bivariate analysis (Table 4.3), height and weight, which are commonly used to describe the body size of children, were found to have strong correlations with each other ($r=0.81$). Height is also found to be correlated with all 50 other dimensions, with 38 dimensions showing a strong correlation and 12 a moderate correlation. Height is very strongly correlated with all length dimensions, mainly with the major vertical dimensions like under-arm length (= 0.93), cervical height (= 0.99), cervical to waist back (= 0.89), inside leg length ($r=0.94$) and cervical to wrist ($r=0.95$). This finding is similar to those of other studies which found a strong correlation between height and length dimensions.[1,5,15]

Height also has a strong relationship with several girth dimensions, namely chest girth ($r=0.76$), bust girth ($r=0.78$) and hip girth ($r=0.77$). This indicates that as height increases, girth dimensions of chest, bust and hip increase likewise. However, height was found to be only moderately correlated with waist girth ($r=0.58$) which shows that waist increment is only moderately associated with height increment. Increases in both length and girth body dimensions are to be expected as children between 7 and 17 years go through rapid physical development before reaching adulthood.[16] Height is often the primary measure used to assess linear growth in children.[17] Body proportion and composition are also essential elements of growth in children and indicate maturation towards adulthood.[18]

These results confirm that height and the three major girth dimensions (chest, bust and hip girth) are reliable key dimensions for children aged 7 to 17 years. Height, chest and bust girth are often used for upper body classification. In contrast, height, waist and hip girth are used for lower body classification.[19–21] In this study, waist girth was not found to be highly correlated with height as compared to hip girth, suggesting that waist girth may be less suitable for classification of lower body than hip girth.

For practical reasons, not all dimensions are used for sizing development. Instead, only the key dimensions are used. As mentioned in Robinette,[22] key dimensions should be those which have the strongest correlations with most other body dimensions. The stronger the correlation, the better suited that dimension is for use as a key dimension in classifying the sample population. In this study, weight was found to be moderately correlated with age (r=0.76). However, it was very strongly correlated with other girth dimensions, namely chest girth (r=0.95) and hip girth (r=0.95). It is also strongly correlated with waist girth. As for the length dimensions, weight is strongly correlated with height (r=0.86), cervical height (r=0.83) and cervical to wrist length (r=0.84). From Table 4.3, it can be seen that weight is correlated with several other dimensions as well.

Table 4.3 shows that most body dimensions like chest, waist and hip are strongly correlated with each other, with r values ranging between 0.90 and 0.98. This result shows the same trend as other studies, that girth dimensions are strongly correlated with each other and with weight.[5,23,24] This implies that girth dimensions, which are more meaningful for apparel manufacturing for children aged 7 to 17, can adequately represent weight. The sample population data used in this chapter confirms that height can serve as the representative for length dimensions since it is correlated with all body dimensions. The girth dimensions that can best represent weight are bust, chest, waist and hip girth since they are strongly correlated to weight and all other girth variables.

As mentioned in the earlier analysis, height is strongly correlated with age (r=0.86) which means that as age increases height also increases. According to Gupta *et al.*,[24] a proportional relationship among body measurements is significant in a sizing system as these dimensions can be selected as key dimensions. However, although height and age are strongly correlated, as shown in Fig. 4.2, it is obvious in every age group that height ranges from 101 cm to 130 cm for children 7 years old, meaning that in age 7 alone the variation in height is 29 cm. The same spread is seen in all age groups. Not only do children of the same age have widely different heights, the same height measurement can be found in widely different ages. Thus, age is not a suitable factor for size system development. The same findings have been reported in other sizing studies.[7,11,25]

The height range is wider between ages 7 to 12 as compared to ages 13 to 17. This finding is consistent with those of A'Hearn *et al.*[26] who found that differences in height by age are greatest between the ages of 9 and 13. Other studies show that height is affected by age, nutrition, lifestyle and health.[27] It can therefore, be assumed that more sizes will be needed for children aged 7 to 12 as compared to those aged 13 to 17 due to the larger size range in the younger group. Another possible reason for a lower size range for age 13 to 17 is their slow height growth as compared to age 7 to 12.

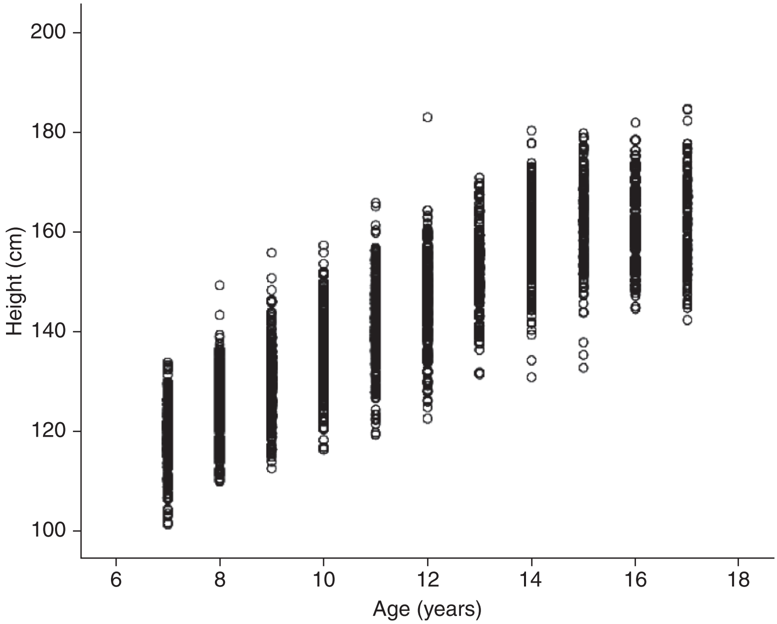
4.5.2 Summary for bivariate analysis

The case study has shown that the strength of relationship among body dimensions is different for different populations, even when the same body dimensions are taken from subjects in different populations. Significant differences between anthropometric data by age are also revealed. The findings also suggest that four dimensions – namely height, chest or bust, waist and hip girth – can be selected as

Table 4.3 Correlation results of body dimensions for sample population (*n*=2035)

	Variables	1	2	3	4	5	6	7	8	9	10	11
1	Age	1										
2	Height	0.86	1									
3	Weight	0.67	0.81	1								
4	Chest girth	0.63	0.76	0.95	1							
5	Waist girth	0.43	0.58	0.89	0.90	1						
6	Hip girth	0.66	0.77	0.95	0.94	0.89	1					
7	Under arm length	0.80	0.93	0.71	0.67	0.50	0.68	1				
8	Cervical height	0.85	0.99	0.83	0.79	0.62	0.80	0.93	1			
9	Cervical to waist back	0.80	0.89	0.78	0.72	0.57	0.73	0.81	0.90	1		
10	Inside leg length	0.81	0.94	0.69	0.65	0.47	0.66	0.92	0.94	0.79	1	
11	Cervical to wrist	0.83	0.95	0.84	0.80	0.64	0.81	0.91	0.96	0.85	0.90	1

Correlation: < 0.5=mild; 0.5–0.7.5=moderate; 0.75–0.90=strong; > 0.9=very strong.



4.2 Scatter plot of height vs. age according to gender.

the key dimensions. These dimensions are strongly correlated and thus can be regarded as significant variables by which to classify the sample population into homogeneous groups for the development of a sizing system.[28]

4.6 Multivariate data examination

In the previous section, key dimensions were selected using bivariate data techniques, specifically using the correlation coefficient. The multivariate method, based on the PCA technique, identifies the variables which show the strongest relationship with each other.

Two analyses were conducted prior to PCA, namely validity and percentile analysis. All 50 body dimensions taken from the sample (children aged 13–17) were tested for validity and reliability. Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) were performed to ensure the adequacy of sampling for PCA analysis. In addition, Cronbach's alpha was used to determine the consistency and unidimensionality of the data.

The KMO results show that all values are greater than 0.9. Bartlett's test of sphericity was highly significant since the observed significance level was 0.0000 ($p<0.005$). For factor analysis, KMO is supposed to be greater than 0.5 and Bartlett's test less than 0.05. As shown in Table 4.4, KMO values were 0.973 for males and 0.965 for females. According to Raykov,[29] KMO greater than 0.9 falls

Table 4.4 Sampling adequacy and reliability tests for male and female (age 13–17 years old)

Tests		Male	Female
Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy		0.970	0.970
Bartlett's test of sphericity			
	Approx. Chi square	34579.55	31437.00
	df	1275	1378
	Sig. ($p<0.005$)	0.000	0.000

into the range of superb or marvelous. Thus, it can be concluded that the relationship between the variables is very strong and factor analysis can be carried out. In addition, it can be seen that the data shows sampling adequacy, which means it is likely to factor well for PCA analysis.

4.6.1 Principal component analysis (PCA)

Principal component analysis (PCA) is the most common form of factor analysis, and is categorized as a multivariate statistical technique. It is used to analyze interrelationships among a large number of variables. The objective of using PCA was to reduce the number of variables and to cluster them into more parsimonious and manageable groups. These groups are known as the components (factors). Each component contains interrelated variables. Thus, from these components, the key dimensions can be selected. Subsequently, these key dimensions can be used to cluster the sample population into homogeneous subgroups.[30] The process flow of each step of PCA is described below, and shown graphically in Fig. 4.3.

The body dimensions of each sample group were extracted using PCA and Varimax rotation. This technique is commonly applied to anthropometric data to describe variations in the human body in a parsimonious manner, as seen in many previous sizing studies.[31,32] Parsimonious means the variations of body dimensions are described using the fewest principal components (PCs) possible.[33,34]

4.6.2 The results of PCA

The results of the extracted components for each sample group were recorded. In general, 50 components were extracted from each sample group in order to explain 100% of the variance in the data. The summarization of variables proves to be very good, as the number of principal components is the same as the number of original variables. This indicates that the original information is not omitted as a variation factor.[35]

According to Pedhauzer and Schmelkin,[36] the first few components should explain at least 50% of the variance in order to prove the usefulness of PCA. The present study shows that of males and females who are between 13 and 17 years old, 72.7% and 54% percent variance was observed respectively. This indicates that PCA is an effective method to obtain a parsimonious solution in describing the variations of body shapes in children.

Furthermore, according to Hair *et al.*,[37] the extracted factor should explain at least 90% of the variance in order to show efficiency. In this sample, 90% variance was explained by 11 and 14 components respectively for male and female samples. By contrast, in a study conducted by Salusso *et al.*[38] only 60% of total variance was explained by 15 components, which is a very low value. However, in 2006, the same researcher improved her studies by obtaining a 60% total variance accounted for by two components.[39]

In order to reduce the number of components for a more parsimonious solution, the criterion of retaining components is applied, which is latent root, scree plot and percentage of accumulated variance. Tables 4.5 and 4.6 show all the components that have been extracted with an Eigen value greater than one (in bold), which implies that these components are suitable to be retained.

The results of male sample population can be seen in Table 4.5. The first five components (Components 1–5) are retained as having an Eigen value greater

Table 4.5 Principal component analysis extraction for males (13–17 years)

Component	Initial Eigen values			Rotation sums of squared loadings	
	Total %	% of variance	Cumulative %	% of variance	Cumulative %
1	**30.7**	61.4	61.4	40.9	40.9
2	**6.9**	13.6	75.0	24.3	65.3
3	**1.7**	3.5	78.5	11.4	76.7
4	**1.2**	2.4	80.9	3.8	80.5
5	**1.1**	2.1	83.0	2.6	83.0

Table 4.6 Principal component analysis extraction for females (13–17 years)

Component	Initial Eigen values			Rotation sums of squared loadings	
	Total %	% of variance	Cumulative %	% of variance	Cumulative %
1	**27.0**	54.0	54.0	39.3	39.3
2	**7.5**	15.0	69.0	20.8	60.0
3	**2.0**	4.1	73.1	7.5	67.6
4	**1.9**	3.7	76.9	6.6	74.1
5	**1.1**	2.3	79.1	3.6	77.8
6	**1.0**	2.0	81.1	3.4	81.1

than 1. The first component has an Eigen value of 30.7% followed by others having a value of 6.9%, 1.7%, 1.2% and 1.1% respectively. The five rotation sums of squared loading show a cumulative percentage of 83.0%.

Results for the female population are shown in Table 4.6. Six components (Components 1, 2, 3, 4, 5 and 6) show an Eigen value greater than 1. The first component has an Eigen value of 27.0% followed by 7.5%, 2.0%, 1.9%, 1.1% and 1.0%. The total rotation sum of squared loadings accounts for 81.1%. For criteria 2, the scree plot, the process of analysis is shown in Fig. 4.3 and the results are shown in Figs 4.4 and 4.5. An elbow where the curve merges into a straight line can be seen at components 2 and 3 (marked by circles).

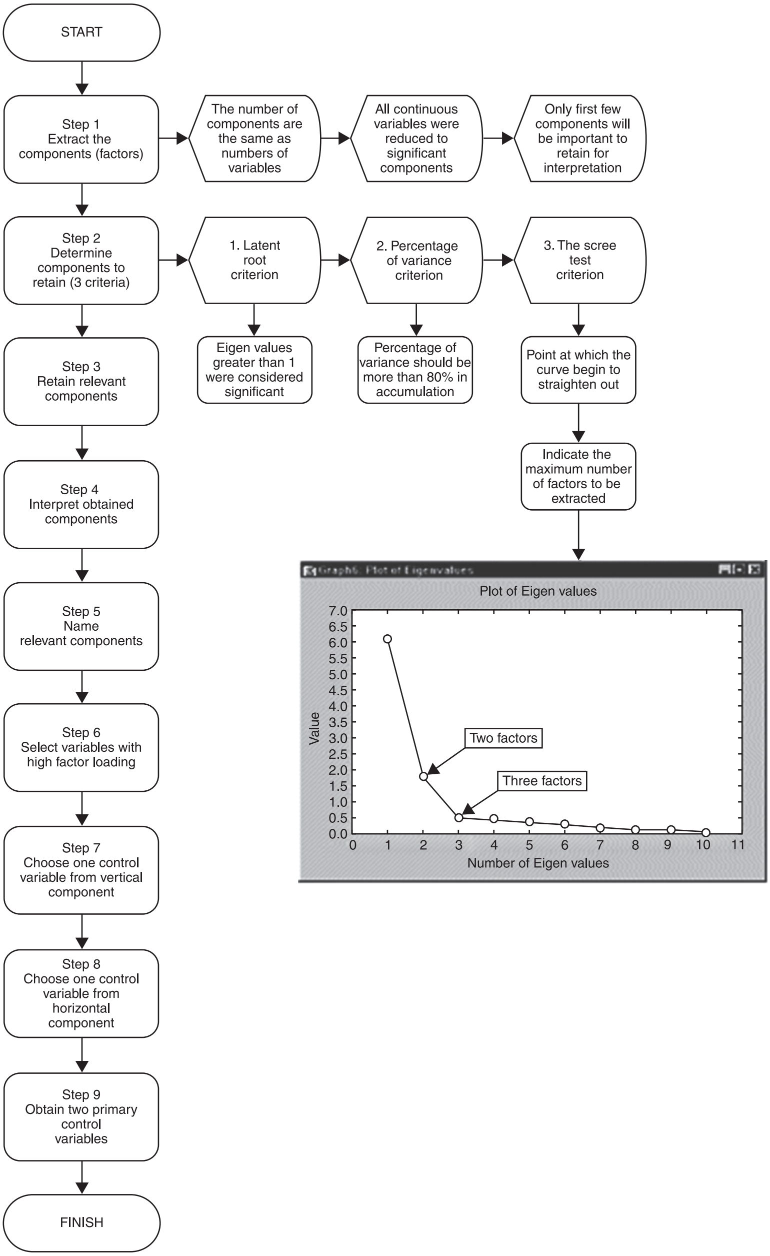
The third criterion for retaining values depends on the percentage of accumulated variance. Based on an examination of the Eigen value and scree plot results, three components were retained for all sample groups with rotation sums of 76.7% for males (13–17 years) and 76.7% for females (13–17 years). It can be observed that the cumulative percentage is reduced when fewer components are retained. However, at this point the number of components is not yet finalized; this does not happen until all the factor loadings of each component have been examined so as to clearly distinguish those variables that correlate most strongly with each component.

In general, previous studies have shown that body dimensions can be collapsed into their own component which can be interpreted as one type of measurement, such as length, girth, or width. Tables 4.7 and 4.8 give the extracted variable components and show the factor loadings for all 50 anthropometric dimensions.

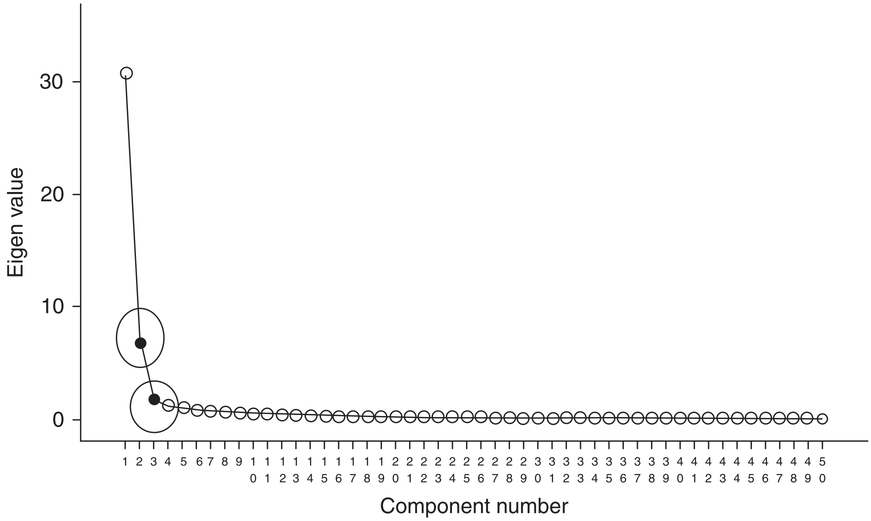
After analysis of factor loading, this study's findings yielded two significant components (i.e., variables with the highest factor loading). Thus, two components were retained and are referred to as principal component 1 (PC1) and principal component 2 (PC2) for each sample group. For the sample group of males and females (13–17 years), 44 variables and 42 variables respectively were grouped into two components. PCA successfully achieved the goal of identifying a parsimonious group of variables, which explained almost all of the variables in the two components.

The two retained components explained cumulative percentages as follows: males 65.3% and females 60.0%, as can be seen in Tables 4.7 and 4.8 at rotated sums of squared loading. The present findings are consistent with other studies, which commonly retained two final components. However, the cumulative percentage for these two components was found to be different in different studies, ranging from 65% to 81%.[39]

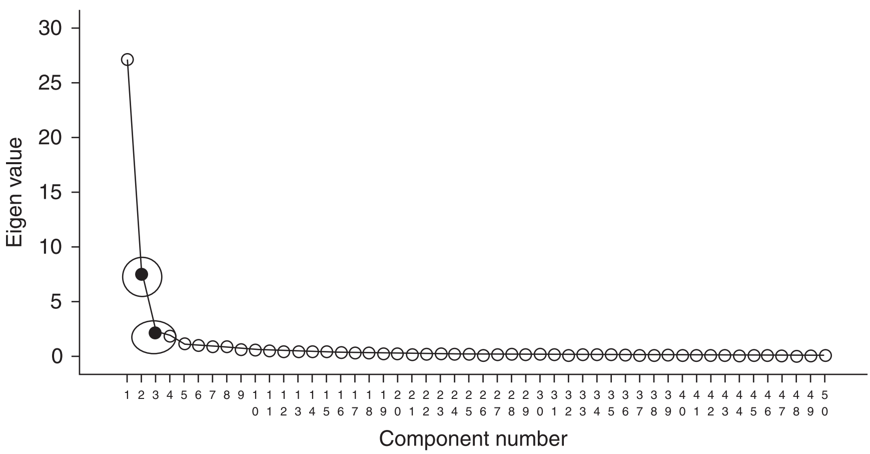
Consequently, the present study found that the first component (PC1) consists almost entirely of girth dimensions – bust, chest, upper arm, hip and waist with few width dimensions, like back width or shoulder width. The second component (PC2) consists entirely of length dimensions such as height, cervical height, upper arm length and arm length. This finding is similar to that of many previous sizing studies which found that two components represent girth and length factors.[40,41]



4.3 Flowchart for PCA process.



4.4 Scree plot for males (age 13–17 years).



4.5 Scree plot for females (13–17 years).

4.6.3 The results of factor loading analysis

All body dimensions with high factor loading (≥0.75) are listed in Tables 4.7 and 4.8 for each sample group. The aim of this section is to select the key dimensions. It is apparent from the tables that most of the variables are strongly correlated with the individual components. Overall, almost all variables can be reduced to two factors.

Table 4.7 Principal component analysis with Varimax rotation for males (13–17 years old)

	Variables	PC1 (girth)	PC2 (length)
	Height		0.77
Body types	Weight	0.91	
Upper body (girth)			
	1. Upper arm girth	0.94	
	2. Neck girth	0.85	
	3. Elbow girth	0.87	
	4. Wrist girth	0.88	
	5. Chest girth	0.88	
	6. Armscye girth	0.87	
	7. Wrist girth	0.87	
	8. Neck shoulder to breast point	0.80	
Lower body (girth)			
	9. Waist girth	0.92	
	10. Thigh girth	0.93	
	11. Lower knee girth	0.94	
	12. Mid thigh girth	0.93	
	13. Hip girth	0.91	
	14. Knee girth	0.91	
	15. Calf girth	0.92	
	16. Min leg girth	0.80	
	17. Ankle girth	0.76	
	18. Crotch	0.80	
Upper body (length)			
	19. Arm length		0.78
	20. Under arm length		0.82
	21. Upper arm length		0.81
Lower body (length)			
	22. Inside leg length		0.96
	23. Hip height		0.90
	24. Knee height		0.85
	25. Outer leg length		0.82
	26. Waist height		0.81
	27. Crotch		0.80
	28. Thigh length		0.80
	Total proportion of the explained variance (%)	40.9	65.3

Table 4.8 Principal component analysis with Varimax rotation for females (13–17 years old)

	Variables	PC1 (girth)	PC2 (length)
	Height		0.77
Body types	Weight	0.93	
Upper body (girth)			
	1. Neck girth	0.81	
	2. Back width	0.81	
	3. Bust girth	0.93	
	4. Upper arm girth	0.93	
	5. Armscye girth	0.90	
	6. Elbow girth	0.85	
	7. Wrist girth	0.83	
Lower body (girth)			
	8. Waist girth	0.94	
	9. Hip girth	0.93	
	10. Thigh girth	0.92	
	11. Mid thigh girth	0.91	
	12. Lower knee girth	0.91	
	13. Calf girth	0.88	
	14. Knee girth	0.84	
	15. Crotch	0.78	
Upper body (length)			
	16. Arm length		0.84
	17. Under arm length		0.82
	18. Cervical to breast point		0.8
	19. Neck shoulder to breast point		0.76
	20. Trunk circumference		0.77
Lower body (length)			
	21. Hip height		0.91
	22. Waist height		0.87
	23. Knee height		0.84
	24. Inside leg length		0.84
	25. Outer leg length		0.83
	26. Thigh length		0.82
	Total proportion (%)	39.3	60.0

As can be seen from Table 4.7, upper arm girth and waist girth are distinguished as the strongest variables correlated to girth factor for males. In contrast, as can be seen from Table 4.8, bust girth has the highest factor loading for females age 13 to 17 years. Under arm length and inside leg length are noted to have the highest factor loading, being strongly correlated to length in males as compared to arm length and hip height in females. PCA analysis for each sample group is discussed below.

Tables 4.7 and 4.8 show significant variables for males and females. It can be seen that 44 and 42 variables respectively out of 50 are loaded on two components. For females, 26 variables were found correlated to the girth and length component as compared to 28 variables in male samples. On the other hand, 10 and 11 variables are loaded on length girths for males and females respectively.

4.6.4 Identifying key dimensions

From the tables above, PCA confirms that those variables shown in Tables 4.7 and 4.8 prove to be the significant dimensions. The key dimensions commonly acknowledged in other literature were also found to be significant in this study, namely waist girth, bust girth, chest girth and height. For example, bust girth has the highest factor loading for females. However, in this study upper arm girth was noted as the variable with the strongest correlation to girth for males; this result has not previously been described in any sizing study. Moreover, under arm length and inside leg length are noted as having the highest factor loading correlated to length in males, and as compared to arm length and hip height in females. Under arm length is another variable found to have a strong relationship with length; this too is not common to other sizing studies.

Overall, the girth variables chosen as the key dimensions for the upper body were chest and bust girth. In contrast, hip girth was chosen as the lower body key dimension. The selection of these body dimensions as the key dimensions confirms the correlation analysis findings which identified the same common girth dimensions as the key dimensions for the upper body, while for the lower body hip girth was chosen instead of waist girth. Hip was a better choice than waist girth. Gordon[42] found that hip girth was a better selection for the lower body simply because this dimension cannot be easily adjusted after a piece of clothing has been made. Hip girth was also considered a better choice for younger children as they are rapidly growing and so alterations or adjustments are common during this period.[43] Previous studies noted that hip girth was a more stable measurement and was found to have a strong correlation with girth components, and therefore selected it as the key dimension for lower body.[7,9]

In general, as shown in Tables 4.7 and 4.8, height was selected as the key dimension for both upper and lower body based on its high factor loading. The present study found for males and females, height represents 77% which is almost 80% (0.77) of the length component. This is consistent with the results from correlation analysis which showed that height is very strongly correlated with other length variables. From the opinion of other researchers, height is a must to be incorporated in a sizing system.[19,43] In addition, according to James and Stone,[44] use of height was found to have an advantage, especially for children, as it could be easily measured in retail shops using a height chart. Height is also regarded as a better estimator of size rather than age.[7] Hence, height is the most suitable dimension by which to cluster the samples.

All the key dimensions mentioned above were finally selected for the classification of sample population. These key dimensions were selected based on their strong relationship with the main body measurements of girth and length. Furthermore, as has been mentioned in previous studies, key dimensions must be convenient to take, meaning that the selected key dimensions should be those that can be measured easily and practically when it comes to children.[1,4] In addition, it has been pointed out that if these measurements will be used as the size coding (e.g., appearing on clothing labels or tags), customers should also be very familiar with the key dimensions.[44] For example, customers are more familiar with measurements like chest girth or bust girth than upper arm girth.

Upper arm girth has been shown to have higher factor loading than chest or bust girth but it is also unstable due to its small variation.[1] Key dimensions must also be easily recognized by and familiar to customers[4,5,45] and should be an integral part of the garment label so that it is easily recognized by consumers when they choose their sizes.[7] Moreover, key dimensions like bust, chest, hip and waist girths are common key dimensions often used by apparel experts and proven to be useful and important in developing new size tables.[4,5,7,11]

As suggested by O'Brien and Shelton,[8] height should be combined with other measurements. Therefore, as shown in Table 4.7, height and chest girth were identified as the key dimensions to segment males and in Table 4.8, height and bust girth were acknowledged as the key dimensions on which to segment females. By contrast, height and hip girth were chosen as the key dimensions for the lower body measurement table for both genders and age groups. These control variables are frequently used by experts in clothing size charts.

4.6.5 Summary of multivariate technique

Results of the current study are significant in at least three major respects. First, the PCA method was shown to be used successfully as a parsimonious summarization tool. Almost all variables were extracted and clustered into two components labeled as girth and length components. Fifty-six percent of the variables were found to be strongly correlated (factor loading ≥ 0.75) to the principal component. Hence, it is reasonable to say that the majority of body dimensions are strongly related to either girth or length dimensions.

Second, the results of PCA analysis gave an insight about which body dimensions should be observed for one particular sample population. For example,

Table 4.9 Body dimensions for both genders and age groups

Upper body variables		Lower body variables	
Girth	Length	Girth	Length
Upper arm girth Armscye girth	Upper arm length Under arm length	Waist girth Mid thigh girth Thigh girth Calf girth Hip girth Lower knee girth	Inside leg length Hip height Outer leg length Thigh length

in the study of children, body measurements which significantly describe the upper and lower body for both genders (male and female) and both age groups (7 to 12 and 13 to 17 years old) could be identified. These body dimensions were the ones with the highest factor.

Referring to Table 4.9, the upper body measurements that have the highest factor loadings are upper arm girth, armscye girth, under arm length and upper arm length. Thus, this study suggests that special attention should be given to these dimensions as they are the most critical body parts to be considered when manufacturing upper body garments for children. On the other hand, another set of body dimensions best describes the lower body of both males and females (7 to 17 years old), namely: waist girth, mid-thigh girth, thigh girth, calf girth, hip girth, lower knee girth, inside leg length, hip height, outer leg length and thigh length.

The third finding of the study relates to the selection of key dimensions from PCA analysis (Table 4.10). At this stage, the highest factor loading variables do not necessarily mean that those are the selected key dimensions. This is because sometimes the highest factor loading variables are not suitable for the key dimensions based on these features: they must be easy to measure and the body dimensions are familiar for everybody. Based on these features, the suitable key dimensions for upper and lower body garments were selected.

The key factor of the selection is that the factor loading must be high which is above 0.8 as shown in Table 4.7 and 4.8. Only two variables with high factor loading from upper and lower body for every different sample population were

Table 4.10 Key dimensions for sample classification

Sample population	Key dimensions upper	Factor loading	Key dimensions lower	Factor loading
Male: 13–17 yr	Height/chest girth	0.79/0.88	Height/hip girth	0.79/0.91
Female: 13–17 yr	Height/bust girth	0.78/0.94	Height/hip girth	0.78/0.92

selected for key dimensions. The technique has successfully shown that statistically only two dimensions need be measured to get a good sizing system and with only two dimensions, the overall fit of the garment can be achieved.

4.7 Future trends

This chapter describes two common methods of analyzing relationships between anthropometric data. These methods demonstrate the importance of knowing the distribution of various body dimensions which is helpful when designing clothing. The variations in body dimensions are analyzed to identify correlations between them. The pattern of anthropometric data can be studied to derive an understanding of the body sizes and shapes of one population.

The importance of selecting key dimensions in the development of a sizing system lies in the fact that understanding the relationships and patterns of body dimensions for a specific population allows a few dimensions – those that have the highest correlation with the rest of the body dimensions – to be selected for subject clustering and size classification. This is the objective of the first phase of analysis of anthropometric data: to determine the primary key dimensions for the development of the sizing system.

Based on many other anthropometric studies, it has been found that different sample populations result in different key dimension correlation values. It has also been discovered that, although the values are different, key dimensions were found to be common. Some of the common primary key dimensions for upper body are chest and bust girth, and for lower body are waist and hip girth.

Both the techniques used to select key dimensions are based on linear relationships. It is important to note that not all anthropometric body dimensions necessarily have linear relationships. For example, waist measurements do not necessarily increase in line with weight, although it has been observed in some populations that when waist measurement increases, the weight also increases. This varies for different age groups and perhaps for different ethnic groups.

With this preliminary understanding, the study has provided insights into more challenges and new techniques in the future by which to analyze anthropometric data for the selection of key dimensions. Future research on selection of key dimensions should be undertaken to ensure better fitting clothing for a successful clothing business which include the following:

- Clothing manufacturers and retailers should concentrate on understanding their own consumers' different body shapes and sizes in order to achieve better consumer relationship management.
- The critical need is to identify the key dimensions for upper body, lower body and whole body, as these key dimensions will become the predictable pattern of body shapes and sizes of a specific population.

- The selection of key dimensions should be correlated to the key dimensions for pattern construction, as this will result in better fitting garment construction
- The application of advanced techniques for better understanding of body dimension relationships and patterns using machine learning techniques such as artificial intelligence and neural networks. Machine learning techniques have been used in many different studies and have been applied successfully to a wide variety of data for prediction tasks.[46] They can be used effectively to discover relationships between different variables and thus make predictions to support meaningful decisions. Machine learning techniques are able to analyze non-linear relationships of body dimensions which could exist in the data analysis for a specific population.
- The advantage of key dimensions selection using the machine learning techniques lies in the fact that they require no *a priori* knowledge about the data since they are non-linear statistical data modeling tools as compared to the traditional linear approach.

In conclusion, the two techniques discussed in this chapter have demonstrated how to analyze the variations of body dimensions in a selected sample population. They have commonly been used to reveal linear relationships among body dimensions. This finding, however, is a good starting point for further research which should utilize advanced machine learning techniques to determine the cause and effect relationships that might exist between relevant variables.

4.8 Sources of further information and advice

Some material on advanced methods of discovering non linear relationships of data can be found in these websites:

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- http://idosi.org/wasj/wasj9(12)10/5.pdf. The article that is relevant is as follow: A. H. Doustaneh, M. Gorji and M. Varsei. (2010). Using self organization method to establish nonlinear sizing system. *World Applied Sciences Journal*, 9 (12): 1359–1364, ISSN 1818-4952.
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- http://www.ismeip.org/IJIMIP/contents/imip1121/5.pdf. The article is as follows: Thitipong Tanpraser and Chularat Tanpraser (2011). Creatinine prediction from body composition. A neural network approach. *International Journal of Innovative Management, Information & Production*, 2 (1): 41–48.

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Part II

Analysing anthropometric data to develop sizing systems

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5
Segmentation and classification of anthropometric data for the apparel industry

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Abstract: Acquisition systems based on laser triangulation or structured light are becoming commonplace in anthropometry. Such systems allow one to capture very detailed data to be used when addressing the sizing problem. This chapter introduces state-of-the-art approaches to describe, to segment and to cluster the data acquired by such systems. We describe methods used to address the deformable nature of human bodies. We introduce isometry-invariant descriptor creation algorithms that are suitable for indexing regions that contain soft tissues. Further, we describe how to cluster a specific population, found in a so-called human body space, into partitions of similar individuals.

Key words: anthropometry, clustering, diffusion distance, geodesic distance, heat kernel, invariance, Isomap, Laplacian, multidimensional scaling (MDS), segmentation, spherical harmonics, Zernike.

5.1 Introduction

The development of methods that facilitate the segmentation and classification of anthropometric data is paramount for the apparel industry (Peña *et al.*, 2012). Despite recent attempts to customize the production of garments, the vast majority are still produced according to a mass production scheme. In practice, this implies that only a limited number of sizes are designed and manufactured (Paquet *et al.*, 2011). Such a reduced number of sizes greatly simplifies the production pipeline, while considerably decreasing the associated costs. Therefore, the problem of sizing is crucial and central to mass production. Indeed, a production that is based on an inaccurate sizing which does not fit the population, consequently will not sell according to expectations. The problem is even more striking for protective equipment (Kwon *et al.*, 2009), in which case a sizing error might translate into serious injury or even death. It follows that any effort made in order to optimize the design and production processes will not be satisfactory unless a valid, and representative, sizing is defined. The sizing is related to the segmentation (or clustering) of the population according to some criteria. These criteria may be based on anthropometric measurements, three-dimensional shapes and even demographic data (Peña *et al.*, 2012). (Demographic data are related to market segmentation and shall not be considered here.)

Several approaches based on anthropometric measurements have been introduced in order to segment the population; many of which have been presented or reviewed in Peña *et al.*, 2012. Here, we analyse the problem from a different perspective. Human body shape acquisition systems are becoming commonplace. Generally speaking, they are either based on laser triangulation or structured light. They allow one to capture the shape of a human body or a body part (feet, heads, etc.). For the vast majority of these techniques, the shape is represented by a set of points for which the three-dimensional coordinates have been acquired although parametric representations are possible (Allen *et al.*, 2003). In this chapter, we propose to segment and cluster the population from three-dimensional shapes. We do not neglect measurements but we define them directly on the acquired three-dimensional shapes. Because the pose of a human body is always ambiguous, we introduce descriptions which are pose invariant. Furthermore, we propose a method to take the non-rigid nature of the human body into account, by introducing representations which are invariant (or at least oblivious) for a wide range of deformations.

The remainder of this chapter is organized as follows. In the first section, we present extrinsic approaches for the representation of the human body shape in which the shape is projected on a common functional basis from which an invariant represented is created. Such a representation may be used further for clustering and sizing. In the following section, we describe human body shape from an intrinsic perspective. That allows us to obtain representations that are invariant (or at least oblivious) to a larger class of transformations. First, we present approaches based on the geodesic and diffusion distances. Both distances are defined directly on the body surface without the need for an external reference frame. The diffusion distance is particularly novel in the sense that it involves all possible measurements in between two points. We further introduce the Laplace-Beltrami operator which allows the representation of both the geometry and the topology of the human body. When this operator is used in conjunction with the heat equation, it is possible to obtain a multiresolution representation which is isometrically invariant. Then, from these representations, so-called *human body spaces*, which correspond to populations we are aiming to typify, may be defined. The *human body spaces* (Allen *et al.*, 2003) associated with these representations may present geometries which are not compatible with the assumptions underlying most clustering algorithms; in particular that the geometry should be Euclidean. If it is not the case, the results provided by the clustering algorithms, and consequently the sizings, may be invalid. In the last section, we explain how to assert the Euclidean assumption and, in cases in which it is not fulfilled, we present an approach in order to determine the best Euclidean approximation for a given *human body space* (or population) in order to perform clustering, and consequently segmentation, efficiently. Finally, we present our conclusions.

5.2 Description and classification of human body shapes using extrinsic approaches

Human body shapes present a wide variability. For that reason, it is difficult to analyse and to compare them directly. In order to overcome that problem, one may project the shapes on a common functional (or shape) basis. In this section, we project the human body shapes on a common functional basis from which we define an invariant representation. This representation (or descriptor) may subsequently be used for clustering and segmentation. Three types of basis are presented: namely the spherical harmonics, a basis derived from the Schrödinger equation, and the Zernike basis.

We do not work directly with the shape. Instead, we project the shape on a basis and we perform the analysis in the vectorial space spanned by the common basis. The projection of a three-dimensional human body shape X on a basis $\{\beta_\xi\}$ is obtained by projecting, on each element of the basis β_ξ, the shape with an inner product.

$$\Xi_\xi = \langle X, \beta_\xi \rangle \qquad [5.1]$$

The problem is to find an expressive basis which is suitable for the human body and which is invariant or at least oblivious under certain classes of transformations, e.g. rigid transformations and isometries.

5.2.1 Body part of the form $X(\vartheta,\varphi)$: the spherical harmonics basis

One of the most common bases employed in order to represent three-dimensional shapes is the spherical harmonics basis. It is a solution of the angular part of the Schrödinger equation $\frac{\partial}{\partial t}\Psi(x,t) = i(\Delta - V(x))\,\Psi(x,t)$ and it is defined as

$$Y_l^m(\vartheta,\varphi) = \sqrt{\frac{2l+1}{4\pi}\frac{(l-m)!}{(l+m)!}}\,P_l^m(\cos\vartheta)\,e^{im\varphi} \qquad [5.2]$$

where $\{P_l^m(\cos\vartheta)\}$ are the Legendre polynomials, $l \in Z^+$ and $m \in [-l, +l]$. The spherical harmonics (Godil, 2007)) are mutually orthogonal which means that:

$$\tfrac{3}{4\pi}\int_0^1\int_0^{2\pi} Y_l^m(\vartheta,\varphi)\bar{Y}_l^m(\vartheta,\varphi)r^2 \sin\vartheta\; d\vartheta d\varphi = \delta_{nn'}\delta_{ll'} \qquad [5.3]$$

If it is possible to put the shape of a body under the form $X(\vartheta, \varphi)$, that is, if there is one and only one point associated with each radial direction e_r, the body may be described in terms of spherical harmonics and has the following expansion:

$$X(\vartheta,\varphi) \simeq \sum_{l=0}^{L}\sum_{m=-l}^{l} c_l^m Y_l^m(\vartheta,\varphi) \qquad [5.4]$$

where the $\{c_l^m\}$ are the coefficients of the expansion: the latter are obtained by projecting the human body shape, with an inner product, on each element of the spherical harmonic basis

$$c_l^m = \left\langle X(\vartheta,\varphi), Y_l^m(\vartheta,\varphi) \right\rangle_{\frac{3}{4\pi}} \int_0^1 \int_0^{2x} X(\vartheta,\varphi)\, \bar{Y}_l^m(\vartheta,\varphi) r^2 \sin\vartheta \, d\vartheta d\varphi \qquad [5.5]$$

5.2.2 Body part of the form $X(r,\vartheta,\varphi)$: the Schrödinger basis

Many body parts may be put under the form $X(\vartheta,\varphi)$; for instance the cranium, the upper leg or a finger, amongst others. Nevertheless, this is clearly not the case for the human body as a whole. For instance, let us consider a radial line that goes through the torso and the upper arms. Here, there are three points associated with that direction, namely one point on the torso and two points on the surface of the upper arm. This observation implies that a more general representation is required. That is, one must be able to describe bodies of the form $X(r,\vartheta,\varphi)$ i.e. with radial and angular distributions. One possible generalization to address this problem is to introduce, in addition to the angular basis, the spherical harmonics, a radial basis. Then, assuming that the radial and angular parts are separable, the expansion takes the form

$$X(r,\vartheta,\varphi) \simeq \sum_{n=1}^{N} \sum_{l=0}^{n-1} \sum_{m=-l}^{l} c_{nl}^m R_{nl}(r) Y_l^m(\vartheta,\varphi) \qquad [5.6]$$

where the $\{c_{nl}^m\}$ are the coefficients of the expansion and $R_{nl}(r)$ is the radial part of the basis. Numerous radial bases (Mavridis and Ritchie, 2010) may be employed many of which are the radial part of the solution of the Schrödinger equation for a particular potential. For instance, for a radial harmonic potential $V(r) \propto r^2$, one obtains

$$R_{nl}(r) = \left[\frac{2}{\kappa^{3/2}} \frac{(n-l-1)!}{\Gamma\left(n+\frac{1}{2}\right)} \right]^{1/2} \exp\left(-\frac{r^2}{2\kappa}\right) \left(\frac{r^2}{\kappa}\right)^{1/2} L_{n-l-1}^{(l+1/2)}\left(\frac{r^2}{\kappa}\right) \qquad [5.7]$$

where the $\{L_n^{(\alpha)}\}$ are the generalized Laguerre polynomials and κ is a constant.

5.2.3 The Zernike basis

Most of the time, the three-dimensional shape of the human body is obtained either with a laser scanner or with a structured light system. In both cases, as a result of the virtualization operation, a dense set of points is acquired. From that set of points, one may construct various representations of the human body. For instance, it is possible to tessellate the points in order to obtain a triangular mesh representation. Sometimes, it may be more convenient to assign a certain thickness to this surface. This is relevant in the case where, for instance, one intends to compare the body with correlation-based approaches. Such a thickness may be obtained by representing the body as a mixture of Gaussians

$$X(x) = \frac{1}{\sqrt{2\pi}\sigma}\sum_{i=1}^{N}\exp\left(-\frac{1}{2\sigma^2}\left\|x - x_i\right\|^2\right) \qquad [5.8]$$

That is, a Gaussian function is associated with each acquired point. Such a representation is particularly suited for the Zernike basis (Novotni and Klein, 2003). Like the Schrödinger basis, the Zernike basis is defined as a product of a radial function and of a spherical harmonics

$$Z_{nl}^{m}(r,\vartheta,\varphi) = R_{nl}(r)Y_l^m(\vartheta,\varphi) \qquad [5.9]$$

in which the radial basis is simply a power expansion over the radius. The Zernike basis takes the form

$$Z_{nl}^{m}(r,\vartheta,\phi) = \sum_{v=0}^{k} q_{kl}^{v}\left\|x\right\|^{2v} Y_l^m(\vartheta,\varphi) \qquad [5.10]$$

The elements of the Zernike basis are orthonormal by construction

$$\tfrac{3}{4\pi}\int_0^1\int_0^{2\pi}\int_0^{\pi} Z_{nl}^{m}(r,\vartheta,\varphi)\,\bar{Z}_{n'l'}^{m'}(r,\vartheta,\varphi)\,r^2\sin\vartheta\, d\vartheta d\varphi dr = \delta_{nn'}\delta_{ll'}\delta_{nn'} \qquad [5.11]$$

The coefficient q_{kl}^{v} may be obtained by enforcing such an orthonormalization constraint

$$q_{kl}^{v} = \frac{(-1)^k}{2^{2^k}}\sqrt{\frac{2l+4k+3}{3}}\binom{2k}{k}(-1)^v\frac{\binom{k}{v}\binom{2(k+l+v)+1}{2k}}{\binom{k+l+v}{k}} \qquad [5.12]$$

A human body may be represented in the Zernike basis with the following expansion

$$X(r,\vartheta,\varphi) \simeq \tfrac{3}{4\pi}\sum_{n=0}^{N}\sum_{k=0}^{\left[n/2\right]}\sum_{v=0}^{k} q_{kl}^{v}\left\|x\right\|^{2v}\sum_{m=-l}^{l}\Omega_{nl}^{m}Y_l^m(\vartheta,\varphi) \qquad [5.13]$$

where $[n]$ is the nearest integer to n. The coefficients of the expansion are obtained by projecting the body shape on the Zernike basis with an inner product

$$\Omega_{nl}^{m} = \left\langle X(x), Z_{nl}^{m}(x)\right\rangle = \tfrac{3}{4\pi}\int_{\left\|x\right\|\le 1} X(x)\,\bar{Z}_{nl}^{m}(x)\,r^2\sin\vartheta\; dr d\vartheta d\varphi \qquad [5.14]$$

As indicated by the previous equation, the body shape must be normalized within a unit sphere in order to correspond to the integration domain $\|x\| \leq 1$. For a shape to be normalized, a spherical reference frame must be associated with the shape. The origin of the reference frame is taken as the barycentre of the human body shape. Subsequently, the radial coordinates of the shape are normalized such that the maximum radius is set to be equal to one. Such a procedure is not free of ambiguity. Indeed, it implicitly assumes that all human body shapes have the same anthropometric posture. If this is not the case, the barycentre may not be consistent from one body to the next. Even if a common anthropometric posture is enforced, it may be difficult to obtain a consistent definition of the barycentre if the variability of the population under scrutiny is large. Furthermore, the anthropometric posture is always approximate.

5.2.4 Rotation invariance and human body shape comparison

From the Zernike coefficients, one may obtain rotationally invariant coefficients (Canterakis, 1994) by calculating the Euclidean norm associated with the orbital index l.

$$\Omega_{nl} = \sqrt{\sum_{m=-l}^{l} \left(\Omega_{nl}^{m}\right)^{2}} \qquad [5.15]$$

These rotationally invariant coefficients allow for the comparison of two human body shapes either by computing a correlation distance in between the two shapes

$$d_C(X, Y) = \frac{\sum_{nl} \Omega_{nl}^{X} \Omega_{nl}^{X}}{\left(\sum_{nl} \Omega_{nl}^{X}\right)^{1/2} \left(\sum_{nl} \Omega_{nl}^{X}\right)^{1/2}} \qquad [5.16]$$

or by computing their Euclidean distance

$$d_E(X, Y) = \sqrt{\sum_{n=0}^{N} \sum_{l=0}^{n} \left(\Omega_{nl}^{X} - \Omega_{nl}^{Y}\right)^{2}} \qquad [5.17]$$

Consequently, it is possible to compare the shape of two human bodies without any prior alignment as long as the two bodies share a common anthropometric posture. One should notice that exactly the same procedure may be applied to the basis (spherical harmonics or Schrödinger) as was introduced earlier. The projection does not modify the information associated with the human body shape but rather reformulates the latter in terms of a new and common basis. A vast range of bases may be chosen: the choice of a particular basis is rather a question of convenience; for instance, a particular invariance may be required or it may be easier to represent certain human features with a specific choice of a basis. It is difficult to determine the optimal basis a priori and, it may be appropriate to experiment initially with a few of them in order to determine the most suitable choice.

5.2.5 Comparison of human body parts

As stated earlier, the previous approach is not limited to the human body as a whole. It may be applied to body parts, or specific regions of interest on the body surface. Nevertheless, in that case, the problem associated with the normalization becomes more pronounced. Recall that the form of the normalized shape is highly dependent on the location of the barycentre. The barycentre, in turn, depends strongly on the boundary of the region of interest. Indeed, it remains a great challenge to accurately determine the boundary of a region of interest in a consistent and unambiguous manner. As a result, the normalization of a given region of interest might not be consistent from one body to the next and, as a corollary, the Zernike expansion might become inconsistent. Consequently, it may become impossible to compare the Zernike coefficients in order to assert the similarity between two regions because they are defined on incompatible external reference frames. Although invariant under translation and rotation, the coefficients are not invariant under more general transformations, such as non-elastic deformations. That means that it is implicitly assumed that the bodies (or body parts) that are compared are related by a rigid transformation. Such an approximation is justified for the cranium (or for the body as a whole if the entire body has a well-defined anthropometric posture). However, this does not apply for soft tissues like the stomach or for muscular regions for which non-rigid deformations are commonplace.

In order to address this issue, a change of paradigm is required. So far, our approach has been extrinsic in the sense that an external reference frame is required in order to project the shape onto a particular representation. As we have seen, such a reference frame cannot always be determined in a consistent and robust fashion. In the next section, we propose intrinsic approaches which are potentially more robust and that are suitable for the description of deformable or flexible human body shapes.

5.3 Description and classification of human body shapes using intrinsic approaches

As we saw in the previous section, extrinsic approaches are difficult to apply to body parts because the external reference frame cannot be robustly determined. In this section, we explore intrinsic approaches in order to describe the human body and its parts. Our objective is twofold. First, we want to free ourselves from any external reference frame and, second, we want to obtain a more general invariant representation in order to be able to describe soft tissues like, for instance, the stomach. These representations may be subsequently used in order to segment the population.

5.3.1 The geodesic distance

The first intrinsic method is based on the concept of geodesic distance (Gupta *et al.*, 2010) which is the length of the shortest path connecting two points on a body. If the surface of the body is represented by a tessellation, which is almost always the case if the shape is obtained as the result of a virtualization process, the geodesic distance may be assimilated to the graph distance which is the length of the shortest path in between two nodes or vertices on the graph or mesh. In the latter case, a path is formed from the various connected edges forming the tessellation. Such a distance may be evaluated with various algorithms such as the Dijkstra algorithm (Dijkstra, 1959) and the fast marching methods. Formally, the geodesic distance may be defined as

$$d_\gamma(x_i, x_j) = \arg\min_{\gamma \subset X} \int_\gamma ds \qquad [5.18]$$

where γ is a path in between x_i and x_j and where ds is an infinitesimal line element. It should be noted that the geodesic distance does not require the introduction of any external frame and consequently is an intrinsic feature of the shape. The geodesic distance is invariant under isometry, which is a class of deformation that encompasses all the deformations that are not elastic. This includes, but is not limited to, translation and rotation. In other words, an isometry is a transformation that preserves the geodesic distance in between the points forming the body. Therefore, an isometry is a deformation of minimum energy and, as such, constitutes a good approximation for most deformations, at least when their amplitudes are relatively small. As a result, in addition to being isometrically invariant, the geodesic distance is oblivious to most deformations.

Various isometrically-invariant representations or descriptors may be constructed from the geodesic distance in order to characterize the intrinsic geometry of a human body shape. The most common is the distance matrix which may be defined as

$$D(X) = [d_\gamma(x_i, x_j)]_{\forall\, xi, xj \in} X \qquad [5.19]$$

where $D(X)$ is the matrix of the geodesic distance in between all pairs of points belonging to the body shape. If the number of points is too large or if only certain points are of interest, the set of points may be restricted to some particular anthropometrical landmarks. The distance matrix may also be defined from a set of classical anthropometrical measurements. In that case, x_i and x_j correspond to the points from which the measurements are initiated and terminated. Such an anthropometric distance matrix is fully invariant by construction.

If two bodies X and Y differ by an isometry, their distance matrices are related by a permutation which is due to the fact that, despite the geodesic distances being isometrically invariant, the correspondence in between the two shapes is generally unknown.

$$D(Y) = PD(X)P^T \qquad [5.20]$$

The permutation matrix (Dubrovina and Kimmel, 2010) reduces to the identity matrix if the distance matrix is constructed from anthropometrical landmarks (Azouz *et al.*, 2006) if the latter may be identified unequivocally. The permutation matrix in between two human body shapes is not easy to determine and does not scale well with the number of points. For this reason, the distance matrix should be restricted to a small number of anthropometrical landmarks. Therefore, it is preferable to construct a descriptor which is entirely invariant under isometry in order to be able to handle a large number of points. One possibility is to construct the histogram (Dryden and Mardia, 2002) of the geodesic distances which is defined as

$$H = \left[H_k\right] = \left[\sum_{i>j} \mathrm{I}_{d_\gamma(x_i,x_j)\in\left[d_k,d_{k+1}\right]}\right] \qquad [5.21]$$

where I is a binary indicator and $[d_k, d_{k+1}]$ is an interval of geodesic distances. Such a histogram is entirely invariant under isometry and may characterize the entire body or a part thereof. No external reference frame is required since it is constructed entirely from the geodesic distances: an intrinsic quantity. The histogram provides a simple and relatively robust way to describe the shape of a human body or a specific region of interest. As for the Zernike basis, the composition of the histogram is also affected by the particular boundary of the region of interest, but to a much lesser extent because a relatively small proportion of the geodesic distances are affected by the boundary: the others remain unaltered.

5.3.2 The Laplace-Beltrami operator as a representation for the human body

In this section, the Laplace-Beltrami operator (Reuter *et al.*, 2005) or graph Laplacian is introduced in order to characterize the topology of human body shapes. We assume that the body is represented by a tessellation or graph, for instance, a triangular mesh. The Laplace-Beltrami operator is formed from two matrices: a weighted adjacency matrix W and a degree matrix D which attribute weights to the edges and the vertices of the graph respectively. Given an unoriented edge $\overleftrightarrow{ij}$, its associated cotangent weight is given by

$$W_{ij} = \frac{\cot(\alpha_{ij}) + \cot(\beta_{ij})}{2} \tag{5.22}$$

where α_{ij} and β_{ij} denote the two angles opposite to the edge $\overleftrightarrow{ij}$. The degree matrix $D = \mathrm{diag}[D_1, \ldots, D_n]$ is defined as

$$D_i = \frac{1}{\aleph(\Delta \in N(i))} \sum_{\Delta \in N(i)} a(\Delta) \tag{5.23}$$

where $a(\Delta)$ is the area associated with the triangle Δ (for instance, the sum of the areas of the triangle sharing a common vertex) and where $\aleph(\Delta \in N(i))$ is the number of triangles in the neighbourhood $N(i)$ of node i (connected by an edge). From the weighted adjacency matrix, one may define the diagonal matrix

$$V_i = \sum_{j \in N(i)} W_{ij} \tag{5.24}$$

as well as the following matrix

$$A = V - W \tag{5.25}$$

Then, the Laplace-Beltrami operator (Reuter *et al.*, 2009) may be defined either as

$$\Delta = D^{-1}A \tag{5.26}$$

or as

$$\Delta = D^{-½}AD^{-½} \tag{5.27}$$

which is inspired by the de Rham Laplacian in differential calculus (Vallet and Lévy, 2008). The latter Laplacian is symmetrical while the former is not. The Laplacian describes both the geometry and the topology of the surface to which it is associated. Because it is also related to the topology, the Laplacian is sensitive to topological defects. For instance, when scanning a human body with a full body scanner, some regions cannot be virtualized: for instance, the top of the head, the fingers and the toes. Consequently, it is preferable to fill all the holes on the surface of the body prior to the calculation of the Laplace-Beltrami operator.

5.3.3 Description and classification of the human body with a spectral approach based on the heat kernel

The Laplace-Beltrami operator may be characterized by its Eigen spectrum (Reuter *et al.*, 2005)

$$\Delta\phi_i = \lambda_i\phi_i \tag{5.28}$$

if the Laplacian is symmetrical or by its generalized Eigen spectrum

$$A\phi_i = \lambda_i D\phi_i \tag{5.29}$$

otherwise. The generalized Eigen spectrum is required in order to ensure that the Eigen values are real and that the Eigen vectors are orthogonal with respect to each other. There is a strong relationship in between the Laplace-Beltrami operator and the heat equation

$$\frac{\partial u(x,t)}{\partial t} = \Delta u(x,t) \quad [5.30]$$

which characterizes the propagation and the distribution of heat on the graph associated with the human body at time t. The appearance of the heat equation in a study about the human body shape (Fang *et al.*, 2011; Lovato *et al.*, 2011) might seem surprising at first. Nevertheless, its introduction is fully justified for the following reasons. First, the heat equation is based on the Laplacian which, as previously indicated, describes the geometry and the topology of a surface. Second, the distribution of heat, which is described by the heat equation, is strongly dependent on the geometry of the surface. Finally, by studying the distribution of heat with time, one obtains a multiresolution description of the surface.

The heat equation is better analysed in terms of the heat kernel K. The heat kernel is the solution of the heat equation with the initial conditions $u(x_i,0) = \delta(x_i - x_j)$ and corresponds to the amount of heat found at a point x_i when a unit of heat is applied on the surface of the body at a point x_j. It is also a formal solution of the heat equation

$$\frac{\partial K}{\partial t} = \Delta K \Rightarrow K = \exp(-t\Delta) = \sum_{n=0}^{\infty} \frac{\Delta^n}{n!} \quad [5.31]$$

where the Taylor expansion has been utilized. If the formal solution is projected on the Eigen basis of the Laplacian operator one obtains

$$K_{ij}(t) = \sum_{l=1}^{L} \exp(-\lambda_l t)\phi_l(x_i)\phi_l(x_j) \quad [5.32]$$

That means that the heat kernel is fully determined by the Eigen spectrum of the Laplace-Beltrami operator associated with the tessellation of the body. There is actually an interesting connection between the heat kernel and the random walk. Namely, the heat kernel is a function of all possible random walks between points x_i and x_j. From the heat kernel, it is possible to construct an isometrically invariant descriptor. A descriptor based on the heat kernel is potentially more robust than a descriptor based on the geodesic distance. This is because the heat kernel considers all possible paths in between each pair of points while the geodesic distance only considers the shortest path in between them. It may be shown that the diffusion distance (Bronstein and Bronstein, 2011)

$$d_{ij}(t) = \sqrt{\sum_k \left|K_{ik}(t) - K_{jk}(t)\right|^2} \quad [5.33]$$

is a weighted average over all possible paths in between points x_i and x_j. Such a distance is invariant under isometry. Consequently, it is possible to construct a histogram of the distances, as previously defined, in order to characterize the shape of a human body or a part thereof in an isometrically invariant fashion. The diffusion distance is an elegant solution to the measurement selection problem. Indeed, instead of considering only a unique and somewhat arbitrary measurement in between two points, the diffusion distance considers *all* possible measurements simultaneously. Such a measurement is much more robust since it does not depend on a particular path. Furthermore, by considering all possible paths in between a pair of points, the diffusion distance establishes a correspondence between that pair of points and all the other points representing the body. The heat kernel signature, presented in the next section, shares all these characteristics.

5.3.4 The heat kernel signature

From the heat kernel, it is possible to define a descriptor which is isometrically invariant for each point on the surface of the human body: the so called heat kernel signature (Ovsjanikov *et al.*, 2009):

$$\kappa_i = \frac{\left[K_{ii}(t_1),\ldots,K_{ii}(t_n)\right]^T}{\sqrt{\sum_{k=1}^{n} K_{ii}(t_k)}} \qquad [5.34]$$

In the heat kernel formalism, the time is related to the resolution of the descriptor: the smaller the time, the smaller the region described by the descriptor. This correspondence between time and spatial resolution is to be found in the heat equation: the more time passes, the more the heat propagates on the surface of the body. This implies that the heat kernel signature is a multiresolution descriptor. The time should be sampled such that the resolution of the descriptor corresponds to the resolution of the features of interest on the human body. The number of elements in the heat kernel signature is equal to the number of points forming the surface of the body which may be large: for instance, if the points are acquired with a body scanner. Compact descriptors may be obtained if the number of points is small such as in the case of anthropometrical landmarks. In the general case, the heat kernel signature must be integrated on the surface of the body in order to obtain a manageable representation. Two approaches are foreseen. In the first approach, the heat kernel signature is simply integrated over the whole surface of the body in order to obtain a multiresolution descriptor (remember the previous equation). In the second approach, one uses the fact that the heat kernel is also a metric and a propagator which means that the heat kernel may relate two heat kernel signatures at two different locations. Then the location aware descriptor (Ovsjanikov *et al.*, 2009) is defined as

$$F(X) = \sum_{i=1}^{K} \sum_{j=1}^{K} k_i K_{ij}(t) k_j^T a_i a_j \quad [5.35]$$

which provide a more complete description of the body surface by taking into account the relationship between each pair of points.

We have introduced various intrinsic approaches for the description of human bodies and regions of interest which are invariant under isometry. In the next section, we address the problem of segmenting the population from these invariant representations.

5.4 Body spaces, multidimensional scaling, dimensionality reduction and segmentation

In the previous sections, we have presented various approaches for the description of human body shapes. The first category, the extrinsic approaches, aim to project the shape on a functional basis defined on an extrinsic reference frame and, from the projection, to create an invariant representation. Among these are the approaches based on the spherical harmonics, the Schrödinger basis and the Zernike basis. The second category, the intrinsic measurements, are defined on the surface itself without any requirement for an external reference frame. This category includes the geodesic distance and the diffusion distance which considers all paths in between two given points. Both these distances are invariant under isometric transformations. The last intrinsic approach that we have presented is based on the heat equation, which describes the propagation of heat on the surface of a body. The motivations behind this choice are twofold. First, the heat equation is based on the Laplacian which is particularly well adapted for the description of the geometry and the topology of a surface. Second, the distribution of heat is strongly dependent on the geometry of the surface. Then, we have introduced the heat kernel and the heat kernel signature. The heat kernel signature is a multiresolution, isometrically invariant descriptor that characterized the geometry of the human surface around a given point. We have shown that these descriptors may be integrated and it is possible to take into account their interrelationships with the help of the heat kernel which acts both as a propagator and a metric.

Whatever our choice for characterizing a human body or a region thereof, our main objective remains unaltered: finding an optimal partition of the population and, for each partition, a representative individual or archetype, on which a design may be based. This observation brings us to the notion of a '*human body space*' (Younes, 2012). A *human body space* is a multidimensional space in which each point belonging to the space corresponds to a particular body, body part or region of interest. In our case, a point is a descriptor associated with a human body or part thereof. Such a descriptor may be, for instance, associated with the spherical harmonics, the Schrödinger or the Zernike basis, or the heat signature kernel integrated over the surface of the region of interest. A partition of the population then corresponds to a clustering of the *human body space* and an archetype corresponds to a representative individual within a cluster, for instance the barycentre if the cluster is convex. If the cluster is not convex, more than one archetype may be required.

The use of clustering and constrained clustering has been an active field of research for decades (Abdali *et al.*, 2004). Despite many breakthroughs, most methods assume, at least implicitly, that this *human body space*, or for that matter any space of interest, is Euclidean. That means that the distance in between two points may be obtained with the familiar Euclidean distance. There are a priori no reasons whatsoever why a manifold associated with a *human body space* should be restricted to Euclidean geometry (Paquet and Viktor, 2010). For instance, the human manifold might be curved and consequently may present a Riemannian geometry. The distinction has far-reaching consequences. In order to clarify this concept, let us consider a hypothetical *human body space*: an ellipse in which the points are uniformly distributed along its circumference. In this particular case, the *human body space* is a one dimensional curved manifold corresponding to the ellipse itself. Naturally, the ellipse may be embedded in a bidimensional Euclidean space.

Unfortunately, for the Euclidean distance to be meaningful, one must be able to construct a line in between any pair of points and this line must be contained entirely within the original manifold i.e. that all the points of the line must belong to the circumference. Clearly, this is not the case here. Rather, for any pair of points belonging to the ellipse, there are no other points from which the line could be constructed. A similar observation may be made about the point density. As stated earlier, within the Riemannian manifold, the one-dimensional point density is uniform by construction. This is not the case if the ellipse is embedded in a bidimensional Euclidean manifold. The consequences for clustering are paramount. If the use of the Euclidean distance is not legitimate, Euclidean distance-based cluster analysis algorithms (like the popular *k*-means cluster analysis algorithm) are likely to provide an incorrect partition of the population. A similar observation may be made for density-based cluster analysis algorithms. In that context, one must ascertain if the discrete human manifold presents an underlying Euclidean geometry or not. Such an assertion is important, because most clustering algorithms implicitly assume such a geometry.

Based on the above discussion, we present in the following an approach that allows determination whether the geometry of the *human body space* (or population) is Euclidean or not. In the case where the geometry is not Euclidian, we show how to find the closest compatible Euclidean geometry. Subsequently, the segmentation analysis may be performed in terms of standard clustering algorithms.

One of the most successful and computationally efficient approaches to transform a non-Euclidian manifold (usually a Riemannian manifold) into a Euclidean manifold is called multidimensional scaling (Tenenbaum *et al.*, 2000).

In this approach, the squared geodesic distance (one may use the diffusion distance as well) in between every pair of points of the human manifold is calculated

$$S = \left[d_{ij}^2 \right] \quad [5.36]$$

When the matrix S assumes such a form, the algorithm is also called Isomap. From the matrix of the squared distances, the following centred distance matrix is constructed

$$Q = -\frac{1}{2} HSH \quad [5.37]$$

where

$$H = I - \frac{1}{N} e_N e_N^T \qquad e_N = \left[1 \ldots 1 \right]^T \quad [5.38]$$

Such a matrix admits a spectral decomposition

$$Q = V \Lambda V^T \quad [5.39]$$

where Λ is the diagonal matrix, in descending order, of its Eigen values of the centred distance matrix and V is the matrix of the corresponding Eigen vectors. It may be further demonstrated that the coordinates of the corresponding Euclidean manifold are given by

$$Y = \Lambda^{\frac{1}{2}} V^T \quad [5.40]$$

where each row of matrix Y corresponds to a particular point in the manifold and each column corresponds to a particular coordinate in the new Euclidean space. Not only does multidimensional scaling allow one to map a non-Euclidean manifold onto a Euclidean manifold but, in addition, it allows one to perform dimensionality reduction. Indeed, the dimensionality of the Euclidean space may be decreased by conserving only the coordinates corresponding to the Eigen values having the largest magnitude. For instance, in order to reduce the number of dimensions from n to $d < n$, only the first d columns of Y are retained $Y_{[1 \ldots d]} = \Lambda_{[1 \ldots d]}^{\frac{1}{2}} V_{[1 \ldots d]}^T$. Such a dimensionality reduction becomes particularly important when the original human space has a large number of dimensions: most clustering algorithms, including those based on distance and density, do not perform well when the dimensionality is excessive (curse of dimensionality). The corresponding Euclidean space exists only if the Eigen values are real. Otherwise, the previous equation generates a representation in terms of complex numbers (refer to the square root in the previous equation). Even in this case, an approximate Euclidean representation may be obtained by an extension of the previous approach named robust kernel Isomap (Choi and Seungjin, 2007). In addition to the previous centred distance matrix, this approach requires a new centred distance matrix Q' which is defined as

$$Q' = -\frac{1}{2} HS' H \qquad [5.41]$$

where

$$S' = [d_{ij}] \qquad [5.42]$$

is the matrix of the geodesic or diffusion distances (not squared) in the original manifold and where

$$\begin{pmatrix} 0 & 2Q \\ -I & -4Q' \end{pmatrix} \qquad [5.43]$$

is a block matrix obtained from Q and Q' and where I is the identity matrix. If one computes the largest Eigen value of this matrix λ_{max}, it is possible to define a new centred distance matrix $\tilde{Q}$:

$$\tilde{Q} = Q + 2\lambda_{max} Q' + \frac{1}{2}\lambda_{max} H \qquad [5.44]$$

All the Eigen values of this matrix are positive (the matrix is positive definite) and consequently the standard multidimensional scaling approach is always legitimate. Therefore, it is possible to obtain an approximate Euclidean representation for many diverse *human body spaces* and, if required, to perform dimensionality reduction by retaining only the Eigen vectors corresponding to the largest Eigen values of $\tilde{Q}$.

5.5 Conclusions

In this chapter, we have presented various approaches for the invariant representation of human body shapes. From each of these representations, a *human body space*, which contains descriptors of the population under investigation, may be defined. Once the *human body space* is clustered, a partition and a segmentation of its corresponding population may be obtained. The first type of approach we presented is based on an extrinsic representation in which each body or region of interest is projected on a common functional basis for which a rigidly invariant representation may be defined. The coordinates of a projected body in the common basis constitute a point in a human body space. A drawback of this representation is that a common human body space may only be defined if the external reference frames associated with the bodies are consistent in between themselves. In the second type of approach, we introduce intrinsic measurements, including the geodesic distance and the diffusion distance. These measurements allow one to describe a human body without any external reference frame and to obtain a broader invariance which allows for the description of soft tissues. The diffusion distance constitutes a considerable paradigm shift in the sense that the notion of a single measurement must be replaced by the notion of all possible measurements between two points. Finally, the geometry and the topology of the human body is analysed in terms of the Laplace-Beltrami operator and the heat kernel which allow us to obtain a multiresolution, isometrically invariant representation in which the interrelations between the various points forming the body are taken into account. A *human body space* may also be defined from these descriptors. The segmentation of the population corresponds to the clustering of the *human body space*. We have shown that the geometry of the manifold associated with the *human body space* is not always Euclidean. Since the vast majority of clustering algorithms assume implicitly a Euclidean geometry, we have introduced multidimensional scaling and kernel Isomap which allow us to map a non-Euclidean manifold into an Euclidean manifold and to perform dimensionality reduction in order to segment the population efficiently with standard clustering algorithms.

In a future work, we intend to address the problem from a constrained clustering point of view. Indeed, the motion of a body is constrained in many ways. Consequently, a more realistic segmentation or clustering should be obtain if these mechanical constrains are taken into account.

5.6 References

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6
National size and shape surveys for apparel design

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Abstract: This chapter outlines a global context for the apparel industry, describes how size and shape data from intergenerational population surveys can not only help to provide better-fitting clothes but also a more sustainable supply chain. It considers ways in which surveys have been planned and implemented using 3D scanning technology and looks as the ways in which emerging technologies could influence the methods by which future surveys might be undertaken to ensure inclusive design strategies.

Key words: sizing survey, body scanning, anthropometric measurement, sustainable development, inclusive design.

6.1 Introduction

The clothing industry is a global economic success, worth $500 billion, but its supply chain has a significant environmental and social impact, with the consequence that it is one of the world's most polluting industries. Millions of tonnes of clothing are being committed annually to landfill, some of which is as a result of poorly fitting garments that could, in some cases, be traced to a lack of accurate anthropometric data. The success of the clothing industry comes at huge environmental cost and part of this problem has arisen because many countries have seen major demographic change – age expectancy beyond 80 years, a broadening ethnic mix and increasingly sedentary life styles – all of which has affected body shapes and sizes. These changes have led to growing complaints from consumers about the fit of clothes, while retailers perceived them as presenting commercial opportunities.

The key to meeting some of these challenges has been the advent of reliable three-dimensional (3D) whole body scanning systems, with accurate measurement extraction capability. Such systems have enabled many size and shape surveys to be undertaken over the past decade.

This chapter outlines the global context of the apparel industry, shows how size and shape data can help to provide a more sustainable supply chain, introduces the concept of inclusive design and looks at ways in which surveys can be undertaken.

6.2 A global context

A quarter of a century ago the concept of sustainable development was introduced to the international community as a new paradigm for economic growth, social equality and environmental sustainability.

The broad definition of environmental sustainability was conceived at that time as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'; the central idea being one of intergenerational equity. The report *Our Common Future* (UN, 1987) led to earth summits in 1992, 2002 and, in 2012, to Rio + 20. Following the 2012 conference it was suggested that sustainable development is not a destination but a dynamic process of adaptation, learning and action. It was described as being about recognising, understanding and acting upon interconnections between the economy, society and the natural environment (UN, 2012a).

However, while progress has been made, it was stated in 2012 that the world is not yet on this path and, if we are to meet the impact of some of the drivers of current change (production and consumption patterns, innovation, demographics, political dynamics and changes in the global economy) then we need to build an effective framework of decision making processes at local, national, regional and global levels (Ibid.)

Over the past 20 years there have been different responses from UN member states to the agreement to develop and implement national strategies for sustainability. Despite pressure from many internal, national groups, some countries have not developed strategies while other regional bodies only introduced strategies following the first (1999) agreement. These were revised in 2005 to include a two-year reporting commitment (an example here is action taken by the European Union and its member states). Some governments drew up their own strategies, with significant international and societal dimensions. A UK publication incorporated five principles with an explicit focus on the environment.

- Helping people make better choices.
- One planet economy, sustainable consumption and production.
- Confronting the greatest threat – climate change and energy.
- A future without regrets: protecting our natural resources and enhancing the environment.
- From local to global: creating sustainable communities and a fairer world.

(HM Government, 2005)

The second of these principles, 'One planet economy, sustainable consumption and production', became the umbrella under which a sustainable clothing UK 'roadmap' was launched in 2007 (Defra, 2011). It aimed to improve the sustainability of clothing across the life cycle, from crops that are grown to make fabric to the design and manufacture of garment, retail, use and end of life (Ibid).

The clothing industry is, as indicated above, a global economic success, worth some $500 billion and, while the roadmap is a UK initiative, it is linked to Asia, the EU and the USA, as most clothes consumed in the UK have a global supply chain (ibid). That supply chain has, however, a significant environmental and social impact (exacerbated by high consumption levels) as was made clear at the Rio + 20 conference, where the fashion industry was described as not only being one of the world's most polluting industries but also one that exploited labour across the globe (UN, 2012b).

Notwithstanding these recent affirmations of the adverse effects of the apparel industry, considerable progress continues to be made to reverse its global impact. Life cycle assessment of product, process and services is being widely applied for sustainability accounting (see the ISO 14000 series); there are many clothing and textile organisations actively engaged in promoting and supporting sustainability programmes, (e.g. Sustainability Apparel Coalition), with some individual companies who are at the forefront of life cycle changes in their supply chains, such as Nike and Marks and Spencer (M&S). An ideal outcome of these activities is for companies to have a closed loop strategy such as Patagonia and, more recently, Puma (Shankleman, 2013) and Marks & Spencer (Bateman, 2012), where products are returned to the company for recycling or to nature at the end of product life (see also Nike, 2010). However, while this strategy is easier for sportswear or outwear companies, it is considerably more complex for fast fashion, where large quantities of clothing are thrown away – often the outcome of serial product honeymooners (Chapman, 2009). In the UK one million tonnes of clothing is thrown away each year, and, despite warnings that decomposition releases harmful greenhouse gases, 50% of the total is committed to landfill, as is 11 million tonnes in the USA (Defra, 2010; Wallander, 2010). It is some of these unsustainable challenges that many of the organisations that joined the UK roadmap initiative are planning to resolve (both national organisations, such as M&S and Tesco, and international organisations, such as Nike and Adidas). In their ongoing Sustainable Clothing Action Plan they are working to improve key target areas in the clothing product life cycle.

- Improving environmental performance across the supply chain, including:
  - sustainable design;
  - fibres and fabrics;
  - managing reuse, recycling and end-of-life management;
  - clothes cleaning.
- Consumption trends and behaviour;
- Awareness, media, education and network;
- Creating market drivers for sustainable clothing;
- Instruments for improving traceability along the supply chain (environment, ethics and chain).

(Defra, 2010)

However, despite these extensive national and international activities, little information has been found that addresses, or is planned to address, the issue of poorly fitting clothes. The contribution they make to a high percentage of clothing returns (e.g. 40% in some industrial countries), a large volume of mark downs and subsequently the growing volume of landfill are all unsustainable and, while not all these issues can be directly attributed to poor fit, it is the capture and application of contemporary and accurate anthropometric data that has the potential to help reverse these trends.

6.3 Importance and significance of national size and shape surveys

The value of size and shape surveys for clothing is considerable. But, if we recognise the need to confront urgent sustainability issues (the growth of and changes within populations and variable life styles) then we shall need to undertake anthropometric studies at regular intervals in order to accurately reflect such developments.

Countries comprise people of differing cultures, ethnicities, life styles and ages, which in turn influence the size and shape of people within populations. Data collected during anthropometric surveys (the scientific study of the physical dimensions, shapes and sizes) can be used for a variety of applications requiring different ranges of static and dynamic dimensions. For this reason the type of anthropometric data collected during a sizing survey needs to be appropriate for the people, the products they use and their purposes.

Interest in collecting body data from large groups of people for clothing applications has been well practised for the military, but little was achieved for civilian groups until the mid-twentieth century, and then primarily for women. Those early studies, together with an increase in mass-produced clothing, prompted many countries to undertake national, clothing-specific anthropometric studies. Although manual studies are still being executed (see Table 6.1), the advent of three-dimensional body scanning systems has accelerated those interests, particularly during the last ten years (see Table 6.2).

Table 6.1 Manual sizing: a compilation of recently reported civilian surveys

Location	Date	Comments
Australia	2001	Study of the elderly.
Croatia	2009	Major survey.
India	2008–10	Small study of younger people.
Malaysia	c2009	Small study.
Nigeria	2009	Small study of hand, foot and ear among young people.
Turkey	2007	Medium scale Masters project in 18 cities across Turkey.

Table 6.2 Digital anthropometric sizing surveys:a compilation

Country, survey	Date	Ages (years)	No., male and/or female	Scanner	Postures/ measurements
Japan: HQL	1992–1994	7–90	34000, M & F	Voxelan, Hamano	Not known/178
Netherlands: CAESAR	1999–2000	18–65	1255, M & F	Vitronic	(As USA)
Germany: Hohenstein	1999–2000	14–80	1500, F	Vitronic	3/84/intimate apparel
USA: CAESAR	1998–2000	18–65	2375, M & F	WB4, Cyberware	3/57 (+40 manual)
UK: SizeUK	1999–2002	16–90+	11000, M & F	TC2	2/130 +10 manual
Italy: CAESAR	2000–2001	18–65	801, M & F	WB4, Cyberware	(As USA)
Germany: E-Tailor	2001	16–70	500, F	Vitronic	2/10
USA: SizeUSA	2002–2003	18–65	10500, M & F	TC2	2/130+10 manual
Germany: Elderly women	2002	50–80	1300, F	Vitronic	2/84 + 1 manual
Japan: Size-JPN	2004–2007	18–89+	6700, M & F	Not known	Not known/217
France	2005–2006	5–70	11562, M & F	Vitronic	2/55 +10 manual
China: (heads) SizeChina	2006	18–71+	2500	Cyberware head scanner	Not known
Thailand	2006–2008	16–60+	13442, M & F	TC2 NX16	1/140
France: Seniors	2007	70–100	400, M & F	Vitronic	2/'Varied'/
Germany: SizeGermany	2007–2008	6–87	13400, M & F	Vitronic	4/43
Spain	2007–2008	12–70	9159, F	Vitronic	3/95
Sweden	2005–2010	18–65	367, M & F	Vitronic	4/55 +10 manual
Mexico: SizeMexico	2010	18–65+	17364, M & F	TC2 NX16	1/200+
UK: NDA pilot[1]	2010	60–75	30, M & F	TC2 NX16	2/130 + 10

[1] The New Dynamics of Ageing (NDA, 2012): Newsletter for Summer 2010.

The importance of these 3D technologies lies in their capacity not only to extract large amounts of accurate data very quickly and without subject contact, but to do so in a way that enhances and extends traditional, one-dimensional measurement. Anthropometric data collection can now capture information for one, two, three and even four dimensions. Three-dimensional scanning and data extraction systems offer opportunities to increase our understanding of the static and dynamic shapes of a population rather than an aggregate of its one-dimensional sizes.

Data collected through surveys using 3D technologies whether for whole bodies or body parts (head, hand or foot) provide a wealth of benefits; for government, academia, industry and, ultimately, the consumer, as well as helping to make a collective contribution to meet new, global, economic and social demands.

6.3.1 Government

In addition to giving governments an opportunity to foster innovation and to support the use of new technology, national body shape and size surveys can generate tremendous interest in both its scientific applications and in the provision of highly detailed data on a population, supplying direct commercial benefit to a nation.

6.3.2 Academia

There are ongoing educational opportunities for university students and staff. Research teams can gain experience of the initial organisation and implementation of surveys, enabling them to explore technologies and, when data sets are available, to continue to develop new applications; for example to advance knowledge of shape classifications (Tahan *et al.*, 2003; Simmons and Istook, 2003; Ball *et al.*, 2012), to aid understanding of the size and shape of older populations (NDA, 2010), and to propose methods for animating virtual body models for active wear (Ruto, 2009).

6.3.3 Apparel industry

The main driving force for the majority of national surveys has been better body data for the apparel industry. Initial interest in surveys on the part of industry was limited to the use of one-dimensional data to update, augment or create new body sizing systems. However, provision of new shape and size data is enabling a much wider range of products for clothing design and development and, as tools for interrogating survey shape data continue to develop (Ruto, 2009) these shape data help to structure the basis for:

- new shape and sizing systems;
- understanding the impact of shape through the ageing process;

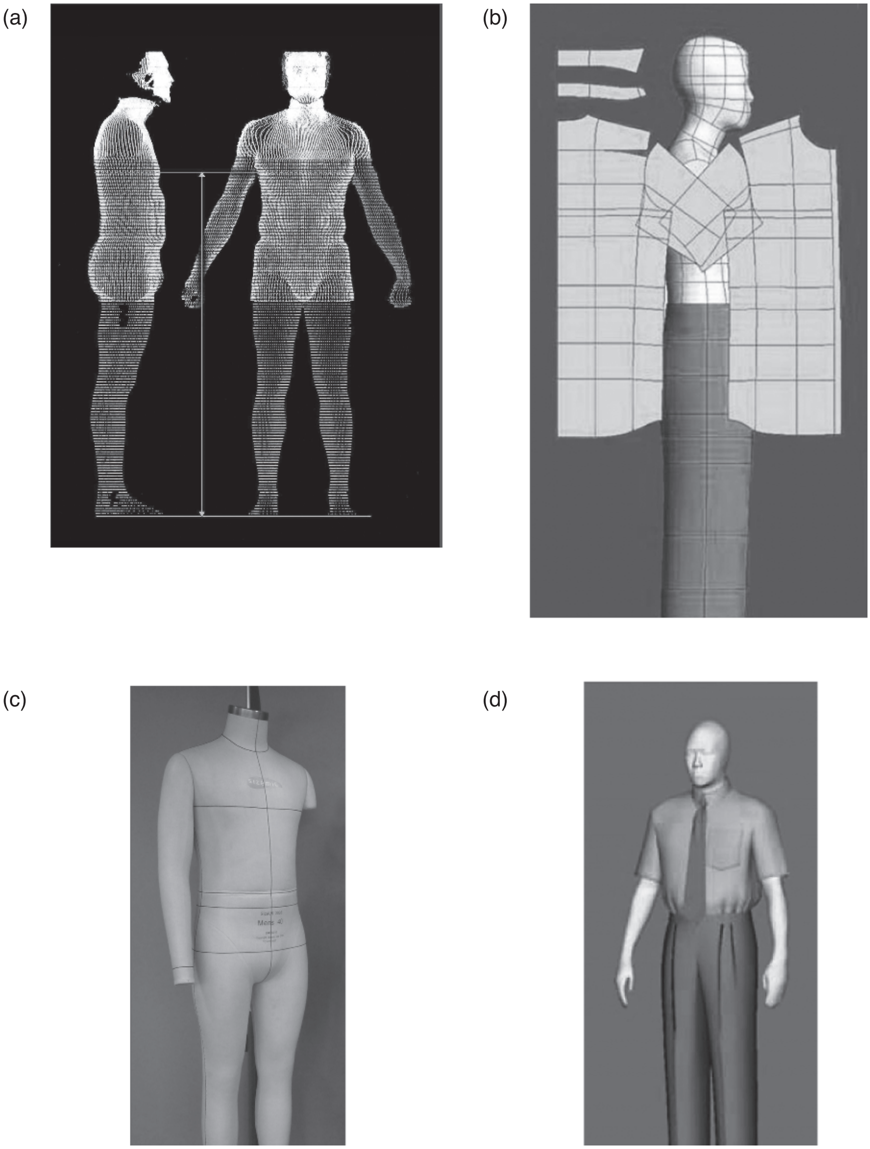
- identifying shapes within a specified market;
- confirming the *shape* as well as the size of physical fit models, for specified markets;
- three-dimensional design;
- automating block pattern generation;
- morphological grading;
- creation of physical fit mannequins;
- digital in-store and online fitting.

The availability of these products and of market-specific applications created from 3D anthropometric data (e.g. Sizemic Ltd, see Fig. 6.1) has the potential to meet some of the environmental, social and economic challenges discussed above and, in doing so, helps to streamline the fit of products across the supply chain, by:

- enabling apparel designers and technologists to understand demand in specific shape and size categories and encouraging expansion of size ranges to meet the needs of a whole population;
- improving garment fit and consistency of fit across sizes and products, bringing a positive impact to sustainable development and on customer loyalty and sales;
- enabling fitting to take place on the same body shape and size that can increase the efficiency of the product development process and establish a fit standard for all products across supply chains;
- reducing the number of iterations of samples with shorter lead times, with a positive impact on sales and longevity of garment wear;
- achieving efficiencies in the product development cycle with consequent environmental and cost benefits (fewer samples, fewer fit sessions, lower fit model costs and a reduction in staff time for processing and managing sample approval);
- increasing suppliers' sample approval rates with lower sample making and delivery costs and considerable time saving;
- improving the overall level of quality control (due to physical mannequin provision), which provides an excellent QA communication tool;
- improving margins due to reduced returns and better sell-through rates/lower markdowns.

(Sizemic, 2012)

Further sustainable practice can be achieved by using representative virtual shapes from a survey to upload into virtual design systems (such as Optitex and Assyst), where both contour and some free form clothing designs can be created, patterns unwrapped and flattened (TPC, 2012; Krzywinski, *et al.*, 2005; Kirchdoerfer *et al.*, 2011). In addition, two dimensional cross section data are being used to identify air gaps between body surface and garment to help establish fit; while apparel design teams and retail buyers are using 3D virtual body shapes



6.1 Streamlining the fit of products across the supply chain using 3D data: (a) scan and automatic measurement extraction; (b) automatic pattern and morphological grading; and (c, d) physical and virtual fit mannequins. (Sources: TPC Hong Kong Ltd; Sizemic Ltd.)

and two-dimensional pattern wrapping techniques to remotely assess fit and approve garment designs.

6.3.4 Consumers

The aim of all regularly conducted clothing-specific size and shape surveys is to provide data that can be used by designers and technologists to create well-fitting, ready-to-wear (RTW) garments for all consumers in a population. Evidence discussed (see above, section 6.3.3) suggests that, if all design and product development tools (e.g. sizing system, mannequins) across the supply chain are created from the same segmented data, then consumers of identified market segments could expect to find clothes that have an appropriate fit. This is the case whether purchasing RTW garments, in-store or online and, in some cases, mass customisation where size and shape data are drawn from national surveys. Consumers will only be satisfied with garment fit and maximise a garment's life use if the data produced for a survey accurately reflects the entirety of a population that it is designed to serve. For example, for all ages and sizes. And, if designers and retailers chose to use those data, to embrace the concept of Inclusive Design: 'a process that results in inclusive products or environments which can be used by everyone regardless of age, gender or disability' (CEBE, 2002). A definition that can be extended to address 'not only age, gender and disability, but also race, income, education, culture etc.' (Ibid.).

6.4 Planning a national anthropometric survey of clothing

Running a national anthropometric survey is akin to planning and executing a military operation. Likewise, even with the most thorough planning and preparation, many issues will only appear during the survey and will need to be resolved once the survey is under way.

There are several reports setting out the process of planning, executing, applying and reviewing anthropometric surveys. They describe similar stages but the aims and data to be collected vary. Studies conducted during the previous decade include:

- clothing-specific studies (e.g. SizeUK and SizeUSA);
- clothing with health studies (e.g. Size Thailand);
- clothing with technological design (e.g. Size Germany).

The priority is therefore to set out the focus and objective for the survey, the population and the clothing products for which the data are to be used at the beginning of the survey.

The following sections – infrastructure (6.4.1), preparation (6.4.2), implementation (6.4.3) and data storage (6.4.4) – will be confined to clothing-specific surveys, though it is recognized that data collected may have secondary application in such areas as health studies (Wells *et al.*, 2008).

6.4.1 Infrastructure

A number of fundamental decisions need to be taken when planning a survey. The identification of the partners who will collaborate to promote and conduct the survey; the source of funding for the survey and whether the data can and will be sold to third parties to help to recoup survey costs; legal ownership of the results of the survey; whether participating clothing textile companies receive data in return for funding; and whether any part of the data will be made publicly available.

Organising committee

If the organising committee and partners are to maximise the impact of a national study it is important to involve the government, leading clothing organisations, research centres and technology companies. A lead organisation is required to manage the survey, the finance, press and publicity and to negotiate all legal requirements. Normally a committee will comprise representatives of government, clothing and textiles organisations, major clothing companies and universities.

Management of a survey

In addition to planning and organising meetings, the management team handles issues involving the scheduling of the time, the distribution of the work and completion of outcomes that are vital to the success of the survey.

Survey funding

Funding typically comes from a government and from clothing companies – cash from government covers equipment and staff, and contributions from companies that may be made in cash or kind (shopping vouchers for participants, the donation of staff time, equipment and consumable materials such as underwear – Underwear may need to be provided that meets style and colour requirements for a scanner, commercial partners or those specified in ISO 20685). These items can be given a monetary value and offset against a notional purchase price for the data.

Legal considerations

Legal requirements will vary from nation to nation, but the following need to be considered.

- Collaboration agreements. These would normally be issued when governments fund a survey.
- Intellectual property rights (IPR). Legal rights of access to data and results can be protected and controlled through licensing.
- Ethical considerations. Approval for scanning or manual measurement should be sought with reference to relevant data protection legislation and processed by the lead organisation (e.g. Council of Europe, 1981). Ethics approval documentation can comprise a letter explaining the aims and nature of the project, formal participation and confidentiality agreements that enable the survey to collect anonymised personal data, scan and measurement data from subjects in each of the local data collection venues.
- Protection. The interests of children and vulnerable adults must be protected in the conduct of a sizing survey. (In Britain legislation is in place requiring those responsible for the conduct of a sizing survey to be certified as having been subject to a check against a record of those with relevant criminal convictions.)
- Confidentiality. All members of the data collection team would be required to complete an agreement to protect the confidentiality of subject data. Survey data need to be analysed, applied and stored so as to maintain the anonymity of the subjects who have been scanned and measured.
- Licence agreement. It may be that, following the sizing survey, data are to be made available to companies that did not participate in the initial arrangements; the sale of such data should be licensed on the basis that confidentiality will be maintained.

Press and publicity

As indicated earlier, a national sizing survey can generate considerable public interest, and publicity for participating organisations. It is important that the lead organisation manage interaction with the media by, for example, establishing a press office to prepare press packs and arrangements for the release of news and statements. Typically, press events are the means by which subjects are encouraged to participate in the study, both local and national launch events, and announcement of headline results.

6.4.2 Preparation

The key issues to be dealt with may include: the preparation of logistics software; a lifestyle questionnaire; an anthropometric measurement set; benchmarking and the purchase of equipment; statistics; a model for a data collection centre; a proofing study; and the selection of survey staff and their training.

Logistics software

A comprehensive set of software is needed for: subject registration; subject selection; the lifestyle questionnaire; uploading the body scan and other data collected and tracking statistics (see Fig. 6.2).

Subject registration

The aim of encouraging online registration is that subject details could all be processed so that a bar code could be issued and appointments for visits to venues agreed well in advance of the data collection programme (i.e. details needed for recruitment selection – age, gender, ethnicity, key measurements – height, weight, chest/bust, waist and hip; location and contact details). In addition, information related to the project (ethical papers, confidentiality agreement, a comprehensive description of 3D body scanning, data collection process and preparation for scanning) could all be accessed and, where necessary, processed prior to appointment.

Lifestyle questionnaire

Questionnaires would normally be designed and tested in conjunction with the marketing departments of the commercial partners. They would also tend to be gender specific (and, in the case of children's study, age specific). A questionnaire needs to include, for example, subject clothing, size and fit issues, shopping habits

6.2 Screen shot showing a recent example of a logistics software package. It shows a 'Home/Welcome' page. (Source: University College London.)

6.3 Screen shot of a recent lifestyle questionnaire incorporated into logistics software. (Source: University College London.)

(both in store and online) and personal details related to body measurements, health and income, etc. (see Fig. 6.3).

Anthropometric measurement set

The selection of measurements will depend on the objectives of the survey. If it is to be intergenerational (that is, all adults and/or all children) and it is also to include a full range of shapes and sizes and the majority of clothing product types then it will be necessary to identify the following: first, the body poses to be scanned (e.g. standing/seated); and then assess the basic measurements offered in ISO 8559 and ISO 7250 (note that there is an overlap of 14 measurements). Should they not be sufficient to meet the requirements of Inclusive Design and to develop the majority of clothing product types, then it would be necessary to create a survey-specific measurement set (with relevant body landmarks, body locations, images and an estimation of allowable errors) in preparation for an evaluation of available measurement extraction software offered during scanner benchmarking. Should there *not* be compatibility (between the survey-specific set and software offered) then it may be possible for a scanner manufacturer to extend their current measurement provision. For example, TC2 software and, when intergenerational adult studies (17–100 years) are undertaken, a means of addressing lifestyle morphological changes would be required (e.g. in spinal posture, see e.g. Ashdown *et al.*, 2008).

Equipment benchmarking and purchase

All subjects need to register with the survey and would ideally complete an online lifestyle questionnaire. However, in order not to exclude any potential volunteers, an additional set of PCs and paper copies of questionnaires would need to be made available at each data collection centre.

To maximise national benefit it may be necessary to supplement 3D body scanners with head or foot scanners and include a height gauge and a body composition monitor to record, automatically, subject height and weight. Depending on the objectives of the study and the 3D scanner selected it may also be necessary to include: traditional anthropometric equipment; under/scanwear; head covers; and materials for the hygienic maintenance of equipment, etc.

It is advisable to benchmark all equipment to be used during the survey. This includes scanners, height, weight and any other manual measuring equipment. Types of technology used to capture the 3D surface shape of the body include lasers, projected light and, latterly, millimetre radio waves. Each has its advantages (resolution, cost, automatic measurement extraction, etc.), but new, extended or enhanced systems are being offered on a regular basis (e.g. Kinect) and, although reviews of systems are published (e.g. Hometrica, 2012) and guidance is available in some ISO standards (e.g. ISO 20685) it is advisable for those planning surveys to conduct a benchmarking exercise; in particular, if it is planned to:

- scan subjects with differing heights, sizes, skin shades and ages;
- use a range of under/scanwear – this will depend on the objectives of the study, the requirements of commercial partners and of the selected scanner;
- scan subjects who may not be able to remain still for longer than 8–10 seconds;
- use survey-specific measurement sets that include dimensions that are not included in ISO standards.

(see Allen *et al.*, 2003, for an example of benchmarking).

A key issue raised by the need for benchmarking is an assessment of the accuracy of 3D scans and accuracy of measurement extraction. ISO 20685 gives guidance for reducing error in 3D scanning and for establishing accuracy of body dimensions by comparing hand measurements with those extracted from scanners and, although such comparisons are still the subject of debate, it is acknowledged that some scanners have now reached a stage of development where they can automatically measure subjects with a higher accuracy and consistency than trained hand measurers. Notwithstanding these advances and debates what is perhaps as important is the need to agree definitions and measurement positions as can be seen in the some recent work, where the waist definitions of ISO 8559 (2.1.11) are compared with those of a preferred waist taken during the CAESAR study (Veitch, 2012).

Statistics

The determination of a statistical sample of earlier clothing-specific surveys (e.g. SizeUK) was based on the pioneering work of US military studies (Gordon *et al.*, 1989) and, as can be seen in Table 6.3, it comprised three geographical regions and seven age bands.

However, an ISO standard (15535) was introduced in 2006, which sets out options for desired levels of relative accuracy and confidence – for stature, chest circumference and shoulder breadth – with proposed numbers of subjects for the achievement of each level. How those numbers are distributed will depend on the number of regions selected. Account needs to be taken of the homogeneity of the population (e.g. age distribution, ethnicity and socio-economic status); a country, for example, that has a homogeneous population might be treated as a single region. A further difference in the ISO standard is the age bands. For example, in the case of the SizeUK survey, the lower adult age band was determined by the (then) UK school leaving age of 16 years, as those subjects could be included in a socio-economic category. The new standard suggests that adult population data should be collected from those aged over 20 years, and that young adults should be considered as single year bands. No upper age limit is proposed (and, as can be seen in recent studies, there is a wide range of upper ages of recent studies – Tables 6.1 and 6.2) but, with an ageing global population and the fastest growing group being those 80 years and above, future anthropometric studies for clothing will need to address these intergenerational clothing requirements. Studies will need to include data for fit and healthy centenarians if they are to meet an Inclusive Design strategy for RTW clothing (i.e. to provide a choice of garment shape, size and fit for all members of a population).

There are several options for subject recruitment but, if software is designed to constantly monitor registration, subjects can be selected in two stages: first, to meet the recruitment strategy (gender, age and geodemographics) and, second, to ensure other national statistics (ethnicity and socio-economic grouping) before being invited to a centre to be scanned.

Table 6.3 The recruitment of subjects participating in the SizeUK survey figures for seven age bands recruited to each of three regional centres

	Age group (years)							
	16–25	26–35	36–45	46–55	56–65	66–75	76+	Sum
Region 1	188	188	188	188	188	188	188	1316
Region 2	188	188	188	188	188	188	188	1316
Region 3	188	188	188	188	188	188	188	1316
Totals	564	564	564	564	564	564	564	3948

Source: Allen *et al.*, 2003.

Model data collection centre

A model centre for the collection of data, setting out the orientation of equipment for easy team measurement operations and subject processing needs to be arranged and tested, prior to training. A data collection centre, whether a static of a mobile unit, is likely to comprise:

- a reception desk with a PC;
- additional registration facilities;
- an auto height gauge;
- an auto weight scale (e.g. a body composition monitor);
- a set of traditional anthropometric tools;
- a foot and/or head scanner;
- a whole body scanner, with dedicated PC and integral changing space;
- storage facilities (e.g. under/scanwear, cleaning equipment and materials).

Proofing survey

Crucial to the efficient operation of a survey and to its overall cost is the number of subjects that can be processed per day by a given collection centre. Issues that could arise so as to affect the operation of a collection centre might include the selected equipment, the data collection team, subject ages, the location of the data collection centre and the recruitment of a steady stream of subjects for measurement. To test the process, the layout and efficiency of the equipment and to provide an estimate of the daily subject throughput it is important to conduct a proofing survey of at least 40 subjects – recruited according to the objectives of the study and in the proportions indicated in the national census for gender, age and ethnicity.

Selection of data collection team and training

If a survey is *not* to be conducted using a mobile unit (Fig. 6.4) then the identification and inspection of all venues in selected cities would need to be completed prior to selection and training of a team or teams. Collection of data may be either one team of experts that travels to each venue, or several individual teams recruited and trained for each venue (e.g. university venue and team); if the latter, then the selection of the training team and the method of training would be influenced by the selected scanner. If the system is to include manual landmarking then guidance can be found in e.g. the publication of International Standards for Anthropometric Assessment (Marfell-Jones, 2006), the International Society for the Advancement of Kinanthropometry – ISAK (Stewart *et al.*, 2011) and ISO standards 7250 and 15535; if the survey is to be designed for its data to be internationally compatible, a further standard such as ISO 20685 is useful. For systems with automatic measurement extraction and surveys requiring

6.4 Mobile scanning unit: University College London and Sizemic Ltd.

supplementary manual measurements (e.g. height), methods can be found in ISAK. Whichever system, it would be necessary to assemble an appropriate training team, training manual and associated set of materials.

A team of trainers could comprise a computer scientist responsible for logistics software, trained anthropometrists and scanner operatives. Male and female models that represent the proposed population could be recruited to act as subjects, though it is advisable for all team members to experience the subject measuring sequence.

Proposed training materials could include information related to:

- data collection centre: health and safety issues for subjects and team;
- subject: registration, questionnaire and measurement briefing papers, preparation for scanning procedures, processing sequence;
- physical training: team presentations; instructions for logistics software and manual measurement; equipment and scanning systems procedures; videos of subject processing; care and maintenance.

The number of teams and selected scanner would determine the number of days required for training, although the aim would be to ensure that all team members would be multi-skilled and hence able to:

- prepare, maintain and de-rig a venue;
- welcome, brief and guide subjects through each stage of a measuring process;
- ensure subjects prepared for measuring process;

- use and maintain all measuring equipment;
- evaluate the capture and accuracy of all manual measurements (i.e. intra and inter-validation, where necessary);
- assess accuracy of 3D scan images and the extracted measurements;
- record and store data in accordance with chosen system.

6.4.3 Implementation

Effective recruitment, scheduling, processing and tracking of subjects is vital to the success of the data collection process; as is the need to ensure the quality of the shape and size data prior to its automatic uploading to a logistics software system.

Recruitment

Having determined some of the key issues in the preparations made for the conduct of a size and shape survey, the success of data collection will depend on having recruited sufficient subjects at each venue. Given public interest in clothes sizing, a national survey receives massive amounts of free publicity with a consequent surge in the number of volunteers coming forward to be measured. For example, with SizeUK, 17 000 individuals registered interest through a dedicated website, 11 000 returned registration information and a questionnaire through retail outlets and, in response to mail shots, 20 000 people telephoned the helpline established for the purpose. However, with subject registration being processed through a central system, daily lists of subjects for each centre can be generated well in advance of data collection scheduling.

Schedules

The most straightforward, but time consuming method of collecting data is to have one team to visit all centres, as this only involves recruiting one set of subjects at a time and the organisation required to set up and take down one set of equipment. If, however, there are to be multiple data collection teams then a more complex scheduling is required to ensure the transport and installation of equipment and the availability of technical support. For example, SizeUK used eight centres, three scanners and three sets of equipment, plus one expert support team to complete data collection within a six-month time and funding frame.

Processing subjects

Prior to the arrival of the subjects to be measured the data collection team (with assistance from the support team) need to set up the data collection centre, calibrate and test all equipment, organise ancillary materials (such as under/

scanwear) and set up appropriate internal and external signage (e.g. guidance for those arriving, visuals of the scanning process, postures, health and safety guidance and help in navigating within the centre). On arrival at the centre a subject would be welcomed and the team would confirm registration and the completion of a confidentiality agreement before giving an explanation of the measuring sequence and the required process needed for each individual item of equipment. All procedures for the maintenance of hygiene and safety need to be observed throughout preparation, scanning and following data collection.

Data quality

If the planning and preparation for a survey is carefully considered (e.g. a benchmarking exercise has been undertaken) then in-process validation of scans, landmarking and measurements, whether manual or automatically extracted, should be easily assimilated into the subject processing sequence. However, the data quality maintenance procedures followed would depend on the selected measurement process and the scanners being used. For example, validation could include:

- intra and inter evaluation of manually-placed landmarking and measuring;
- checks to define or modify preset landmarks and measurements (Preiss and Botzenhardt, 2012);
- the visual appraisal of all scans and automatically extracted measurements so that (where, for example, a subject has moved or has assumed an incorrect posture) a repeat scan can be made.

Data tracking

At the end of the measuring process a team member would need to verify completion using a subject barcode and, if necessary, complete the process with the issue of a shopping voucher. At the end of each session the team would:

- ensure that data has been successfully transferred to the logistics system;
- clean and close down all equipment in preparation for the next session;
- help the support team at the end of data collection exercise to de-rig the centre and secure equipment and materials for transportation.

6.4.4 Data storage and access

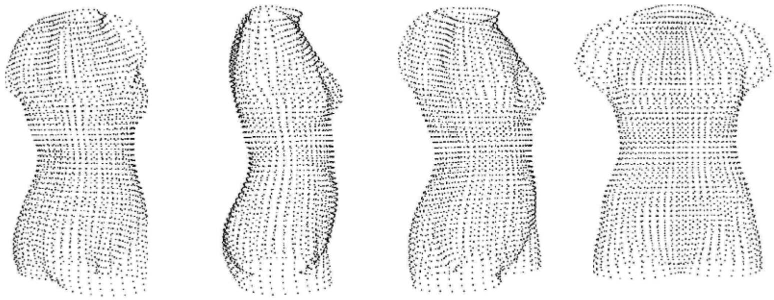
A database can be organised for national, regional and international use, comprise a wealth of data and be accessed for analysis through a variety of routes. A format and set of contents for organising a database is proposed in ISO 15535 and, although the recommended measurement set would need to be reviewed (see section 6.4, above) and legal agreements may prevent data being available in the public domain, the standard can serve as a useful guide.

National database

A lot of data are likely to be collected during a clothing-specific study using 3D technologies. For example, each subject's set of anonymised data could comprise: personal data (excluding name and home address); one or more 3D scans; and as many as 250 extracted and derived measurements. There may also be manual measurements and, if used, information from a body composition monitor as well as data from a clothing market research lifestyle questionnaire. Each subject's data could occupy 15–20 MB of storage. To protect raw and analysed data, results need to be held in a secure server and, if appropriate, for the study to be accessed via software tools. A suite of online tools, such as those developed by SizeUK, can run on a database server and be used to check data integrity, extract and analyse 3D body size and shape and associated marketing data, and compile body size measurement charts for selected markets. (See Figs 6.5 and 6.6.)

Raw data are difficult to protect and, if commercially sensitive, would not normally be released. Both SizeUK and SizeUSA chose only to release

6.5 Screen shot captured in 2002 by the SizeUK team, showing web-based software tools for 3D data analysis. The online software allows the user to view (images, left to right) 3D shape analysis, seated 2D cross section, the front silhouette and side profile; and in the panel of figures below (not legible as recorded more than a decade ago) are sets of automatically generated one, and two, dimensional measurements.



6.6 Four views of an average female torso computed from subjects in the preliminary SizeUK survey. The torso is rotated about a vertical axis between views (Tahan *et al.*, 2003).

analysed data. Options for commercial partners to access data could include the use of:

- real time, online software tools;
- online national analysed data; and
- a bespoke service.

Experience has shown, however, that most clothing companies prefer ready-to-use data, such as body size charts or (physical) fit mannequins. Central to the organisation of clothing-specific surveys (such as SizeUK and SizeUSA) is the sale of the data to clothing companies that did not participate as partners in the national studies. This can be done to offset the cost of a survey or to meet any cost overruns. It is therefore particularly important to protect data from illicit copying.

Regional and international databases

Organisations that assemble regional and international databases include the following:

- *Eurofit* – a European research project designed to implement an online, *3D shape data platform*. It will enable designers and industrialists to draw useful shape information, owners to pool data and receive revenue, and IT companies to develop new services (Eurofit, 2012).
- *iSize* – developed by Human Solutions together with the Institut Français du Textile et de l'Habillement (IFTH) and the Hohenstein Institute. An international *body dimension portal* that draws on data collected (both manually and digitally) from more than 100 000 men, women and children aged from 6 to 75 years, with 44 body dimensions taken from ISO 8559 and ISO 7250. The portal enables country, age, gender selections and analysis of body dimensions according to target groups. Size tables, grading steps can be examined and SizeGermany Scantars are available to download and transfer

to CAD software systems such as Assyst. Over 120 companies are now accessing measurement data for global applications (iSize, 2012).

- *World Engineering Anthropometry Resource* (WEAR), an international membership organisation set up by a group of experts in engineering anthropology. It offers a database site that comprises data from over 100 surveys. Access is limited to *members who share data or tools*. The group maintains quality control of the WEAR anthropometric databases accessed through that site. WEAR proposes checklists for validity (sampling, subject population, secular change), comparability (definition of measurements) and accuracy (before, during and after measurement capture) and suggests ways in which these may be effected (Kouchi *et al.*, 2009). There is an Anthropometric Measurement Interface (AMI) with a web-based software tool to facilitate collaboration and data sharing between anthropometric researchers across the globe. It enables users to plan, compare and search for measurements taken by others (WEAR, 2012).

6.5 Reflection

Many anticipated problems fail to appear while others, not envisaged, emerge. Of the surveys completed during the previous decade few organisations have published reflections on their studies. Some comments set out below cover information drawn from reports of two studies: CAESAR and SizeUK.

6.5.1 The CAESAR study

Concerning CAESAR (summary details in Table 6.2) active participants reflected on the study and flagged four recommendations.

- *User support*. It is vital to get a plenty of feedback from prospective users of the data, from the conceptual stage of a study right through to the delivery of results.
- *Equipment*. The team should test all equipment before initiating data collection, even where a new item appears to be very similar to one used previously.
- *Recruitment*. It is a good idea to use more than one means to recruit subjects. For example, invitations and advertisements may need to be translated into many languages. Allied to this is the need to consult on the recruitment strategy with representatives of the different segments of a sampling strategy.
- *Planning*. Be flexible and have a backup plan for every stage and aspect of the study that might go wrong.

(Robinette *et al.*, 2003)

6.5.2 SizeUK

The experience of the authors outlined above leads them to concur with some of the conclusions drawn from the CAESAR study. In addition, the following observations are offered.

- *Press and publicity.* It is important in creating momentum for a survey that major public interest is generated. All journalists are given equal opportunity and access as, if some parts of the press are favoured, then others may decline to give coverage or, in extreme cases, may disparage a project.
- *Funding.* Most surveys use a mix of government cash and, from industry, a mix of cash and 'in kind' support. It is important to underline the need for prior agreement among partners on what is meant by 'in kind' contributions (e.g. personnel costs) and (if offered) to allow for the different levels of popularity between shopping vouchers.
- *Equipment.* All potential hardware and software needs to be thoroughly benchmarked. Unsurprisingly, given the prominence of a national sizing survey, an organiser is likely to come under considerable pressure to use equipment that may not be the best for conducting a survey, or may be persuaded to purchase equipment before the requirements are fully understood. This could distort the survey process and add to overall costs.
- *Data collection.* As suggested earlier, it is extremely useful to allocate a unique barcode to each subject on registration for a survey. This will help to ensure that discrete sets of subject data can be tracked and assembled in the database. Further, although a seated scan was captured, there were no resources available to develop the software for automatically extracting measurements. (That capability is now available, but it has been designed for military use rather than for clothing-specific applications.)
- *Data analysis.* SizeUK undertook extensive basic data analysis on behalf of the industrial partners and, while this produced a mass of statistical data in formats requested, partners really required RTW body size charts.
- *Data sales.* Most national surveys have typically sold their data, but each has addressed data exploitation differently. For example, SizeUK estimated the value of the data and, depending on the turnover of a client, contributed £40 000, £60 000 or £80 000. This rather complicated the sale of data at a price smaller clients could afford, particularly in the case of negotiations with very small clothing retailers and with individual fashion designers. (Bougourd *et al.*, 2010)

6.6 Future trends

There has been a particular focus on the generation of one-dimensional data from 3D anthropometric surveys. Three dimensional static data can do much more: it can, as seen in section 6.3.3, above, dramatically improve the process of design and development across the supply chain, enhancing the shape, size and fit of clothing. However, despite the strides that have been made, it has been suggested that 'a perfect suit is more than static data' (Meixner and Krzywinski, 2011).

Interest is growing in creating and capturing dynamic scan data. That is, data from a subject whose movements range between mild and extreme activities, such as walking and skiing. Initial developments using captured scan variations and shape analysis tools led to animated body scans (e.g. Ruto, 2009). More recently, an anatomically correct scan has been created with movements relevant to high-performance sport (e.g. cycling), where different poses can be used to construct 2D patterns from 3D scans for close-fitting garments (Meixner and Krzywinski, 2011).

The impact of these developments on size and shape surveys is not yet known but, with four-dimensional, real-time scanning technologies becoming available, it may be that survey databases will be compiled not only with a range of dynamic poses but also with dynamic sequences, leading the way to an increase in a more sustainable future with strategies for inclusive clothing design.

6.7 Sources of further information and advice

The 3D scanning conference series and associated publications of Hometrica. Contact Dr. Nicola D'Apuzzo, Hometrica Consulting, Lugano, Switzerland.

The International Standards Organisation publishes standards relevant to traditional and digital anthropometrics, and for clothing developments.

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7
The development of apparel sizing systems from anthropometric data

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Abstract: The development of a sizing system originates from an anthropometric study or survey. The data is analyzed statistically to obtain the standard body measurements (SBM) size charts of the population. The SBM size charts in turn will have the required ease allowances added to obtain the required garment size charts for individual size charts by designers and manufacturers. Fit testing is required to ensure that the final size charts are appropriate for fitting to the targeted market.

Key words: anthropometric study, sizing system development, size charts, fit test.

7.1 Introduction

Since the age of industrialization there has been a need for a consistent and uniform system of sizing clothing. For a system to be acceptable and satisfactory, it must be based on an understanding of the variations in body dimensions of the population to be clothed and fitted. Any system of body sizing requires data to start with. It is important to start with accurate body dimensions taken from a scientific anthropometric study or survey. Many years ago, such studies or surveys would have taken many resources in terms of manpower, time and effort. This is the reason why such studies have been lacking in the civilian population, but were more easily undertaken amongst military personnel. However, in the last decade or so, with the advent of new technology such as the automatic body scanner, and the participation of institutions like universities, commercial corporations and consumer movements, more up-to-date studies have been made in many countries.

Each and every country has its individual population and the various attributes associated with it. Therefore, an aim of the anthropometric study is to get the actual dimensions of the population. In order to obtain true data without going to the lengths of measuring each and every one in the population, it is important to select a sample size that is reflective of the various attributes of the population. Using a stratified sampling method, one can come up with a sample size that as far as possible represents the various attributes of that population. The attributes that influence the selection of the sample are gender, ethnic group, age group, occupation, geographical location and other social-demographic requirements. Many of these attributes can be obtained from the national census office and the information will then form the starting point in selecting the sample size. In practice, anthropometric study can vary in terms of age groups or gender depending on the requester and its intention, e.g. a retailer of infant and children clothing will focus on children in the age group between 0 and 12 years or a national brand specializing in female office clothing will focus on women in the age group between 18 and 40 years. It is imperative that the various attributes mentioned be selected for the results to be representative.

7.2 Importance of anthropometric data for the development of a sizing system

It can be said, '*Without true data, nothing can be done*'. Anthropometric data are most important to many industries, be they furniture makers, car producers, handicapped facilities, workplaces, etc. With the availability of the anthropometric data, many of today's consumer items including clothing can be produced more accurately and cost-effectively. To produce high quality clothing, the most important question in merchandising would be 'What sizes do I make to cater for the target population most accurately, without wastages?' The anthropometric data will generate meaningful size distribution which in turn will provide accurate pattern cutting and satisfactory fit for the consumers.

Anthropometric data is a mass of collected information, and for it to be useful it has to be sorted out and treated in a manner relevant to the sizing of clothing so as to cover a large proportion of the targeted population. In order for the size range in the system to be effective, it has to be statistically angled towards the intended users and the kind of clothing concerned. The average of the data is generally not adequate as it can be affected by extreme values and any garment designed for the average will not fit the varied range of people. While grading to smaller and larger sizes will create a sort of size roll, nevertheless, garment fit cannot be guaranteed. Hence, it is essential to decide on the range of body sizes to be covered by a size roll and this is best done statistically. Percentile values of body measurements are often more useful in practice that the averages alone, since they indicate the range of a dimension in the population and can be used to estimate the coverage of the population achieved by a particular size roll.

In general there are basically three approaches towards the development of sizing systems of ready-to-wear clothing, namely: an indirect approach, a direct approach and a direct-indirect approach. The first uses two measurements, e.g. height and weight as controls and these measurements are not directly related to the fit of the garment. Generally, the two measurements are reasonably well correlated with most other dimensions of the body whose values are calculated from the controls by the use of regression equations. In this approach, normally height and weight are the measures used to assign the person to his size group. In the second, dimensions which are variable where a good fit of the garment is depended on are chosen as controls. Here, two or three controls are enough for most clothing. However, when fit is of major concern, more control measurements are required.

Where the fit of the garment is the main concern, appropriate tolerances are added and used to divide the population into size groups. Other dimensions used to define the size and shape of the body can be obtained by calculation from regression equations. The two approaches basically differ in the choice of the control measurements. The indirect approach uses control measurements at which no garment fits. The degree of fit of any dimension is correlated with the control measurements. On the other hand, the direct approach uses as controls the dimensions of the body where fit is critical and important, and the garment must fit at these places. The third approach is a hybrid called the direct-indirect approach and has been used in some sizing systems where one of the controls is an indirect dimension, e.g. height and another control is a direct measurement, e.g. chest girth.

From the above, it can be seen that the approaches to the development of final size charts are varied, depending on the requirement of the market. Loose garments where fit is generally not important can use the indirect approach, e.g. casual overalls, but as a closer fit is demanded in our garments, then the vital body measurements become critical. Because of this importance of anthropometrics in the sizing of clothing, a scientific anthropometric study is the starting point in the developing of a suitable sizing system for the benefit of the consuming public and the apparel industry overall.

7.3 Statistics used in sizing system development

In this chapter, the figures used are quoted from an anthropometric study on Hong Kong adult men.[1] Based on the raw anthropometric data collected, the stage of analysis is an important integral part of the study so the masses of data obtained can be processed into meaningful information for the users. Such statistical analysis can be processed by various commercial statistical packages such as SPSS and the like. The results of the analysis will fall under: (a) the distribution of the sample measured in terms of their attributes as described earlier; (b) summarizing statistics such as mean, median, mode, skewness, kurtosis, variance, standard error, range, standard deviation of each measurement; (c) correlation and bivariate plots between two measurements; and (d) multiple regression analysis. The first two will provide understanding of the individual measurements, while the latter two would be important to understand the behavior of various measurements when pitted against each other.

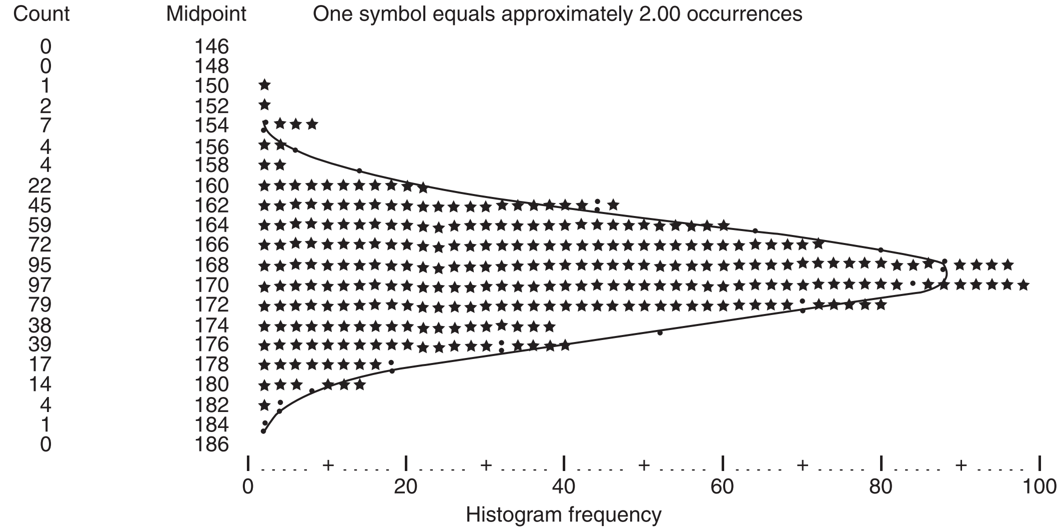
It is the general understanding that ready-to-wear clothing, unlike bespoke tailoring, cannot fit perfectly each and every individual in a population, hence it has to be produced in different sizes to cater for the majority. The correct determination of these sizes is important as individuals cannot easily be categorized into any definite groups in view of the considerable variations that are observed. This leads to the problem of how to divide the population in question into a number of sizes, each constituting a separate body size. In Britain, Kemsley[2] in a study of women's measurement and sizes, stated that:

> . . . since individuals do not fall separately into separate sizes . . . there is no alternative but to construct the sizes artificially, by allocating each individual to a body size according to each size group and when all individuals have been classified into their right size, the description of each group can be completed by averaging the values of each measurement for all individuals in that size.

Because of the numerous ways in which individuals can be grouped, it is vital that in choosing the grouping, the method used should be sufficiently convenient to derive and use. Of the measurements made, not all will be of equal importance in describing the body and it is necessary to find those among the many measurements taken that can be used as *key measurements*. Such key measurements should best describe the individual ratings taken as a whole and should be highly correlated with other measurements, hence allowing any others to be accurately predicted from the key measurements.

Another consideration is the presence of measurements that would distort the resulting averages, thus affecting the relationships between the averages for the various sizes in the sizing system. In order to overcome this unusual facet of variability of average values, the relationship between the key measurements and each other measurement is expressed in term of regression coefficients. These statistical measures can record how much a particular measurement increases or decreases with a unit change in the value of each key measurement. In so doing, it also smoothes out random fluctuations caused by sampling variation and provides a convenient means to summarize the relationships between measurements.

Nothing comes in so varied a form as the human body. To illustrate the development of a sizing system, a body survey for Hong Kong men is referred to. In Table 7.1, the frequency distribution of some of the measurements taken shows the number of subjects in the sample with the corresponding measurements. In all the measurements the frequency distribution, more or less, has a similar pattern in that a lesser number of subjects are at the lower and higher ends of the distribution, while the bulk are in the middle between the low and high values. Figure 7.1 shows an example of the histogram distribution of the measurements for the samples of Table 7.1. In virtually all cases of measurements, they approximate the dumb-bell shape of the normal distribution curve. For each measurement, descriptive statistics such as mean, standard deviation, skewness, kurtosis, range and percentile values are defined and computed. This enables one to understand the behavior of each measurement. Next, bivariate distribution was performed to understand if different sets of measurements have any relationship between them. Figure 7.2 shows the bivariate plots between two measurements. From these



Mean	168.382	STD ERR	0.219	Median	168.500
Mode	170.000	STD DEV	5.366	Variance	28.792
Kurtoses	0.363	S E kurt	0.199	Skewness	–0.155
S E skew	0.100	Range	33.000	Minimum	150.000
Maximum	183.000	Sum	101028.900		

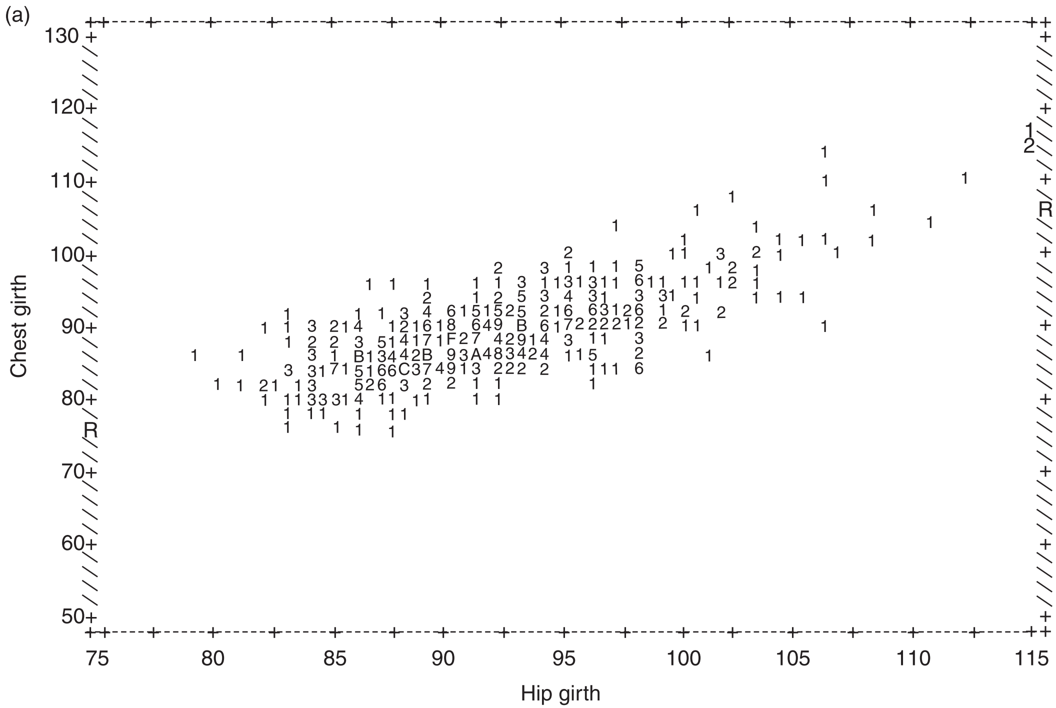
Valid cases	600	Missing cases	0

7.1 Histogram of measurement (stature).

Table 7.1 Frequency distribution of some measurements of a sample of Hong Kong men

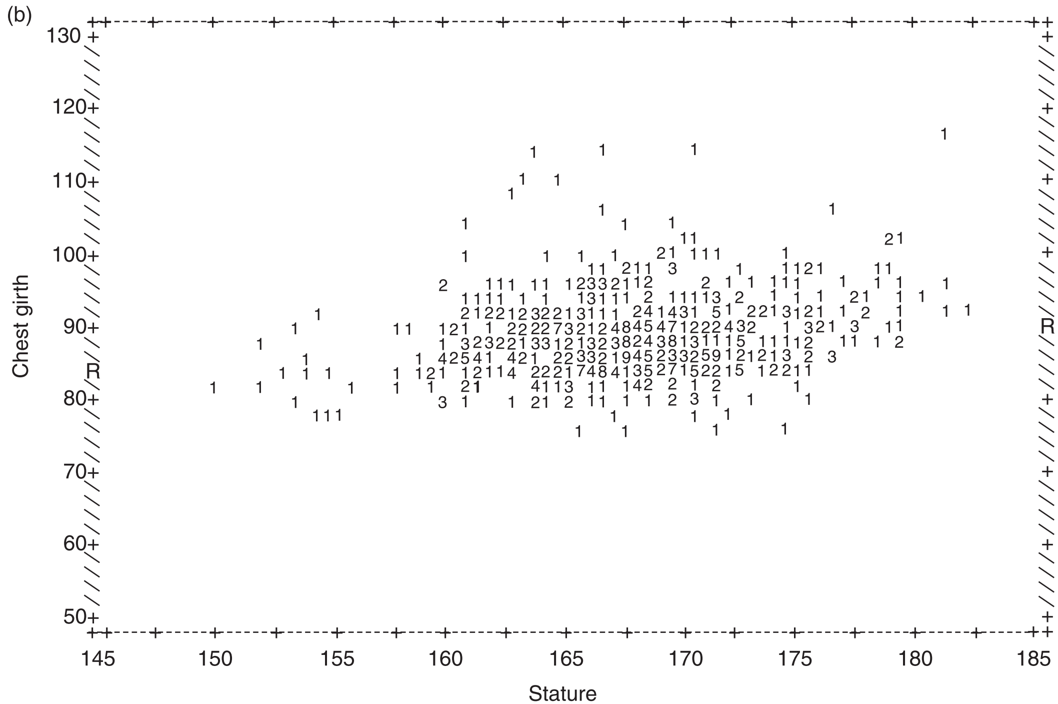
Stature		Cervical height		Chest girth		Waist girth		Hip girth	
cm	No.	cm	No.	cm	No.	cm	No.	cm	No.
150	1	127	1	75	1	63	3	79	1
151		128	2	76	2	64	3	80	1
152	2	129	2	77	3	65	3	81	2
153	1	130	4	78	4	66	8	82	4
154	4	131	2	79	6	67	6	83	10
155	4	132	8	80	14	68	12	84	20
156	2	133	7	81	11	69	22	85	22
157		134	10	82	21	70	40	86	37
158	3	135	13	83	37	71	26	87	27
159	3	136	25	84	48	72	25	88	45
160	15	137	29	85	56	73	43	89	49
161	22	138	44	86	44	74	44	90	55
162	21	139	43	87	38	75	50	91	42
163	23	140	31	88	44	76	55	92	44
164	29	141	38	89	45	77	31	93	49
165	29	142	33	90	41	78	52	94	27
166	37	143	42	91	36	79	26	95	30
167	43	144	49	92	34	80	21	96	27
168	49	145	35	93	16	81	14	97	16
169	56	146	35	94	19	82	21	98	36
170	54	147	30	95	20	83	11	99	8
171	35	148	30	96	11	84	11	100	9
172	41	149	29	97	13	85	7	101	5
173	33	150	19	98	7	86	14	102	11
174	11	151	14	99	10	87	10	103	6
175	21	152	8	100	2	88	9	104	3
176	21	153	9	101	3	89	5	105	2
177	9	154	4	102	2	90	4	106	6
178	9	155	3	103	1	91	4	107	1
179	6	156	1	104	2	92	2	108	2
180	11			105	2	93	2	111	2
181	1			107	1	94	1	112	1
182	3			109	2	95	5	116	3
183	1			114	3	96	2		
				116	1	97	2		
						98	1		
						99	1		
						103	1		
						104	1		
						110	1		
						112	1		

plots, it can be seen they fall into two categories. In one of these, as one measurement increases, the other measurement also tends to increase, e.g. men with big chest girth tend to have a big hip girth and conversely so. In the other category, as one measurement increases, the other measurement may not increase.



600 Cases plotted. Regression statistics of chest girth on hip girth:
Correlation 0.73461 R Squared 0.53965 S.E. of ESI 3.88448 2-Tailed SIG. 0.0000
Intercept (S.E.) 18.03648 (2.66255) Slope (S.E.) 0.75707 (0.02897)

7.2 (a) Example of bivariate plots between two measurements (chest girth and hip girth). (*Continued*)



600 Cases plotted. Regression statistics of chest girth on stature:
Correlation 0.20715 R squared 0.04291 S.E. of EST 5.60098 2-tailed SIG. 0.0000
Intercept (S.E.) 51.22132 (7.18509) Slope (S.E.) 0.22034 (0.04265)

7.2 Continued. (b) Example of bivariate plots between two measurements (chest girth and stature).

They do not relate as well as in the example of chest and hip girths. Men with short stature can have the same average chest girths as taller men, or small chested men can have nearly the same stature as big chested men.

A numerical measure of the degree of relationship between two measurements is the Pearson Product Moment Correlation or simple correlation coefficient. The strength of relationship indicates the goodness of fit of a linear regression to the data, and when '*r*' is squared, the proportion of variance in one measurement that is explained by the other. A value approaching +1 will indicate a high degree of relationship or large correlation between two measurements; an example in the men's study is weight and hip girth with a correlation coefficient of 0.8364. Conversely, a low value near zero will indicate little or no relationship between the two measurements; an example is stature and waist girth with a correlation coefficient of 0.0514. While these two examples show two extremes of positive correlation between 0 and +1, it is possible for the relationship between two measurements to be negative, so that as one increases, the other decreases; however there are comparatively few cases in practice. In general, stature and the vertical measurements are well correlated. This is also true for weight and the girth measurements. However, stature and the vertical measurements are not well correlated with weight and the girth measurements. By themselves, stature and weight stand out to explain a large part of the relationship between themselves and their related measurements.

7.4 Key or control measurements

In an anthropometric study, there are many measurements obtained to be considered, and it is not possible to use any one particular measurement to predict all others. Because of the nature of the measurements, it is necessary to choose one measurement from the length measurements and another from the girth measurements, so that each can represent their group. Stature, having a good relationship with the length measurements, is an obvious choice for the length measurements and similarly, weight for the girth measurements. To confirm their status, Table 7.2 of the same men's study shows the multiple correlation coefficients between stature, weight and a selection of other measurements. The results of multiple correlation coefficients vary between 0 and +1 and it measures the relationship between one measurement and a group of other measurements. From the table, the stature and weight combination gives the best results, though chest and waist girths are only slightly worse. The stature/chest girth and stature/hip girth give values rather close to stature/weight and are possible alternatives to the stature/weight combination. Natural Waist was also used in place of stature, but the results were far less good than when the former was used, showing that it is not a suitable substitute for stature as a key measurement.

Another point to consider in the selection of key measurements is the practicality of obtaining these measurements on the person in the shop so that the person can

Table 7.2 Multiple correlation coefficients between each measurement (selected) of the sample (decimal omitted)

	Stature			Natural waist		
	and weight	and chest girth	and waist girth	and hip girth	and chest and hip girths	and weight
Cervical height	9177	9079	9123	9167	9170	4963
Chest height	8546	8427	8417	8519	8548	4394
Waist height	8711	8693	8690	8702	8702	3626
Hip height	8130	7900	7867	7986	7994	4113
Body rise	6094	5922	5873	5933	5941	3619
Cross back	4285	3559	3548	3800	3817	2764
Cross front	4185	3362	3400	3683	3720	2756
Neck girth	3953	2219	1782	3079	3094	2510
Chest girth	4088		2605	3089		2288
Waist girth	5337	2605		3979	4105	2406
Hip girth	3925	3089	3979			2434
Nat. waist	6032	5518	5360	5670	5670	
Outside leg	7639	7570	7480	7568	7583	3117

be assigned to the correct size category. For stature, there seems to be no suitable alternative to this and natural waist is found to be a 'non-starter'. Other vertical measurements were not as good, though cervical height could be used, but it is a difficult choice for a normal consumer to understand the measure as compared to stature which can be measured more easily. Because of these considerations, stature is used as a key measurement index for vertical measurements.

For girth control measurement, weight, based on the correlation coefficients, is the most efficient; however, it is a disadvantage that practical use of weight is hampered by the general lack of its use in stores or homes. The next alternative choice of either chest or hip girths may not be satisfactory though they correlate well with other girth measurements, due to the exclusion of the other, thus affecting the balance between the upper and lower portion of the body. By using chest and hip girths as key measurements, the balance is restored. In practice, these two measurements are commonly used and give more flexibility as compared to weight. Waist girth also is a good alternative to weight as seen from the table; however, chest and hip girths combine well as evidenced by their higher correlations. Moreover, waist as compared to chest and hip is more variable and the latter two will provide better contrast between the top and bottom portions of the body. From the reasoning above, the key or control measurements chosen are stature, to be used as the key vertical index, and chest and hip girths as key girth measurement indices.

7.5 Establishment of a sizing system

Following from the above, the next step is the determination of the best set of body measurements on which to base a 'standard' sizing system. Data obtained from the analysis is applied to determine what constitutes the standard and the necessary range of body measurements to optimally fit the population. 'Standard' as used in this context does not imply rigidity in the development of the sizing system, rather the standard set of body measurements for the purpose of sizing ready-to-wear clothing must be flexible. This flexibility includes, on the one hand, the largest possible range of sizes so that even specialty producers can refer to them usefully and, on the other, by taking away the less popular sizes, mass producers can reduce the number of sizes to the minimum to cater for their market. It is with this objective in mind that the sizing system is established.

In the development of the sizing system, certain considerations must be taken into account; for example, the measurements needed to define the size and shape of the body for garment fit must be listed. The tolerance required for wearability, beyond which fit becomes unsatisfactory, must be applied to these measurements. The magnitude of the tolerance to be used for each measurement determines the goodness of fit and automatically determines the minimum number of size groups needed to fit the population. An efficient sizing system will need no more size groups than an inefficient one with overlapping size groupings. Before the development of the size system, it is useful to discuss the procedures followed in developing size systems by the direct and indirect methods. While the procedures followed are similar, a basic difference is that, in the former, measurements of the body, e.g. chest and hip girths, which are important to the fit of the garments, are chosen as key or control variables; while in the latter, measurements such as stature and weight, which are not used to fit any garment, are chosen as controls, and thus the assignment of the size of the garment to a person is dependent on these controls which in turn determine the size group the person belongs to. When a size system is based on indirect controls, body measurements which are essential to the fit of clothing become dependent measurements. In such cases, mean values are calculated from a regression equation and the standard error of estimate is computed to indicate the variation about the calculated mean. Generally, the design range of each dependent measurement is within the mean ±1.5 standard deviation, covering about 86% of the population in the size group. The simplicity of this method lies in the fact that the control measurements are quite easily obtained and are usually well known by customers, and the measurements are chosen to correlate well with the other measurements. Experience, however, shows that the method works only if the demand of fit is not critical, e.g. in baby clothing, overalls, etc.

Staples and DeLury[3] (pp. 346–354) highlighted the inadequacy of the indirect method using the choice of height and weight as control dimensions from the fact that, whilst stature is composed chiefly of two dimensions, trunk length and leg length, these two dimensions vary independently of each other and they cannot be controlled by controlling their sum. In the direct method, the key measurements of the body where accurate fit is desired are used as control measurements; all the other measurements become dependent measurements. Here, the control measurements are chosen to minimize the variability of the dependent measurements as well as, or better than, the use of indirect controls.

Perfect fit in respect to each control is ensured within the limits provided by the tolerances chosen for these measurements. However, where fit of a garment is critical at several measurements of the body, this procedure may lead to a large number of control variables being needed, with consequent multiplicity of size groups, and this may not be practical. In such cases, one has to make the choice either to sacrifice the degree of fit which the system provides, or to reduce the number of size groups, thus restricting the proportion of the population that can be fitted. In many ready-to-wear garments, exactness of fit is not too important at more than two dimensions of the body, and the use of direct controls usually results in a system that is practical; hence a satisfactory system for garments that are designed to fit the upper half of the body, or even the whole body, can be based on two controls such as chest girth and hip girth and, where length is important, natural waist length may be used as a third control measurement. Likewise, for below-the-waist garments, the controls can be waist girth, hip girth and crotch height which would provide an efficient size system.

7.6 Standard size system of body measurements

In a study of size systems, conflicting conclusions can be drawn, not because of differing human proportions between different countries or races, but rather by the disagreement among clothing technologists about their requirements. However, all body measurement surveys agree on the general principle that a sizing system, in order to meet the requirements of the population, – must be structurally three dimensional in nature. The choice of the key measurements – namely, stature, chest girth and hip girth – satisfies this requirement.

A primary question that arises in the design of a size system is how many sizes the system should accommodate. Roebuck *et al.*[4] noted that:

> . . .a major difference in approach involves the concept of sizes which instead of the ‘vehicle’ with sufficient adjustments to accommodate a high percentage of the population, it is necessary to provide a set of differing sizes, each having a more limited set of adjustments, but each designed to accommodate a much smaller percentage of the basic population. The selection of the number of sizes is a major focus of attention to balance functional requirements with the economies of developing patterns and of stocking in stores and supply depots.

While every population differs in respect of the state of development of its economy and its clothing industry, flexibility should prevail to cover anything a mass producer would use for popular sizes, and to be useful to individual manufacturers catering for the less popular sizes, e.g. outsize producers. Also, the extent of the size intervals which in itself is an important element of the size system, will determine the multiplicity of sizes. Many previous determinations on which trade practice is based, derive from experience or trial and error, and one can find a range of size intervals from as narrow as 3 cm to as large as 8 cm. It is believed that a size system should have economy in mind, and that a minimum number of sizes should ideally cover a maximum percentage of the population. This could be done by increasing the size intervals, while retaining an acceptable margin of error, rather than by restricting the sizes to a small range about the average of the population, which would not meet the needs of the population in general. Thus, consideration of the size interval should encompass: (a) a margin that is bigger that the measuring error; (b) variation that is inherent in manufacturing, allowing for stretch or shrinkage of the fabric during and after the process of manufacture; and (c) variation within a size of the garment which consumers are likely to accept.

Choosing the size interval can be a rather 'head-cracking' task, as there are many ways in which the values for the size intervals can be chosen. The first consideration must be that intervals must be larger than the measuring error as in (a) above. For example, if a man of 88 cm chest girth is being measured, it is possible for the measurement to appear as anything between 87 and 89 cm, due to differing ways in which a person holds the tape measure during measurement taking. If a size interval of only 1 cm was chosen, this would mean a man may be assigned to different sizes depending on the way his body measurement had been taken. Also, in a system where a small interval is used, for example 3 cm, the argument in its favor is that it would lead to closer fitting garments. However, according to Kunick[5] it is often found that a garment that fits within a tolerance of ±3 cm is quite acceptable, meaning that a size interval could be as wide as 6 cm and still give a satisfactory fitting capability. It can be further said that a garment can be of correct size, but a bad fit, and in that case any variation in this size interval is unlikely to give any improvement. A narrow size interval is thus not only uneconomical but may also be impractical. Aplin[6] stated that:

> . . . the choice of control dimension intervals will depend on factors such as: the standard of garment fit required, the logistic disadvantages of a large number of garment sizes, the disadvantages of having to provide 'special measure' garments for those subjects not accommodated by the size-roll garments, the degree of adjustment of control dimension related measurements which can be provided in the garment design and to some extent the selected garment fabric.

It is understandable that consumers are, to different degrees, willing to accept slight variations within the size of garments; this can be called the 'wearing tolerance' into which the smallest and largest persons within a particular size group can fit. This tolerance is sometimes called the 'wearing ease' and can be affected by the nature of the stretch, or the lack of it, of the fabric used in the make-up of the garment.

The size system, on the one hand, needs to be simple so that it can be modified for special purposes, e.g. specialty garments such as a fire-fighting suit; and on the other hand, it needs be comprehensive in coverage to suit a majority of the persons in a population. In most garments the tolerances just mentioned will cater for the bodily variations that happen in the population, and this is one reason why narrow intervals are not necessary. Narrower intervals that are necessary will result in the use of more separate sizes, hence adding financial burden to clothing manufacturers and retailers.

The design of a size system is a ‘man-made’ convenience, based on factors of economy, fit and practicality. In order to meet these requirements, it is further suggested that the size intervals throughout the system should be uniform between sizes. This allows advantages in industrial pattern grading, so that increases or decreases from the standard pattern can be made to produce patterns for other sizes with better accuracy as compared to the use of non-uniform size intervals. With computer pattern grading well established in the clothing industry, unequal size intervals will make computer grading more tedious than need be.

The method adopted to determine appropriate size intervals uses regression lines. As an example, the parameters are given in Table 7.3, based on the regression equations shown in Table 7.4. Using these regression lines, it is possible to decide on the values of the key or control measurements that will define the separate sizes. Hence, the basic data needed for the sizing system can be reduced to information to construct regression lines. From the regression line, by knowing a single point on the line, together with the value by which the particular measurement as represented by the line is changed by a fixed increase in the key

Table 7.3 System of body measurements (selected) based on stature, chest girth and hip girth

Measurements	Value for	Change in value for increase (value for decrease is reverse)		
		Stature 6 cm	Chest 6 cm	Hip 6 cm
	(1)	(2)	(3)	(4)
Cervical height	142.5	5.5	0.2	−0.4
Chest height	121.0	4.8	0.6	−0.7
Waist height	103.5	4.2	0.2	−0.2
Hip height	84.3	3.6	1.4	−0.3
Body rise	29.0	1.4	−0.3	0.8
Cross back	39.0	0.6	0.2	1.2
Cross front	37.5	0.5	0.4	0.8
Neck girth	40.5	0.04	0.6	0.9
Waist girth	76.0	1.4	3.3	3.3
Natural waist	43.0	2.1	−0.2	0.5
Outside leg	105.0	4.0	−0.6	0.7

For explanation of numbers (1) to (4) see text.

Table 7.4 Multiple regression equations used for calculating change in body measurements (selected)

$Y = aS + bH1 + cC2 + k$	
Dependent	= *a*(Stature) + *b*(Hip girth) + *c*(Chest girth) + constant
Cervical height	= 0.9223(S) – 0.0746(H) + 0.0309(C) – 8.8138
Chest height	= 0.7951(S) – 0.1240(H) + 0.0971(C) + 9.8438
Waist height	= 0.6968(S) + 0.0292(H) – 0.0003(C) – 16.8468
Hip height	= 0.6042(S) – 0.0472(H) + 0.0362(C) – 16.0560
Body rise	= 0.2350(S) + 0.1365(H) – 0.0576(C) – 17.8896
Cross back	= 0.6042(S) – 0.0472(H) + 0.0362(C) – 16.0560
Cross front	= 0.0843(S) + 0.1327(H) + 0.0645(C) + 5.5618
Neck girth	= 0.0075(S) + 0.1449(H) + 0.1025(C) + 16.8970
Natural waist	= 0.3467(S) + 0.0780(H) – 0.0309(C) – 19.0455
Outside leg	= 0.6586(S) + 0.1110(H) – 0.1028(C) – 7.0883

measurement, called the regression coefficient, other points can be calculated. Here, the key measurements are used as independent variables. Table 7.3 shows the 'centre of the range' values of the average man. The key measurements are stature: 169 cm, chest girth: 88 cm and hip girth: 91 cm. These figures are used to define the start of the size range. Columns 2, 3 and 4 show the increases or decreases in each dimension for a 6 cm change in stature, chest and hip girths respectively, and show the adjustment to be made to the values in Column 1 for an increase or decrease of 6 cm in the control dimensions. These changes are useful for grading purposes. The regression equations used in the calculation of changes of body measurements are based on the key measurements of stature, chest girth and hip girth. For each equation the correlation coefficients and the constants will be provided by a statistical program so that the regression equations can be constructed. Hence, for a man of average 169 cm stature, 88 cm chest and 91 cm hip, the average measurements for the rest of this person as calculated from the regression equations are shown in Column 1. These measurements are the corresponding 'centre-of-the-range' values of the sample. Any change from this mean in respect of stature, chest girth and hip girth can be made by using the adjustments as necessary in the regression equation; for example, for a person of 94 cm chest girth, the corresponding value of the cervical height will be 142.5 cm + 0.2 cm, and so on, working down the rest of the measurements. Consideration is also given to the subsidiary measurements. From Table 7.3, it is seen that where the principal girth measurements are graded in 6 cm intervals, the subsidiary measurements can have very small gradations. A move to decrease the grade of the girth measurement will result in even smaller grades for these subsidiary measurements.

While it has been said that a sizing system is a 'man-made' convenience, to group people of similar body dimensions into the 'cells' of the size system, it is obvious that this system must be systematically uniform and the size intervals made convenient and consistent. It is industrial practice to make such size intervals uniform, to allow pattern grading to be carried out effectively, efficiently and correctly, using a middle size and increasing or decreasing from this to obtain sizes larger or smaller according to the requirements of the size chart and of the customers. A standardized approach to pattern grading thus encourages a direction of uniform sizing intervals within the size system.

In many size systems, stature, based on its high correlation with most vertical measurements is used to designate garment sizes, as promoted, for example, in the ISO Mondoform. As far as fit is concerned, stature is not as critical as the girth measurements; however, its inclusion is necessary so that changes or allowances can be made for variations in length measurements, e.g. inside leg of trousers, sleeve length of shirts, or natural waist length of a jacket. Adding stature to the sizes, however, multiplies the total number of sizes, and a grade of small intervals will give a multiplicity of sizes making logistics rather difficult for manufacturers and retailers. Thus, a compromise must be reached whereby on the one hand, the stature of the person is accounted for, and, on the other, an optimal number of size intervals is obtained.

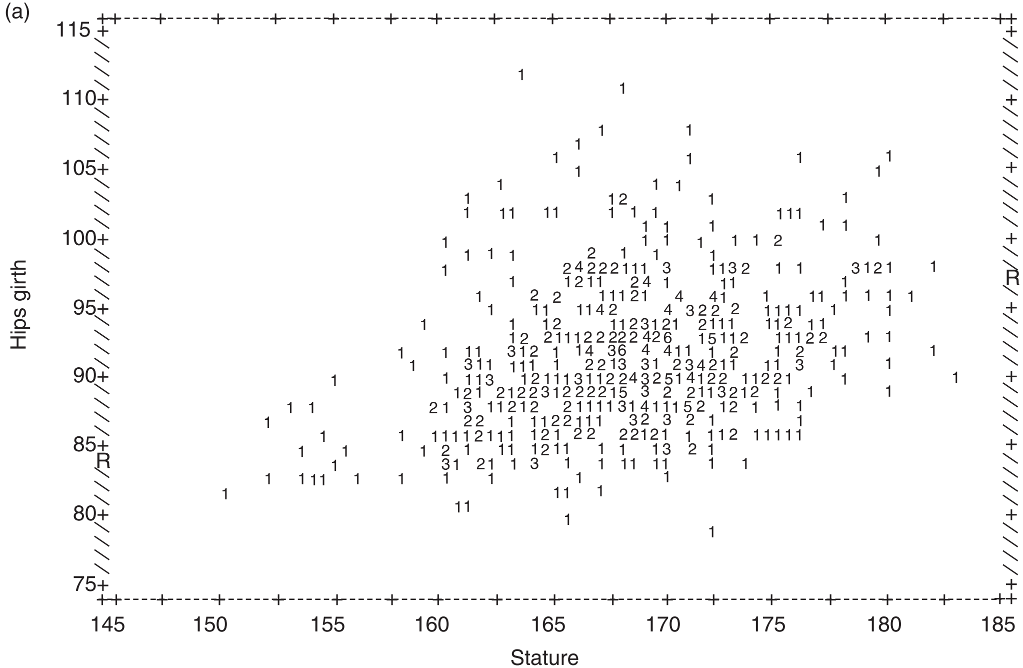
In considering a size interval for stature, it has been seen that stature follows a symmetrical distribution, such as the normal distribution curve seen in the sample distribution (Fig. 7.1), so that the sizes are balanced about the average. As to the number of sizes, it is the practice to use an odd number of sizes as this allows the middle size to stand out for grading purposes. In the example (study), stature ranges from 150 to 183 cm with the 5 percentile value at 160 cm and the 95 percentile at 177.5 cm. The spread of the middle 90% of the population is thus 17.5 cm and the intervals for stature are conveniently set at 6 cm to read as follows:

Stature	Range	Interval	Average stature
Short	160–165.9 cm	6 cm	163 cm
Medium	166–171.9 cm	6 cm	169 cm
Tall	172–177.9 cm	6 cm	175 cm

The intervals of 6 cm together effectively cover almost 90% of the population and for ready-to-wear purposes provide a good coverage. To summarize, the size interval chosen for the chest and hip girths is 6 cm and for stature is also 6 cm.

We next determine the total number of sizes needed to cover the local population. In Fig. 7.3a the joint distribution of stature and hip girth, based on data obtained from the sample, is given. It can be seen that the range of stature on the X-axis is from 160 to 178 cm which is equivalent to the 5th to 95th percentiles of the distribution covering slightly more than 90% of the sample. This range of 18 cm is divided into three groups; Short, Medium and Tall, based on an interval of 6 cm each as described earlier. Correspondingly, on the Y-axis, the range for hip girth is effectively from 82 to 100 cm, which is equivalent to the 5th to 95th percentile

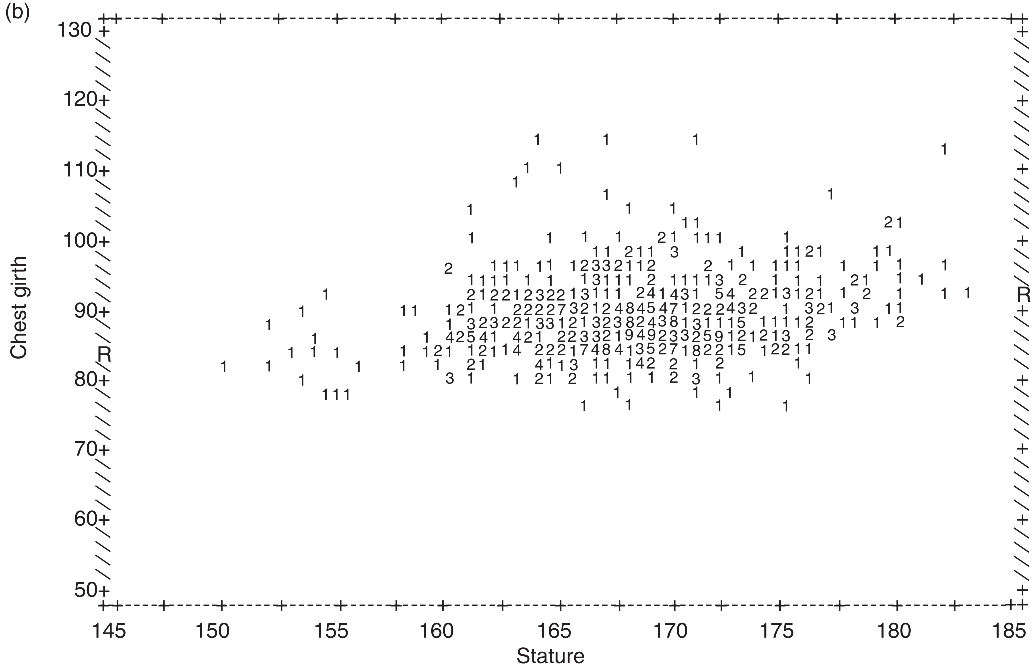
(a)



600 Cases plotted. Regression statistics of hips girth on stature:
Correlation 0.30763 R squared 0.09463 S.E. of EST 5.21700 2-tailed SIG. 0.0000
Intercept (S.E.) 38.85398 (6.69250) Slope (S.E.) 0.31408 (0.03973)

7.3 (a) Joint distribution of stature and hip girth.

(*Continued*)



600 Cases plotted. Regression statistics of chest girth on stature:
Correlation 0.20715 R squared 0.04291 S.E. of EST 5.60098 2-tailed SIG. 0.0000
Intercept (S.E.) 51.22132 (7.18509) Slope (S.E.) 0.22084 (0.04265)

7.3 Continued. (b) Joint distribution of stature and chest girth.

values, hence covering slightly more than 90% of the sample population. The range of 18 cm, can be divided into three groups labeled Small, Medium and Big hip girths, based on an interval of 6 cm each, that is 82.0–87.9 cm, 88.0–93.9 cm, and 94.0–99.9 cm, respectively. In Fig. 7.3b, the distributions of statute and chest girth are plotted against each other. It can be seen that the range of statute is identical to that in Fig. 7.3a on the Y-axis, the chest girth range is effectively from 79.0–97.0 cm which is about equal to the values of the 5th and the 95th percentile values, hence covering about 90% of the population. This range of 18 cm can again be divided into three groups of Small, Medium and Big chest girths based on an interval of 6 cm each, that is: 79.0–84.9 cm, 85.0–90.9 cm and 91.0–96.9 cm respectively.

The resultant plots from the two figures cover some 85% of the sample population. The remainder that fall outside the plot may not be of much interest to the mass manufacturer; nevertheless, they may remain a niche for the specialty manufacturer, if a large enough market exists.The distribution of the three stature groups and the chest and hip girths can provide the numbers in each of the sizes in the size charts, on which the size system shall be based. As the stature groups of <160 cm and of >178 cm accounted for a rather low percentage, these two groups were not charted. Tables 7.5 to 7.7 show the distribution of chest and hip girths for each of the three stature groups.

As to the method of designating each size, a method which uses the key measurements of stature, chest and hip is employed. For each stature group, a system based on the relations between hip and chest, e.g. hip 91 cm, chest 88 cm is used. From the tables, it can be seen that 'Normal Chest' dominated the distribution. However, there are quite a few cases where chest is slightly bigger (3 cm) than hip which we term 'Full Chest'; chests much bigger than hips (9 cm) do exist but they are relatively few in occurrence and hence may be ignored in the design of the size system. Similarly, 'Small Chest' (smaller by 9 cm) and 'Very

Table 7.5 Estimated percentage distribution of the population by chest and hip girths (short stature – 163 cm)

Chest girth	Hip girth (cm)						
(cm)	79	85	91	97	103	109	Total
112						0.4	0.4
106					0.4		0.4
100				0.4	0.2		0.6
94		0.7	1.7	1.3	0.2		3.9
88	0.2	5.4	5.2	0.7			11.5
82	0.9	6.3	1.1	0.6			8.9
76	0.2						0.2
Total	1.5	12.4	8.0	3.0	0.8	0.4	25.9

Table 7.6 Estimated percentage distribution of the population by chest and hip girths (medium stature – 169 cm)

Chest girth (cm)	Hip girth (cm) 79	85	91	97	103	109	Total
106					0.2	0.4	0.6
100			0.4	0.6	0.9		1.9
94		0.6	3.7	3.0	0.6		7.9
88	0.4	4.3	13.1	2.6			20.4
82	0.2	9.2	4.9	0.9			15.2
76		0.7					0.7
Total	0.6	14.8	22.1	7.1	1.7	0.4	46.7

Table 7.7 Estimated percentage distribution of the population by chest and hip girths (tall stature – 175 cm)

Chest girth (cm)	Hip girth (cm) 79	85	91	97	103	109	Total
100			0.2	0.6			0.8
94		0.2	2.2	2.1			4.5
88		1.7	4.7	1.5	0.2		8.1
82		2.2	1.9				4.1
76		0.6					0.6
Total		4.9	9.0	4.2	0.2	0.4	18.1

Small Chest' (smaller by 15 cm) also exist. Each size within the stature group will be described and designated by the hip measurement and the difference between it and the chest measurement. This can be summarized below:

Very Small Chest – chest 15 cm smaller than hip
Small Chest – chest 9 cm smaller than hip
Normal Chest – chest 3 cm smaller than hip
Full Chest – chest 3 cm bigger than hip
Big Chest – chest 9 cm bigger than hip

Each size can be based on or designated by two descriptions: i.e. the hip measurement and the chest description as outlined above. Referring back to Tables 7.5 to 7.7 a list of main sizes that covers a majority of the population can be grouped as shown in Table 7.8. The size system derived covers some 90.7% of the population. The breakdown of the sizes is as follows:

Short Stature (17 sizes) – 25.9%
Medium Stature (18 sizes) – 46.7%
Tall Stature (11 sizes) – 18.1%

Table 7.8 List of main sizes

	Hip measurement for stature groups (cm)			No. of sizes
	Short	Medium	Tall	
Very Small Chest	97	97		2
Small Chest	91, 97, 103	85, 91,97,103	85, 91, 97	10
Normal Chest	79, 85, 91, 97, 103	85, 91, 97, 103, 109	85, 91, 97	13
Full Chest	79, 85, 91, 97, 103, 109	79, 85, 91, 97, 103	85, 91, 97	14
Big Chest	79, 85	79, 85, 91	85, 91	7
Total no. of sizes	17	18	11	46

Table 7.9 Body measurement (cm) (selected) for men of Medium Stature (169 cm) with Normal Chest (chest smaller than hip by 3 cm)

Chest girth	82	88	94	100	106
Hip girth	85	91	97	103	109
Cervical height	142.7	142.5	142.3	142.1	141.9
Chest height	121.1	121	120.9	120.8	120.7
Waist height	103.3	103.5	103.4	103.9	104.1
Hip height	85.4	84.3	83.2	82.1	81
Body rise	28.5	29	29.5	30	30.5
Cross back	38	39	40	41	42
Cross front	36.3	37.5	38.7	39.9	41.1
Neck girth	39	40.5	42	43.5	45
Natural waist	42.7	43	43.3	43.6	43.9
Outside leg	104.9	105	105.1	105.2	105.3

Approximate population coverage = 26.6%

Of the 46 sizes, the 13 'Normal Chest' cover about half (48.8%) of the population covered by the full range of sizes.

Once the sizes based on the key measurements have been settled, the detailed specification covering the rest of the measurements can be constructed from the data of Table 7.3 by suitable combination of multiples of the regression coefficients; again linearity of the regression and their applicability to outsizes are assumed. The method used to obtain the size intervals is equivalent to dividing a population into size groups and working out the average of each group from the people in that group. Here, in calculating the measurements of each size, the value of the three key measurements is assumed to lie at the center of the appropriate interval. An example of a complete size chart for Medium Stature, Normal Chest is shown in Table 7.9. Other smaller measurements vary relatively little and it is possible to omit these measurements from the size system for the shorter and taller groups, noting that the values of these measurements are the same as for the Medium Stature. It is appreciated that the form of the standard size charts and the specification of each size chart are conditioned by the choice of the key measurements and their values selected in the definition of each size. An even greater proportion can be covered when the wearing ease of garments is taken into account.

7.7 Development of a size roll/system for selected clothing

Having determined the standard body sizes of the population, the next step is to design size charts based on the standard body measurements. As size charts can vary with different garments and their styles, a basic set of selected garments is used to illustrate the method. Before discussing the design of the size roll/system, it is of interest that some technical terms used to define the sizing system be explained. They are:

(a) 'Control measurements' – those body measurements on which the sizing system is based, they are fundamental to the definition of the body size used to assign suitably-sized garments to the wearers. In short, they are the measurements that are required to be measured on the individual intended to be fitted. In systems which have more than one control measurement, the importance given to each descriptor will be primary, secondary and tertiary, in that order.
(b) 'Secondary measurements' – those body measurements, besides the control measurements, that are required to define the body size fully and that are used, together with the control measurements, by the garment manufacturer in the preparation of the garment size system roll.
(c) 'Sizing system (roll)' – a set of pre-determined body sizes designated in a standard manner. The compilation is derived from the data on an anthropometric study of the population concerned.
(d) 'Size scale' – the set of sizes of one body dimension, e.g. chest, waist, etc. having fixed or variable size intervals.
(e) 'Size interval' or alternatively 'Size step', 'Size grade' or 'Intersize interval' – the incremental difference between adjacent components of a size scale.
(f) 'Size range' – the extent of a size scale as defined by its extreme values (smallest and largest values).
(g) 'Size designation system' – the system of size labeling of a garment for the convenience of consumer selection and purchase.

Garments and accessories can be divided into three types: namely uni-dimensional, bi-dimensional and tri-dimensional, according to the number of control measurements required to define adequately the appropriate body dimension size. As the body is three-dimensional, it could be argued that sizing systems for all garments have to be three-dimensional in that each has length, width and thickness. For most clothing however, these can be normally reduced to dimensions composed of a length or height measurement and a girth measurement.

An example using a uni-dimensional system is in headwear, where head girth as a single measurement is used to define the sizing system. In the bi-dimensional system, an example is men's gloves where the primary measurement is hand girth and the secondary measurement is hand length. Examples of the tri-dimensional where a critical degree of fit at defined areas of the body is required are jackets, trousers, shirts, etc. Here, for each control measurement, a size scale must be given and it is the number of combinations of, say, chest girth, hip girth and sleeve length that produce problems and force manufacturers to limit the sizes to a manageable number.

A major difference between a control and secondary measurement is the size interval. For the control, the size scale has definite intervals between all sizes, though not necessarily the same interval throughout the scale, e.g. the chest girth for some outerwear styles may change from 4 to 6 cm within the same scale to cater for the larger sizes. For secondary measurements, the size scale can have intermittent increases as body size increases. Secondary measurements, in conjunction with the control, can define body shape in more detail than the control measurement alone. Using these combined dimensional size charts or tables, the manufacturer can produce his garment size system or roll by adding the necessary wearing (fitting) and fashion styling tolerances or ease. Secondary measurements are restricted to garment manufacturing interests and hence are of no concern to the general consumer. The control measurement is used as a form of size designation or labeling, and this is of concern and benefit to the consumers. In the preparation of the sizing system, the basis of which is the anthropometric study, elements are added which reflect the necessary garment allowance appropriate to the garment styles and comfort factors. It is from this garment size roll that the manufacturer grades the master patterns up and down the scale by making appropriate allowances.

In a three-dimensional system, the elements of the body size roll will consist of: (a) a size scale that ranges from the smallest to the largest in the primary control, with fixed or variable size intervals; (b) a size scale in each of the other controls with fixed or variable intervals; and (c) a means of size designation for the consumers' convenience and to aid common understanding between manufacturers and distributors. Using the first two elements, the total number of sizes in the full size roll can be determined. With this knowledge, a manufacturer can plan his production requirement in the sizes necessary for distribution to the market.In the following section, the size system or roll of a formal dress shirt with normal fitting tolerances is constructed as an example. While fashion trends determine the fashion-styling tolerances in a size roll, nevertheless, it is discounted in the size system here as this can be decided by the individual manufacturer from time to time. A formal dress shirt will be required to fit at the neck more than any other part of the body, as most are designed to be worn with accessories such as bows or ties. Because of this, neck girth has been adopted as being primary importance and is taken as a control measurement for sizing the garment. In men, if a proportionally-constructed shirt fits at the neck, it is most likely that it will fit also at the chest, with due allowance having been made for ease of movement. As the two girths are well correlated, a man with broad chest is likely to have a thick neck. In shirts, waist girth is comparatively less important due to the general looseness of the fitting at that position. However, fashion does change from time to time to more close-fitting styles and it would be useful if the waist girth is known.

Besides neck girth being taken as the control, a vertical dimension also needs to be taken into account. The positioning of the sleeve cuff at the wrist is critical, and as this concerns the arm length (which correlates well with stature), it is necessary to provide for a vertical dimension so that good fit can be achieved. Hence, a size system for shirts may provide for different sleeve lengths for each neck size. Stature, too, can sometimes be used as a guide in place of sleeve length due to the good correlation, e.g. in casual shirts. As neck girth and arm length have a rather low correlation, it is necessary that each is specified in the size system, that is:

Control measurement: neck girth. Secondary measurement: arm length.

The above two size scales can be supported by some other secondary measurements such as chest, waist, hip, wrist, natural waist, cross front and back widths, arm-scye, etc. to form a more comprehensive size roll. From the size roll, the control measurement, i.e. neck girth, and a secondary measurement will be used as designation for the said garment which is in line with the ISO recommendation. The manufacturer shall be responsible for specifying the measurements that are required to define the average body shape of its consumers as in the case of the dress shirt with the list of measurements mentioned. From these measurements, allowances will be included for ease of wearing/movement, comfort and fashion styling, to arrive at the required garment size chart. Gioello,[7] in her book suggested a minimum movement ease or comfort ease allowances to be added to body measurements of men, women and children to assure minimum fit of garments. She further stated that addition to or reduction of ease will depend on factors such as type of fabrics, garment types, styling, garment details and construction. In practice, many garments exhibit greater ease allowances depending on the factors given above. ‘Comfort’ can be a most abstract and subjective phenomenon. A size chart for a dress shirt with ease allowance added to the standard body measurements is shown in Tables 7.10 and 7.11.

Table 7.10 Size chart for men's dress shirt (selected measurements, cm) (Medium Stature: 166–172 cm)

		Size designation >								
Measurements	Ease	37	38	39	40	41	42	43	44	45
Neck girth		37	38	39	40	41	42	43	44	45
Chest girth	24.0	98	102	106	110	114	118	122	126	130
Waist girth	28.0	90	94	98	102	106	110	114	118	122
Hip girth	18.0	98	102	106	110	114	118	122	126	130
Wrist girth	6.0	21	21.5	21.5	22	22	22.5	22.5	23	23
Scye depth	4.5	25	25	25	25	25	25	25	25	25
Natural waist		42.4	42.7	43	43.3	43.6	43.9	44.2	44.5	44.8
Shirt length		70	70.5	71	71.5	72	72.5	73	73.5	74
Cross front	3.5	38	39	40	41	42	43	44	45	46
Cross back	3.5	39	40	41	42	43	44	45	46	47
Shoulder width	5.5	44	45	46	47	48	49	50	51	52

Table 7.11 Alteration to size charts for Short and Tall Stature men

	Short (160–166 cm)	Tall (172–178 cm)
Scye depth	–0.7 cm	+0.7 cm
Trunk length	–1.3 cm	+1.3 cm
Natural waist	–2.0 cm	+2.0 cm
Garment length	–3.0 cm	+3.0 cm

7.8 Fit testing and sizing evaluation

Every clothing item is designed to meet a specific requirement. Whether this requirement is aesthetic or physiological, it needs to function and fit within defined limits before it can be considered to be a successful solution to a given problem. Every item of clothing that is put onto the market is the result of an intensive and cohesive effort made by designers, technologists and manufacturers alike who continuously engage in decisions involving, for example, function, appearance, comfort, safety or cost considerations, in the run-up to the final product.

One of the major tasks facing the manufacturer is the establishment of a sizing system for a clothing item, such as the number of sizes needed to accommodate the user population, dimensions of each size and the tariff for each size to be made. This can be achieved by reference to an anthropometric study as a source, from which sizing system/roll are statistically devised. However, for the eventual success of the sizing program, an essential part of the development is a 'Fit test' in which garments made in accordance with the sizing system are worn by subjects representing the size range of the user population, and are carefully evaluated for its intended function and fit requirements.

In every step in the development of an apparel item, it is desirable that some form of fit testing is performed, especially in the crucial stages of its design and sizing. Close coordination and understanding between the various personnel involved in the development of the clothing item are important as the finished product must closely resemble what the market requires. After all, fit is an important aspect and attribute in clothing. It is not uncommon that a fit test is only called upon after problems have occurred in the fit and function of the garments produced. Fit testing should be one of the steps in the development of the clothing item and should be performed before production as a validation of the size roll.

The main objective of anthropometric fit testing is the assessment of the capacity of the sizing system to accommodate the specified range of the user population. The fit test is a psycho-physical experiment in which observers make judgments about the sensations they experience in response to certain physical stimuli relating to the fit of clothing on their bodies. The fit test and evaluation program involves the following stages: (a) the design and preparation for the fit test; (b) processing the fit test on representative subjects; and (c) reporting and analyzing the results.

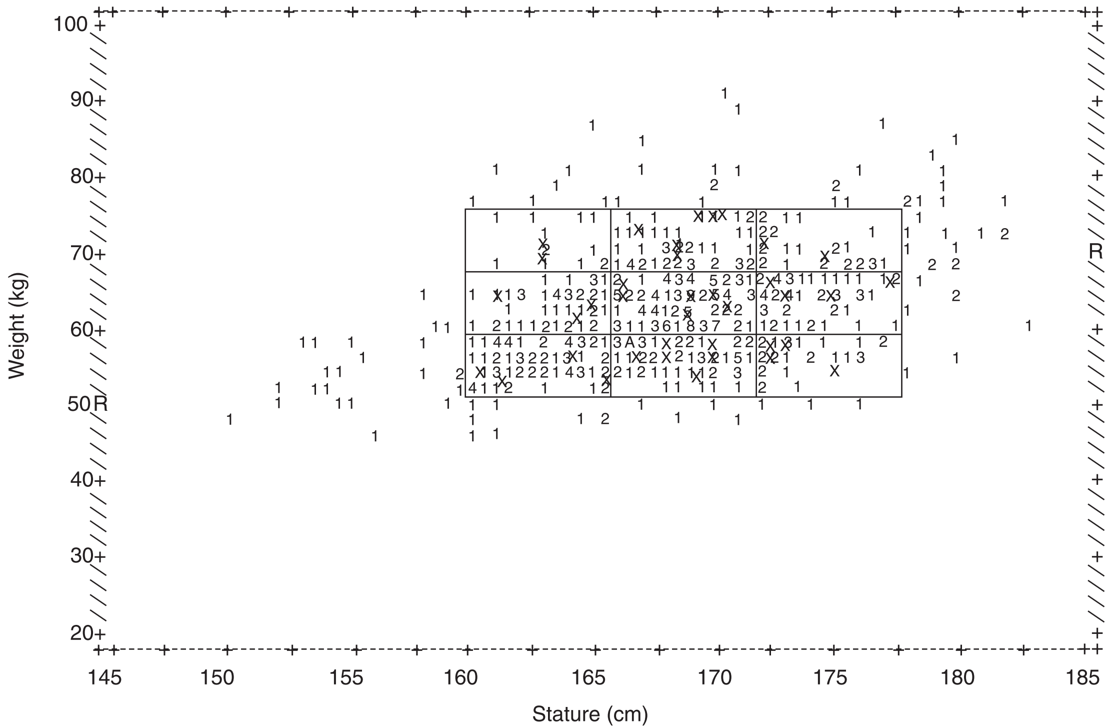
(a) *Design and preparation for the fit test* – from the start, the designed procedure to be taken involves planning for the whole exercise. A well planned fit test will minimize time and cost and, most of all, inconvenience to the fit test subjects. The first to be decided is the range of prototypes that are to be made up from the graded patterns. As one of the basic objectives of fit testing is to identify and gain access to available persons who are a part of the projected user population, it has to be assured that an adequate number of subjects are available. It would provide an 'economy of scale' if a location having subjects with a full range of size variability is available.The selection of a suitable size for the test sample depends on the nature of the garment and the range of sizes for fit testing. While it is desirable from a statistical point of view to have as large a number of subjects as possible for testing in all size categories, nevertheless, the number is in fact limited by the resources available. McConville *et al.*[8] said 'a number of subjects less than 20–30 will produce a biased sample unlikely to represent accurately the ultimate range of body sizes in the user population. As most garments are designed in sizing systems cover between three to twelve sizes, with more subjects required in the middle sizes, thus assuring at least three to five subjects in each sizing group.' The number of subjects selected for fit testing is also dependent on the limit and quality of fit. In ready-to-wear clothing, having a more exact fit will require more stringent limits to be provided in the garment dimensions and thus require more subjects to be used within each size. On the other hand, a looser fitted garment, for example, sportswear, aiming at a wider spread of the user population per garment size would require a more 'relaxed' number of subjects to be fitted. An example of the latter is a nine-size disposable one-piece chemical defense undergarment with a rather loose-fitting tolerance that was test-fitted on 36 subjects only (Alexander),[9] while a four-size oral-nasal oxygen mask was test fitted on 66 subjects (McConville and Alexander).[10]

For each particular control measurement of a clothing item, for which the item is sized, it is best to cover the body size variability within the limits specified for that size. This variability can then be tested against the range covered by that size, for example, for a jacket intended to fit 86 to 90 cm chests, subjects covering these extreme values would be useful to determine the quality of fit. Other measurements related to fit as given in the size charts can be tested accordingly to see if the inherent variability will affect the ultimate fit for the given user group.

The basic vehicle for obtaining information pertaining to fit on the test subject is by means of a questionnaire. Depending on the garments to be tested, the questions asked can be modified according to what information is required. The questionnaire is the foundation on which the conclusion of the fit test is based; hence, it must have a comprehensive scope, clear objectives and be as informative as possible. Thus the form should solicit information, such as identification of the subject, information pertaining to the dimensions of the subject for comparative purposes, sizing data, and the observations of the subject with regards to the various aspects of any inadequate fitting of the garment concerned.

(b) *Processing the fit test* – using the Bivariate Frequency Table as a guide, the sampling procedure used was to obtain more subjects from the medium body sizes, with fewer subjects from the larger and smaller sizes. The purpose of this is twofold: obtaining the average subjects is easier, and the mean values of the test subjects will be closer to that of the population. The subjects who were to test the garment were recalled from the anthropometric study and were representative the 'respective' size groups of Stature and Weight (Fig. 7.4). Through this, it can be assured the subjects are spread throughout the range of the population. Each subject is to be given the prototype garment of their indicated sizes for fitting. Of importance here is the verification of the range of test garments to ensure that the size labeling was correct and, to ensure visibility of the sizes, the size label must be conspicuously placed. Any inadequate fitting point is recorded, and if up-grading or down-grading of sizes is required.

(c) *Reporting and analyzing the results* – as the sample taken for the fit test is much smaller, it is necessary to check the validity and representativeness of the test sample to ensure that the results obtained in terms of fit and purposes of the test garments can be extrapolated from the rather 'small' test sample to the larger user population, thus providing confidence for the ultimate use of the test garments. One way to validate the representativeness is to compare the profile of the fit test sample to that of the anthropometric sample. Should the former follow that of the latter, one can say that the results of the fit test will closely resemble those experienced by the user population. A comparison is made of measurements obtained from the fit test sample and the anthropometric sample. Additionally, stating the population percentile range covered in the test sample will allow more comprehensive comparison in proving the validity of the sample. The above procedure is carried out in order to establish that the fit test sample would, in terms of relevant body size variability, be considered a sufficiently representative micro-population for the



7.4 Fit test subjects tested from respective Stature/Weight size groups.

purpose of the fit test and that the results can be viewed with confidence. Thus from the two tables, it can be suggested that the sample is a good representation of the population. The fit test represents the final stage to be negotiated before a garment can be confirmed into production. It is needed so that personnel making the decisions of whether a particular garment can go into full production as far as size measurement is concerned, can do so with confidence.

A difference between a fit test and other tests is that the former does not incorporate a definite cutoff point of 'pass' or 'fail'. Much depends on the intended use of the tested item and the stringency requirement expected of the product. For example, pressure suits for air pilots have to cover a high percentage of the user population, possibly 98%; while one-piece overalls for mechanics can have a lower percentage coverage. Although no design can fit every user in the population, nevertheless it is important to check any disproportion which can affect the subsequent overall results. It is suggested that an indicator of acceptable results is when at least 80% of the test sample can be fitted properly.[11] Another use of the fit test is the confirmation of the establishment of a production tariff, or quantity of each size in each product, to be manufactured to accommodate the demand of the user population. This will allow the added advantages of better production planning and economical merchandising and other logistical requirements. Fit tests, while tending to be, in some respects, more subjective in nature, are an important aspect in new product development. Designs incorporating different fashion silhouettes can be produced as prototypes for fit testing by subjects with similar variables to the targeted consumer population. The results can be fed back to product development personnel where deficiencies can be adjusted or the design modified in the light of the information provided by the fit test procedure. It is suggested that if the procedure is performed correctly, the millions of dollars of mark-downs caused by badly fitting clothing can be turned into better profits and satisfaction to the consumers.

7.9 Conclusion

The accurate development of a sizing system for clothing can only originate from a scientifically executed anthropometric study or survey. It would result in establishment of standard body measurements which in turn serve to create ready-to-wear clothing size charts with the consideration of ease allowances by practitioners such as designers and clothing technologists. Having established the size charts for the garments, they have to be fit-tested to assess their correctness and appropriateness to the market. If the above steps are taken, mark-downs due to poor fitting will be much reduced.

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8
Developing apparel sizing systems for particular groups

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Abstract: Accurate statistics of body features classified by country, age and gender are important, notably in multiracial societies. Indeed, such statistics allow defining the average virtual individual shape for each class to recognize the growing importance of some of them and to recognize the changes occurring with the passage of time. These changes, though sometimes manifest, seem not to be recognized or reflected in the industry or by the manufacturer until new statistics are made public or in cases of declining profit. Therefore, the statistics are becoming more and more of a necessity to the whole manufacturing community. Moreover, all products that people use or wear in everyday life should be designed by considering the users' anthropometric features for best fit and function. To this end, anthropometric data collections and comparison are conducted at both the domestic and global levels. This chapter deals with size and morphological information and sizing systems for special groups, such as Korean military soldiers and Korean women. It also investigates the human centered design technique for products for the elderly, and the compatibility of international sizing systems.

Key words: anthropometry, sizing system, military uniform, morphology, elderly.

8.1 Introduction

The customers' need for a consumer product is both functional and emotional. When a product is newly introduced to the market, customers' needs are first satisfied by the possession of the product together with its use. While using the product, other higher needs often arise concerning its functionality. Finally, emotional needs relating to personal preferences on style, fitness and other values are also an important element (Lee, 1999a). In the clothing industry, customers' needs develop in a way that is different from the norm. In the Korean domestic market, these needs currently remain, in part, in the second phase – the functional level – while already moving fast toward the emotional level, partly due to the economic development of the country and partly to the globalization engendered by information technology.

The increased complexities of the products people use and wear place a premium on the assurance that the item bought at the store will fulfill the following three objectives: functional suitability, human sensibility and human welfare. The need for such assurance requires that human factors (size, shape factor and human sensibility) be taken into account early in the design and development process (Shinozaki, 1994).

Anthropometric data collection, including three-dimensional information, together with comparison of these data among countries are becoming necessary tools for the entire manufacturing community (Sanders and McCormick, 1992). However, if anthropometric data are necessary, raw data themselves are insufficient for pattern grading and size compositions according to design variations for the producer. The data must be controlled to enhance their validity for product applications. In the clothing industry, there is a critical problem of minimizing the number of sizes to be defined while maximizing their cover rates, in an attempt to strive for more rationalized production methods. Anthropometric surveys devised by each country attempt to fulfill the requirements of the manufacturers, providing them with data and tools, and allowing them to face both the internal and export markets (Hans *et al.*, 1990).

In Korea, the first national anthropometry survey was conducted in 1979 by a Korean Government division, the Korean Agency for Technology and Standard (KATS, 1979). At the time, data were collected concerning 17 000 sample individuals residing in various parts of the country aged between 6 and 50 years. A total number of 117 measurement dimensions were taken using calipers and tape measures. Thanks to these data, the KATS established 46 items defining Korean standards concerning clothing, furniture, desks and chairs. Forty-one of them (KSK 0035 to KSK 0096) were associated with the size designations of men's wear, women's wear, brassieres, socks, etc.

Following this survey, the Korean government has been presenting a national anthropometric survey every five or six years. The surveys of 1986, 1992, 1997, 2003 and 2010 were performed according to the following sequence. The survey was performed with the traditional measurement method (2D) using an anthropometer, somatometer, caliper and tape measure. The 3D body scan data collection (Body Line Scanner, Hamamatsu Co.) method (3D) was also adopted in order to obtain a good compromise and to modernize the fit and construction of their garments for the 2003 and 2010 surveys. All body dimensions were measured with the method defined by the ISO (ISO 3635, 1981; ISO 8559, 1989).

With tremendous economic development and improved health facilities, height, body proportions and even face shapes of the Korean population have evolved and are still continuing to change. The need to reexamine some Korean standards was thus acknowledged, particularly for those relating to body size: clothes, shoes, headgear and the like. KATS has been continuously developing various projects for the renewal of these standards, adopted standards for products including garments with these measurements and also updated its standards using the national surveys' data conducted under anthropometric 2D and 3D methods:

	Surveys					
	1st survey	2nd survey	3rd survey	4th survey	5th survey	6th survey
Years	1979	1986	1992	1997	2003	2010
Sample size	17000	21650	8800	13000	14000	14000
Age range (years)	6–50	6–50	6–50	0–70	0–90	7–69
Dimensions (cm)	117	80	84	120	190	139
Methods	2D	2D	2D	2D	2D and 3D	2D and 3D
Application	Established 46 Korea standard (KSK0031 etc.)	Updated 41 Korea standard (KSK0034 etc.)	Updated 44 Korea standard (KSG2016 etc.)	Updated Korea standard (KSK0051 etc.)	Updated Korea standard (KSK0051 etc.)	Updated Korea standard (KSK0051 etc.)

Young-Suk Lee (Kim and Lee, 1997; Lee, 2003) who was committed to the 1997 and 2003 surveys, compiled the 1998–2004 databases on body shape, body proportion and size distribution for women's garments in the Korean population, and further applied this information to product design. The 1998 data analysis is worthy of attention as it integrates new body size classification and consequently updates the Korean garment sizing system (Lee, 1998). In 1999 and 2000, Lee respectively conducted the standardization of the shoe sizing system and that of headgear sizing (Lee, 1999b). In 2001–2002, Lee also developed the Korean military garment sizing system (Lee, 2001). From 2000 to 2004, research on dummies, products for the elderly and human-centered design products was undertaken using 2D and 3D data (Lee, 2000, 2003).

8.2 Sizing systems for Korean military uniforms

Problems regarding anthropometry of fitness and human engineering are not necessarily unique to the military. However, military populations themselves are unique since they are neither a biological population nor random samples of the biological population. Other aspects of military anthropometry are unique because research results are implemented in military regulations and material equipment specifications which directly affect the safety, performance and careers of large numbers of individuals as well as measurement validity (Greiner and Gordon, 1992).

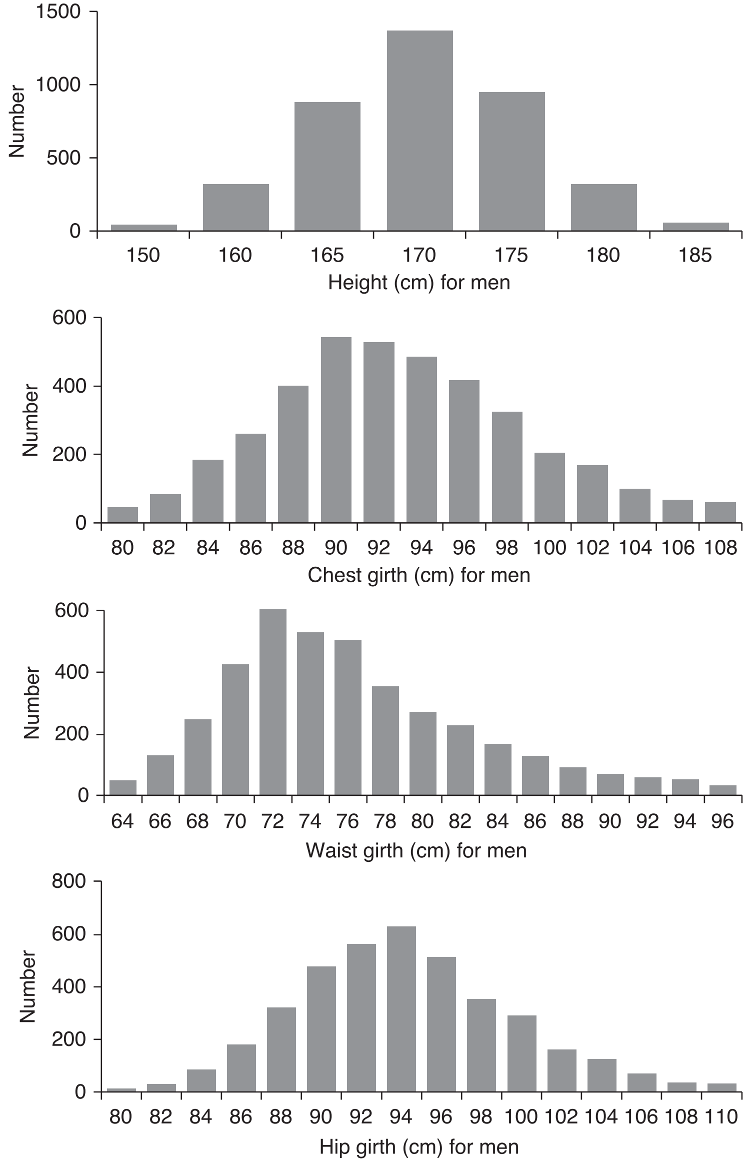
Korean military and many foreign services compile and maintain extensive collections of body-size information used primarily to guide the design and sizing of clothing of personal protective equipment, work stations and computer-generated human models. In order to be effective, such databases must be updated periodically to accurately reflect the body sizes and proportions of the military population which it purports to represent (Gordon, 1994). In order to improve the fitness and simplify the task of size standardization and garment making, the Korean military developed a new sizing system using 2D (traditional measurement method) and 3D (Body Line Scanner, Hamamatsu Co.) anthropometry body data, obtained from the 2001 survey. The development of new standards for an improved military uniform sizing system should allow the military to achieve the following goals:

- Possibility of producing smarter patterns thanks to the computerized preparation of tasks and pattern grading system.
- Generalization of made-to-order clothing.
- Generalization and automation of 3D shape measurement technique.
- Use of patterns produced according to 3D shape information.
- Improvement of cover rate up to 90% level.
- Improvement of fitness and comfort.
- Minimization of clothing waste resulting from clothing inadequacy.
- Improvement in compatibility between KS sizing system (civilian sizing system) and military sizing system.

8.2.1 Size data provided by the 2001 anthropometric survey

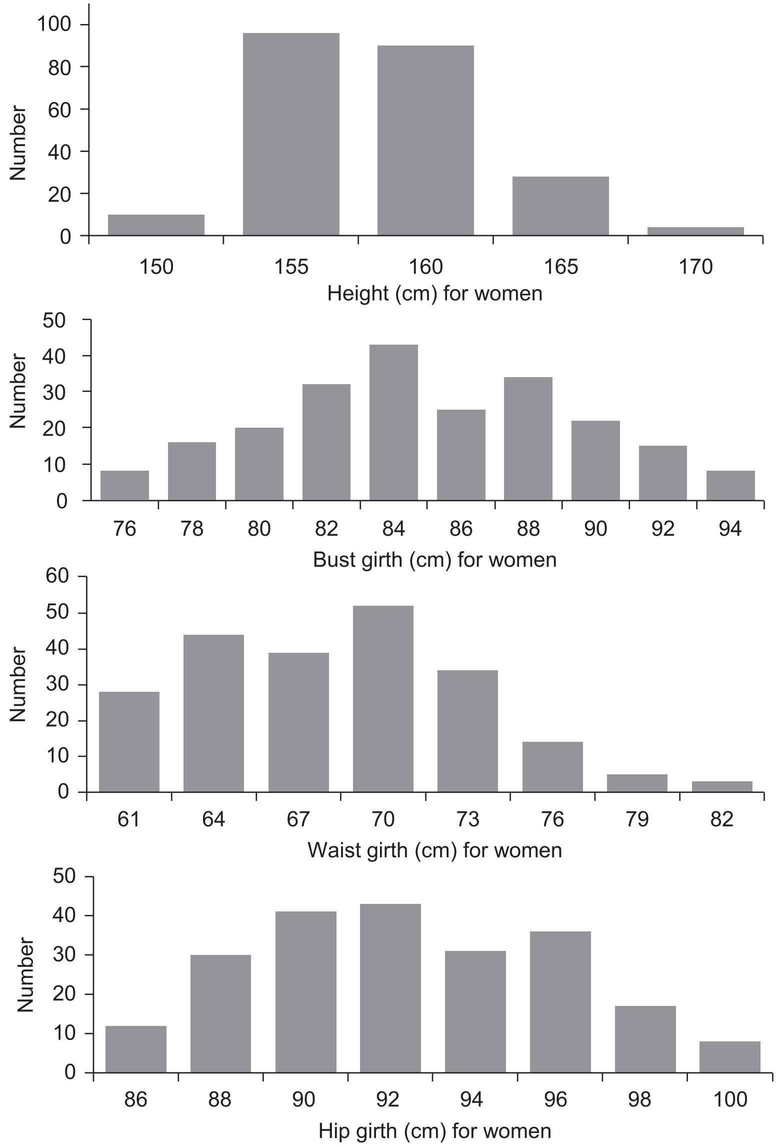
The data of the 2001 survey of the Korean Military have been used in order to improve the different sizes of soldiers' clothing. The 2001 survey concerning the physical conditions of 3800 soldiers and officers (3126 men and 229 women) was conducted using 2D and 3D measurement methods. All body dimensions were measured with the method defined by the ISO (ISO 3635, 1981; ISO 8559, 1989). The results convey a great size change in body size and shape in the last 10 years compared to the 1992 measurements. Regarding the garment industry, some dimensions presented in the survey are of major importance to insure good clothing fitness. Therefore, height, hip girth, chest girth and waist girth as well as a few vertical dimensions, such as arm length and inside leg length assume major importance. On the contrary, waist height is not, strictly speaking, required for the determination of clothing size, but is still useful information because it can be used to locate the vertical position of the waist.

Measurements of height, chest/bust girth, waist girth, hip girth, arm length, crotch height and waist height constitute basic data which are used to develop classifications of the body shapes and body proportions; hence, this information was analyzed in order to determine the evolution between surveys. The data on army men and women's height, chest/bust girth, waist girth and hip girth as well as the data on their waist height, crotch height and arm length, all of which determine the vertical positioning, were distributed according to age classes as shown in Figs 8.1 and 8.2. The average stature of army men was found to be 172.7 cm with a 95 percentile of 189.9 cm for young men in their twenties. In comparison with the 1992 data, which showed an average stature of 170.8 cm, there has been a 2 cm increase. According to the 2001 data, the average chest, waist and hip girths of army men were 94.1 cm, 77.5 cm and 95.2 cm, respectively. In 1992, the sizes of subjects in their twenties were 90.2 cm, 75.8 cm and 89.7 cm, respectively.



8.1 Height, chest girth, waist girth and hip girth means are 172.7 cm, 94.1 cm, 77.5 cm, 95.2 cm for Korean army men.

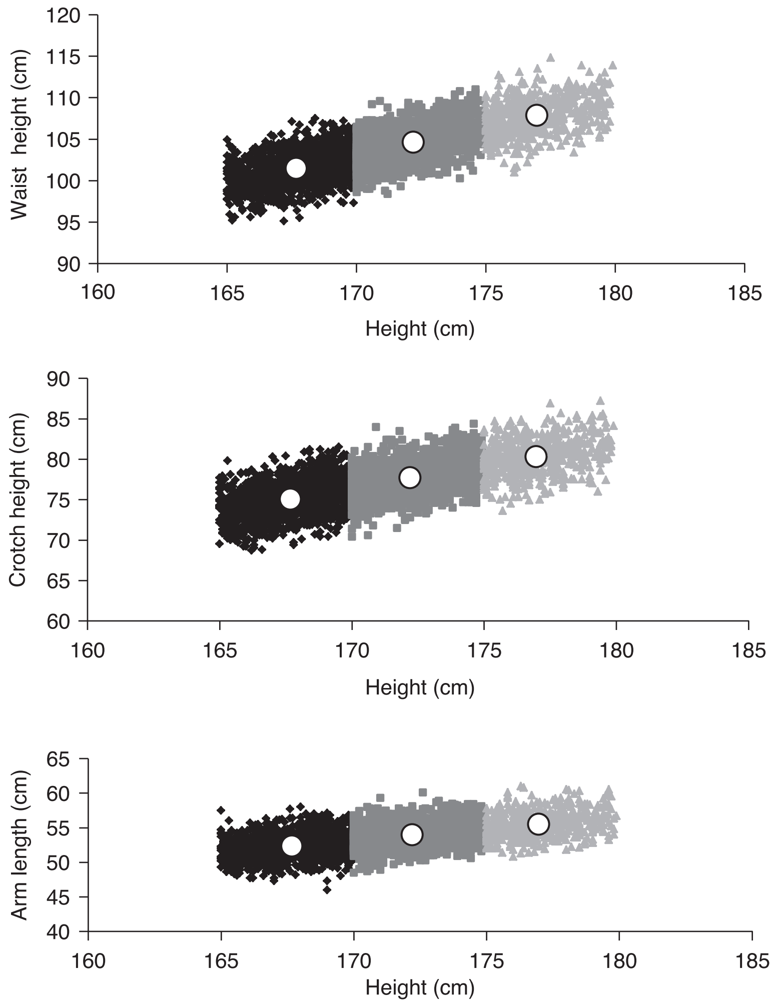
The stature of military Korean women was on average 160.7 cm with a 95 percentile of 176 cm. In comparison with the 1992 data, the new average height in 2001 is 1 cm higher. The 1992 values for military women in their twenties were 83.7 cm for bust girth, 65.9 cm for waist girth and 91.1 cm for hip girth. In 2001, the values were 85.7 cm, 70.2 cm and 93.3 cm, respectively; all values were on the rise.



8.2 Height, bust girth, waist girth and hip girth means are 160.7 cm, 85.7 cm, 70.2 cm and 93.3 cm for Korean army women.

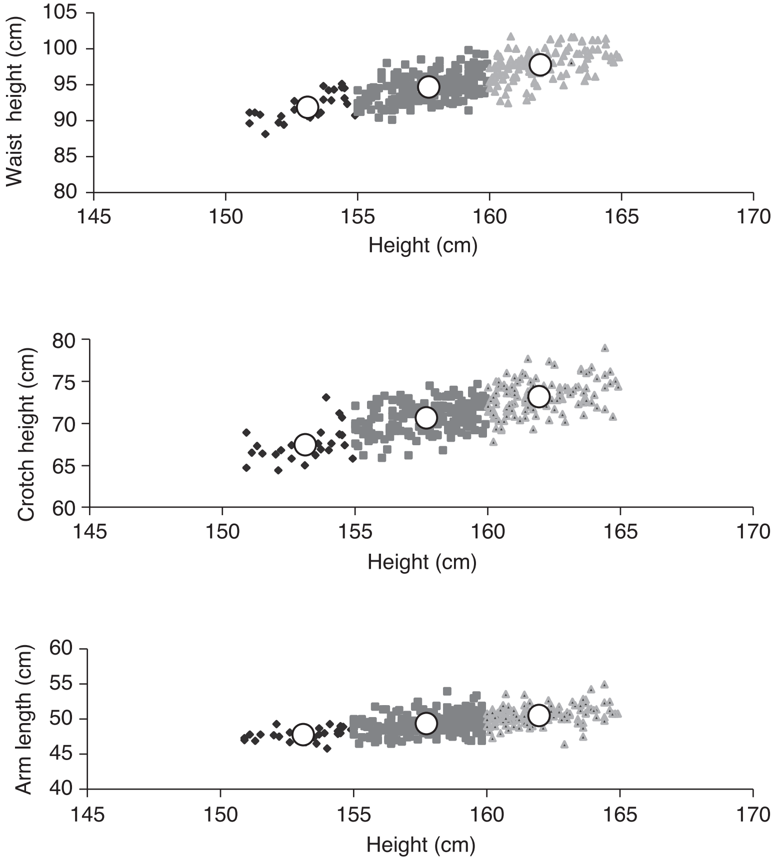
8.2.2 Vertical proportions according to height

The proportions of waist height, crotch height and arm length depending on the three height groups are shown in Figs 8.3 and 8.4. The vertical proportion ratio values to height in three different height groups of army men are 0.60, 0.45 and 0.31 times height, respectively, in waist height, crotch height and arm length.



8.3 Waist and crotch height,and arm length proportion to height for army men. Circles show the means of the range of each height sector.

In the case of army women, the vertical proportion ratio values depending on the height group were 0.61, 0.46 and 0.31 times the height, respectively, in waist height, crotch height and arm length. The proportion ratios of waist and crotch height according to height showed the same tendency between men and women. For the ratio of arm length to the height, there was no difference between genders.

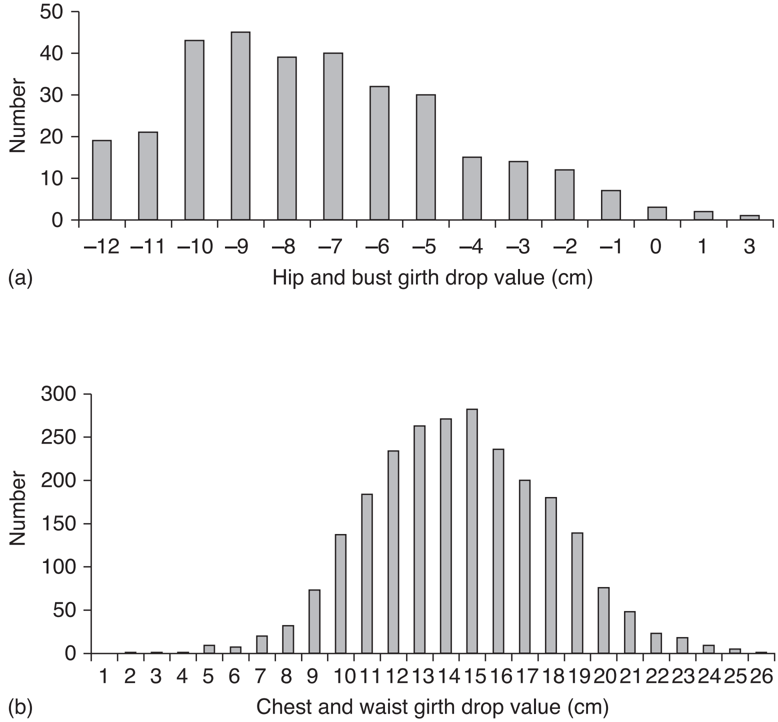


8.4 Waist and crotch height, and arm length proportion to height for army women. Circles show the means of the range of each height sector.

8.2.3 Drop distribution

The distribution of army men according to their chest-waist girth drop value and the distribution of army women according to their bust-hip girth drop value are shown in Fig. 8.5 in order to represent body types. All the surveys discovered that for any given hip girth, there can be a number of different bust girths irrespective of the three height groups (petite/short, regular, tall).

For army women, the main relationships between bust and hip girths were established as being as follows (Lee, 2001). Three figures are provided and are translated as A type (broader hip shape, i.e. bust girth is 12 cm smaller than hip girth), N type (regular shape, i.e. bust girth is 8 cm smaller than hip girth) and H

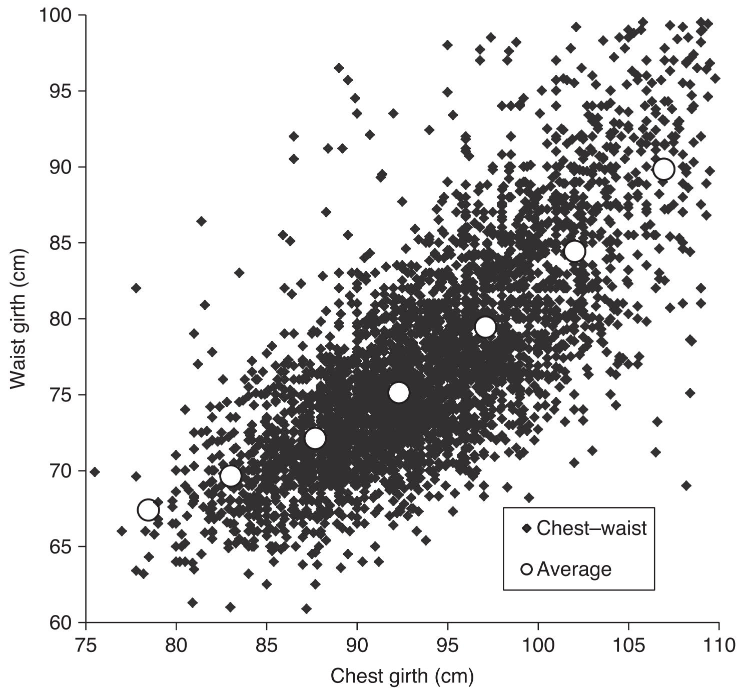


8.5 Drop values between (a) hip and bust girth for army women, and (b) chest and waist girth for army men.

type (slim hip shape, i.e. bust girth is 4 cm smaller than hip girth). Drop values according to height in army women are shown below:

	Body type		
	Petite	Regular	Tall
Height	150–155 cm	155–165 cm	165–175 cm
H type (Drop 4–6 cm)	Drop 4 cm	Drop 4 cm	Drop 6 cm
N type (Drop 8–10 cm)	Drop 8 cm	Drop 8 cm	Drop 10 cm
A type (Drop 12–14 cm)	Drop 12 cm	Drop 12 cm	Drop 14 cm

For army men, the main relationships between chest and waist girths were established as follows. Three figures are provided and are translated as Y type (slim shape, i.e. chest girth is 20 cm less than waist girth), A type (regular shape, i.e. chest girth is 16 cm less than waist girth) and B type (portly shape, i.e. chest



8.6 Waist girth distribution according to chest girth in army men.

girth is 12 cm less than waist girth). Drop values according to height in army men are as follows:

	Body type		
	Short	Regular	Tall
Height	155–165 cm	165–175 cm	175–185 cm
Y type (Drop 20–22 cm)	Drop 20 cm	Drop 20 cm	Drop 22 cm
A type (Drop 16–18 cm)	Drop 16 cm	Drop 16 cm	Drop 18 cm
B type (Drop 12–14 cm)	Drop 12 cm	Drop 12 cm	Drop 14 cm

The distributions of army men based on chest and waist girth drop values are plotted in Fig. 8.6.

8.2.4 Sizing systems of military uniforms

The most practical sizing system, which would suit the largest proportion of the population, is a system whereby three height groups are used, garment proportions are based on a medium category and the grading system employed ensures that these proportions are maintained throughout each size range. Table 8.1 classifies the basis of height, the key dimensions' median values and the cover rate of each

Table 8.1 Median values of key dimensions (a) and cover rate (b) in army women

(a) Median values of key dimensions in army women

Variables	Means	Median (civilian)	Age		
			18–20 yrs	20–29 yrs	Over 30 yrs
Height (cm)	160.4	(159.8)	159.2	160.9	160.2
Bust girth (cm)	85.7	(81.4)	85.7	85.5	90.1
Waist girth (cm)	70.2	(65.2)	70.3	70.1	75.2
Hip girth (cm)	93.3	(89.3)	93.0	93.1	96.9
Drop (Hip-Bust)(cm)	7.6	(8.1)	7.3	7.6	6.8

(b) Cover rate of each body type according to height in women

Body type	Height (cm)	Total (N)	Body type			
			Total (%)	H type (%)	N type (%)	A type (%)
Petite	150–155 cm	10	0.88	2.18	1.31	4.37
Regular	155–160 cm	95	9.17	18.34	13.97	41.48
	160–165 cm	89	3.92	21.84	13.09	38.85
Tall	165–170 cm	29	2.19	6.55	3.93	12.67
	Over 170 cm	4	–	0.44	0.88	1.32
Totals		227(N)	16.16(%)	49.35(%)	33.18(%)	98.69(%)

Table 8.2 Median values of key dimensions (a) and cover rates (b) in army men

(a) Median values of key dimensions in army men

Variables	Means	Median (civilian/ twenties)	Age		
			20–29 yrs	30–49 yrs	Over 50 yrs
Height (cm)	172.5	(171.5)	172.7	170.1	165.5
Chest girth (cm)	94.1	(91.6)	93.9	97.6	100.7
Waist girth (cm)	77.5	(74.0)	77.1	83.9	89.7
Hip girth (cm)	95.2	(91.6)	95.0	97.2	98.2
Drop (Hip-Bust) (cm)	16.6	(17.2)	16.8	13.7	11.0

(b) Cover rates of each height group according to age groups in army men

Body type	Height(cm)	Total N(%)	Age group		
			20–29 yrs(%)	30–49 yrs(%)	over 50 yrs(%)
Short	155–160 cm	42(100)	42(100)	–	–
	160–165 cm	322(100)	284(88.2)	35(10.9)	3(0.9)
Regular	165–170 cm	884(100)	795(90.0)	88(9.9)	1(0.1)
	170–175 cm	1376(100)	1307(95.0)	68(4.9)	1(0.1)
Tall	175–180 cm	956(100)	924(96.7)	32(3.3)	–
	Over 180 cm	383(100)	376(98.2)	7(1.8)	–
Total (N)		3963	3728	230	5

Table 8.3 Size chart of garments in army men

(a) Upper body garments

Size code		85A-R		90A-R	95A-R		100A-R		105A-R		110A-R		85A-T	90A-T
Key Dimension (cm)	Chest girth	85	85	90	95	95	100	100	105	105	110	110	85	90
	Waist girth	70	70	75	80	80	85	85	90	90	95	95	65	70
	Height	170~175											175–180	
Secondary Dimension (cm)	Age	20	30	20	20	30	20	30	20	30	20	30	20	30
	Hip girth	90	92	91	95	93	99	97	103	100	107	102	89	92
	Back width	39	41	41	42	41	43	43	44	44	45	45	39	41
	Back length	43	45	43	43	45	44	44	44	44	45	46	43	44
	Arm length	56	57	57	57	56	57	57	57	56	58	56	58	58
	Crotch length	74	73	75	78	77	81	81	82	83	88	84	76	76
	Waist height	105	104	104	105	104	105	105	105	104	104	102	108	108
	Crotch height	80	81	79	79	80	78	77	77	76	76	78	83	83

(b) Lower body garments

Size code		80–95			80–100		
Key Dimension (cm)	Waist girth	76–81			76–81		
	Hip girth	92–97			97–102		
	Height	Short 155–165	Regular 165–175	Tall 175–185	Short 155–165	Regular 165–175	Tall 175–185
Secondary Dimension (cm)	Crotch length	77	79	81	77	79	81
	Waist height	100	105	110	100	105	110
	Crotch height	75	80	85	75	80	85
	Thigh girth	58	59	59	60	60	61

Table 8.4 Size chart of garments in army women

(a) Upper body garments

Size code		80N-P	85N-P	90N-P	80N-R	85N-R	90N-R	95N-R	85N-T
Key Dimension (cm)	Bust girth	80	85	90	80	85	90	95	85
	Hip girth	88	93	98	88	93	98	103	93
	Height	150–155			155–165				165–175
Secondary Dimension (cm)	Waist girth	64	69	72	67	70	70	73	67
	Back width	38	37	39	36	37	38	38	39
	Back length	36	39	36	38	37	40	40	40
	Arm length	50	52	51	52	52	52	51	55
	Crotch length	70	67	73	70	71	67	68	71
	Waist height	95	94	94	98	97	97	98	105
	Crotch height	69	71	70	75	73	74	73	78

(b) Lower body garments

Size code		65–90			65–95		
Key Dimension (cm)	Waist girth	62–66			62–66		
	Hip girth	87–92			92–97		
	Height	Petite 150–155	Regular 155–165	Tall 165–175	Petite 150–155	Regular 155–165	Tall 165–175
Secondary Dimension (cm)	Crotch length	67	68	69	67	68	69
	Waist height	95	100	105	95	100	105
	Crotch height	70	74	78	70	74	78
	Thigh girth	54	54	54	54	55	55

body type of army women. Table 8.2 classifies the basis of height, the key dimensions' median values and the cover rate of each body type according to army men. The size and body shape characteristics of each size code of military men's uniforms are shown in Table 8.3. The size and body shape characteristics of each size code of military women's uniforms are presented in Table 8.4.

In the case of army men, size designation is based on the following three body dimensions: chest girth, waist girth and height. The range of height is 160–185 cm, which is divided into three groups at intervals of 10 cm between groups. The ranges of chest girth and waist girth are 85–115 cm and 70–95 cm, respectively. There are therefore four chest girth sizes, each with three height groups and with three figure types. The total number of possible sizes is 36, which ranges from the small narrow chested (90 cm) body type to the comparatively large, heavy type (110 cm). For example, size information of size code 95-A-R of army men in their twenties

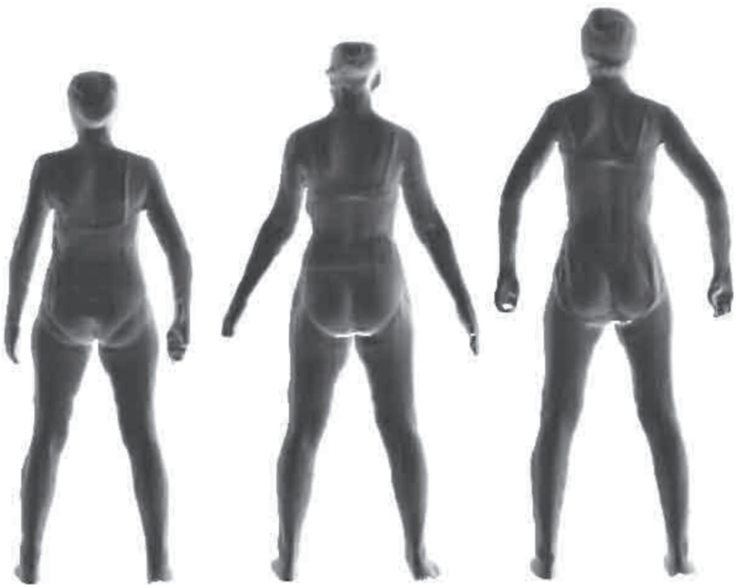
Size codes according to body size for men

Height	Short	Regular	Tall
Age	25 yrs	24 yrs	22 yrs
Height	168.5 cm	172.0 cm	174.0 cm
Chest girth	94.6 cm	93.7 cm	92.7 cm
Waist girth	74.4 cm	79.2 cm	88.0 cm
Hip girth	100.9 cm	95.6 cm	103.6 cm
Size code	95 (Y)-S	95 (A)-R	95 (B)-T

8.7 Different 3D body shapes according to size code for army men.

includes a height of 172 cm, a chest girth of 93.7 cm, a waist girth of 79.2 cm, and a hip girth, which is considered a secondary dimension, of 95.6 cm. Examples of the three different body shapes according to height are shown in 3D shapes in Fig. 8.7.

In the case of army women, size designation is based on the following three body dimensions: bust girth, hip girth and height. The range of height is 155–175 cm, which is divided into three groups at intervals of 10 cm between groups. The ranges of bust girth and hip girth are 80–100 cm and 90–105 cm, respectively. There are therefore four bust girth sizes, each with three height groups and with three figure types. The total number of possible sizes is 36. For example, size information of size code 80-A-R of army women in their twenties include a height of 162.5 cm, a bust girth of 80.2 cm, a hip girth of 93.6 cm, and a waist girth, which is considered as secondary dimension, of 64.2 cm. An example of the three different body shapes according to height is shown in 3D shapes in Fig. 8.8.



Size codes according to body size for women

Height	Short	Regular	Tall
Age	24 yrs	23 yrs	22 yrs
Height	156.0 cm	162.5 cm	172.0 cm
Bust girth	83.0 cm	80.2 cm	81.1 cm
Waist girth	68.7 cm	64.2 cm	62.6 cm
Hip girth	91.6 cm	93.6 cm	90.8 cm
Size code	85 (N)-P	80 (A)-R	80 (N)-T

8.8 Different 3D body shapes according to size code for army women.

For clothes in which a larger step size is sufficient, size is defined by letter codes. The size range of S, M and L for upper body garments in each size sector according to chest and bust is as follows:

Code	Meaning	Chest girth (men)	Bust girth (women)
S	Small	78–86	70–78
M	Medium	88–96	80–86
L	Large	98–106	88–96

This code represents chest girth for men and bust girth for women. Each range combines two adjacent size steps. The range can be extended to XS, XL or LL if necessary. The distribution rate in each size sector between height and bust girth for army women is illustrated in Table 8.5.

The size range of S, M and L for lower body garments in each size sector between height and waist girth for army men is presented in Table 8.6. The range could be extended to shorter MS (short group) or taller MT (tall group) height groups. The waist size range by each letter code is as follows:

Code	Meaning	Waist girth (men)	Waist girth (women)
S	Small	62–68	60–66
M	Medium	70–78	66–72
L	Large	80–88	72–80

The cover rate in each size sector between chest girth and waist girth for army men is summarized in Table 8.7.

8.3 Analysis of body proportions of Korean women

The anthropometric data of Korean women measured in 1997 (KATS, 1997) and the data measured from 2003 and 2010 (KATS, 2003, 2010), as well as the data measured from 2003–2004 (Lee, 2004) which was derived from 360 adult females between the ages of 20 and 60, were analyzed in this section to obtain information on Korean women's physical features. The 2004 data, generated by direct traditional measurement, sliding gauge measurement and 3D body scanner measurement, consisted of anthropometric data of 140 women in their twenties and of 220 middle-aged women. The anthropometric data included stature, six girth dimensions (bust girth, under-bust girth, waist girth, hip girth, abdominal girth and thigh girth), five breadth dimensions (inter-bust point breadth, chest breadth, waist breadth, hip breadth and acromion to acromion breadth), four depth dimensions (chest depth, waist depth, abdominal depth and hip depth), three height dimensions (waist height,

Table 8.5 Distribution of the bust girth according to height in army women

Bust girth	66 cm	68 cm	70 cm	72 cm	74 cm	76 cm	78 cm	80 cm	82 cm	84 cm	86 cm	88 cm	90 cm	92 cm	94 cm	96 cm	98 cm	100 cm	102 cm	104 cm	Total (N)
Height																					
140 cm																					0
								MP	5			**LP**	2				**LLP**	1			
145 cm																					0
150 cm						1	1		2	2		2			1	1					10
			S	2				**M**	95			**L**	55				**LL**	2			
155 cm					1	3	7	12	15	22	9	9	7	7	2	2					96
160 cm					1	2	6	6	11	16	14	18	10	4	2						90
								MT	13			**LT**	15								
165 cm						2	2	1	5	3	1	4	5	3	3						29
170 cm								1		1	1										3
175 cm													1								1
Total	0	0	0	0	2	8	16	20	33	44	25	33	23	14	8	3	0	0	0	0	229

Table 8.6 Waist girth distribution according to height for army men

Waist	60 cm	62 cm	64 cm	66 cm	68 cm	70 cm	72 cm	74 cm	76 cm	78 cm	80 cm	82 cm	84 cm	86 cm	88 cm	90 cm	92 cm	Totals
Height																		
150 cm					3													3
			SS	78				**MS**	195				**LS**	79				
155 cm			3	7	9	6	6	6				1	1		1		1	41
160 cm	1		9	18	31	42	42	41	33	19	17	25	17	9	8	1		313
			S	253				**M**	1382				**L**	495				
165 cm		6	13	35	59	115	133	102	94	78	64	46	37	29	18	15	15	859
170 cm	2	3	14	35	86	167	205	189	176	123	92	78	53	48	30	23	19	1343
			ST	97				**MT**	757				**LT**	295				
175 cm		1	8	25	51	65	135	132	143	96	65	55	38	31	23	19	15	902
180 cm				6	6	25	31	48	50	32	26	20	19	11	7	7	5	293
185 cm				2		4	4	10	6	7	7	4	2		3	3	2	54
Totals	3	10	47	128	245	424	556	528	502	355	271	229	167	128	90	68	57	3808

Table 8.7 The cover rate of S, M, L sizes in army men

Chest girth	76 cm	78 cm	80 cm	82 cm	84 cm	86 cm	88 cm	90 cm	92 cm	94 cm	96 cm	98 cm	100 cm	102 cm	104 cm	106 cm	108 cm	Total
Waist girth																		
60 cm			1	1		1												3
					S 392				**MY** 445									0
62 cm	1	1	2		2	3	1											10
64 cm		3	9	7	11	9	3	3	1									46
66 cm	1	7	7	19	29	24	20	9	10	1			1					128
68 cm	1	1	10	23	40	45	57	26	26	6	6	2					1	244
70 cm			7	15	46	72	83	101	47	32	13	5		2		1		424
					SB 180				**M** 1708					**LY** 319				0
72 cm			3	8	29	48	105	114	126	66	37	16	3	1		1		557
74 cm			2	5	16	25	67	130	102	102	43	21	9	3	2		1	528
76 cm			1	3	9	21	42	80	85	90	94	42	20	4	10			501
78 cm			1		1	6	8	43	65	74	64	43	29	17	1	1	2	355
80 cm			1			1	5	22	40	56	48	45	23	18	9	1	2	271
									MB 210					**L** 428				0
82 cm	1			1		2	4	9	20	25	53	48	22	28	6	5	2	226
84 cm					1	1	1	2	4	23	25	44	29	14	11	6	3	164
86 cm			1				1		1	5	18	26	31	23	8	7	4	125
88 cm								2		4	6	16	14	23	11	5	7	88

(*Continued*)

Table 8.7 Continued

Chest girth	76 cm	78 cm	80 cm	82 cm	84 cm	86 cm	88 cm	90 cm	92 cm	94 cm	96 cm	98 cm	100 cm	102 cm	104 cm	106cm	108 cm	Total
Waist girth																		
90 cm						1	2				5	8	10	13	11	9	4	63
														LB	103			0
92 cm						1		2	1	2	1	1	7	10	11	14	2	52
94 cm							2			1		5	6	6	6	6	6	38
96 cm							1				2	2	2	2	4	6	7	26
98 cm										1	1	1		2	6	2	7	20
100 cm															2	2	5	9
102 cm														1	1	1	3	6
Total	4	12	45	82	184	260	402	543	528	488	416	325	206	167	99	67	56	3884

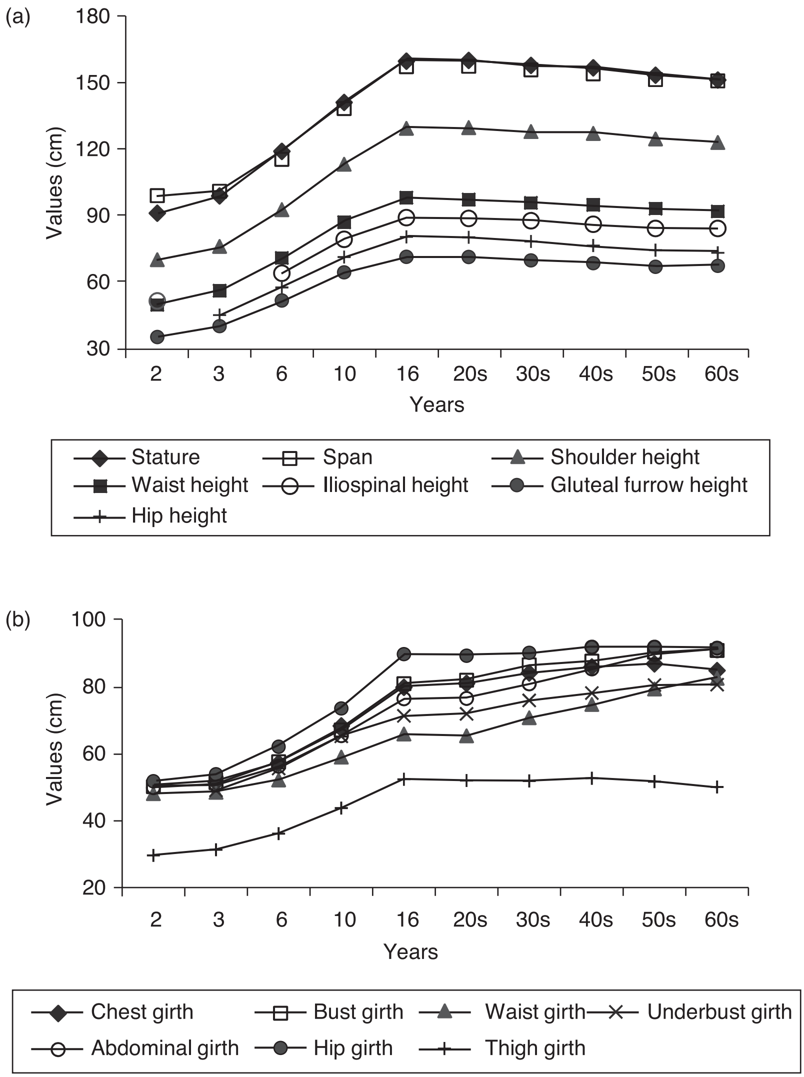
crotch height and hip height) and span, which were analyzed to indicate body shape and body proportion (Lee, 2003, 2004).Three dimensional modeling data, body silhouette data of the mid-sagittal plane, front median line, form front and form side views measured by the sliding gauge, and index values calculated from the differences between bust-waist, bust-hip girth and waist-hip girth measurements, were used as elements for body shape and proportion comparison. Data on size and annual growth changes of measurements of subjects aged from 0 to 60 years were used to clarify the tendency of maturation in body size. The 3D shape data and patterns of growth according to age are presented to emphasize Korean women's body shape, size and body proportion characteristics.

8.3.1 Size data and annual growth changes of measurements

The size changes of height, arm length, weight, bust girth, waist girth and hip girth measurements, which present body development features and annual growth changes of measurements by age 2–18 years in the Korean population, are shown in Figs 8.9 and 8.10.

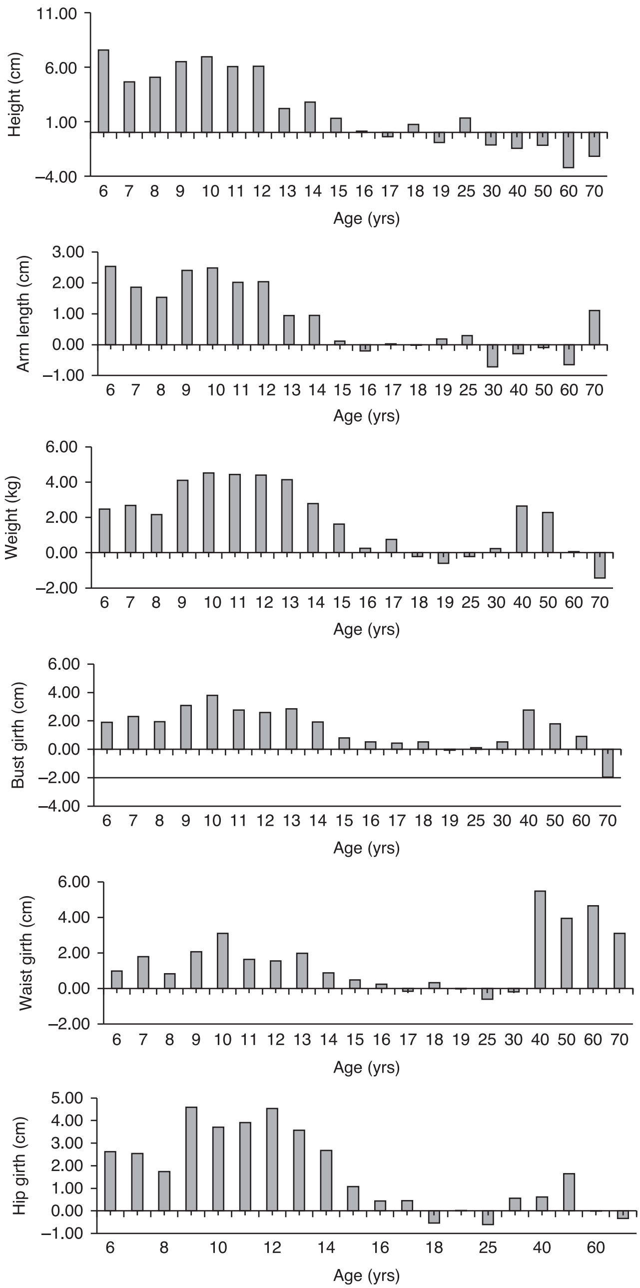
At age 2, a child reaches about one-half that of the adult standing height (height at age 2 is 80 cm while the height of the average woman is 160 cm). At age 5, the values of height, arm length, weight, bust girth, waist girth and hip girth are 110.28 cm, 34.05 cm, 18.70 kg, 55.19 cm, 50.12 cm and 58.16 cm, respectively. Each year, height increases 4–6 cm between the ages of 6 and 12 years, and 2–4 cm per year in other girth dimensions (bust and hip) aged from 12 to 15 years. On average, maturity of growth in height is reached at the age of 18–19 years for males and 16–17 years for females. In women, height increases from birth to maturity 3.2 times (for comparison it is 3.5 times for men) mainly due to rapid growth in leg length. The ultimate size and shape that a child attains as an adult are reached during 16–17years of age in women and 18–19 years of age for men. We assume that adult size values presented at age 16–17 in females and at age 18–19 in males as 100%. At age 6, height reaches approximately 74% of the adult size. Arm length, bust girth, waist girth and hip girth reach 72%, 71.7%, 77.7% and 67.9% of the adult size, respectively, at the age of 16–17. At age 6, weight reaches about 40% of the adult weight at the age of 18–19 (see Fig. 8.11(a) – from 1997 sample data). Compared to the 1997 data, the 2010 data shows an earlier maturation growth rate regarding the height value (74.3%) and the bust girth (72.0%) (Fig. 8.11(b) – from 2010 data).

Figure 8.12 illustrates the differences in the growth curve of both sexes for the height and weight of subjects aged between 6–20 years. The results are presented in two figures: Fig. 8.12(a) pertaining to the 1997 samples and Fig. 8.12(b) pertaining to the 2010 samples. There are no differences in curve pattern between the surveys. It appears that the somatotype reflects the general biological differences in shape and composition of boys and girls, as reported in Hall (1982). Boys appear to overtake girls in height around 13–14 years of age: while bust girth exceeds that of boys during preadolescence, and then, after adolescence (12 years of age), bust

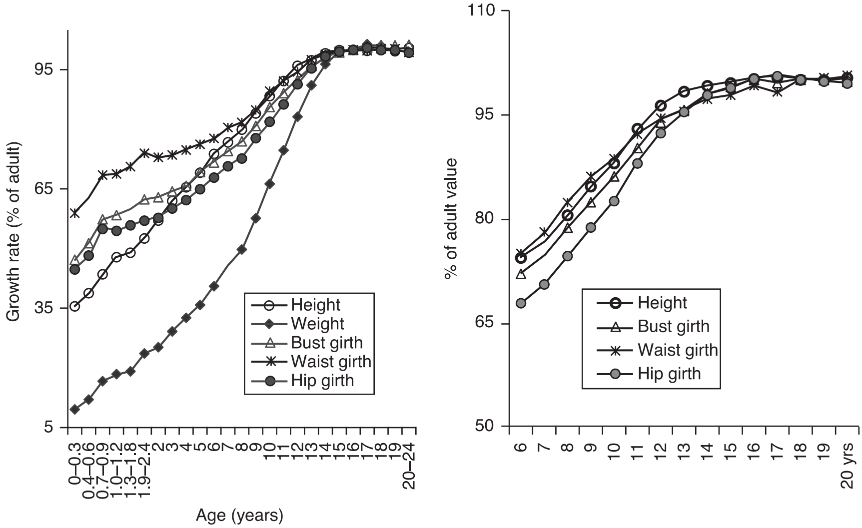


8.9 Changes of (a) height and (b) girth dimensions by age in women.

girth in boys continuously uptakes that of girls until they become adults. Limbs grow at different rates from the rest of the body: infants have a proportion index ratio of arm length to height of 32%. This ratio then reaches 31.4% at the age of 14–17. Body proportion is critical for manufacture of body fitting clothes. The proportion ratio index of body height dimension corresponding to height should be taken into consideration when designing good product construction systems (Lee, 1999c,d). Five body dimensions, namely total body height, eye height, shoulder



8.10 Annual growth changes of measurements from age 6 to 70 years in women.

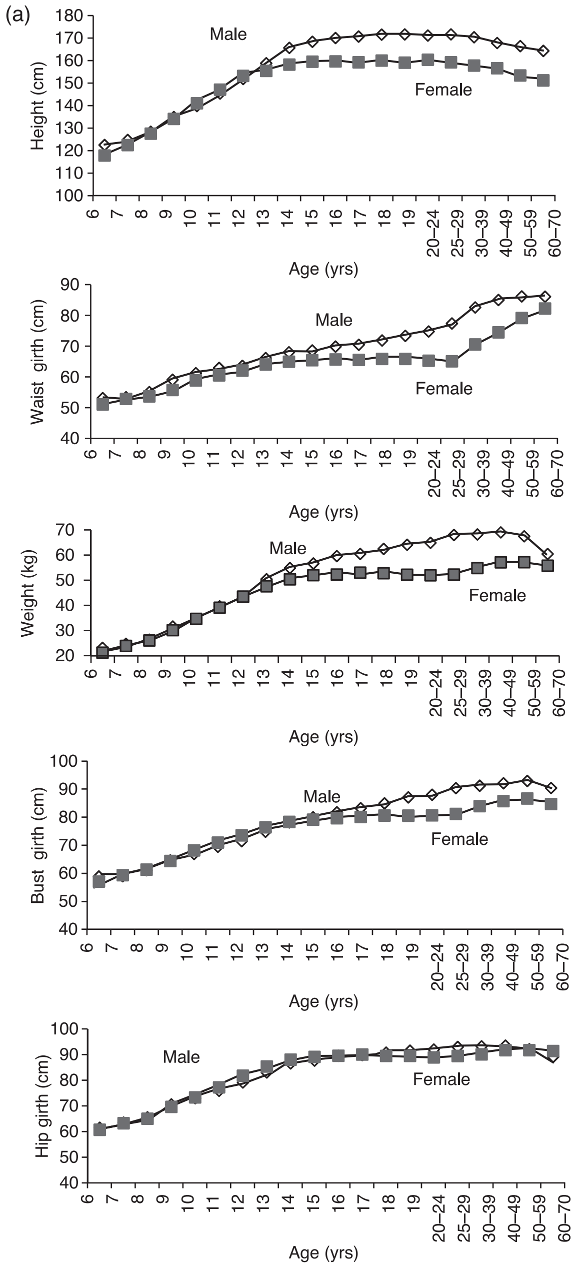


(a) (b)

8.11 Changes of annual growth rate age from birth to 24 years from 1997 data (a) and from 6 to 20 years from 2010 data (b). These measurements show the same growth pattern of Korean women's body shape. Both measurements show a similar pattern of change. Both measurements show that the height, bust, waist and hip sizes reach 100% of the adult size at age 16–17. However, as for age 6, 7 and 8, the height value respectively reaches 73.8%, 76.7% and 79.9% of the adult size according to the 1997 data, and respectively reaches 74.3%, 76.7% and 80.4% according to 2010 data. The 2010 data show that the height has a slightly more rapid growth than the 1997 data. The differences between the two periods are probably due to different physical activity, eating habits and other factors.

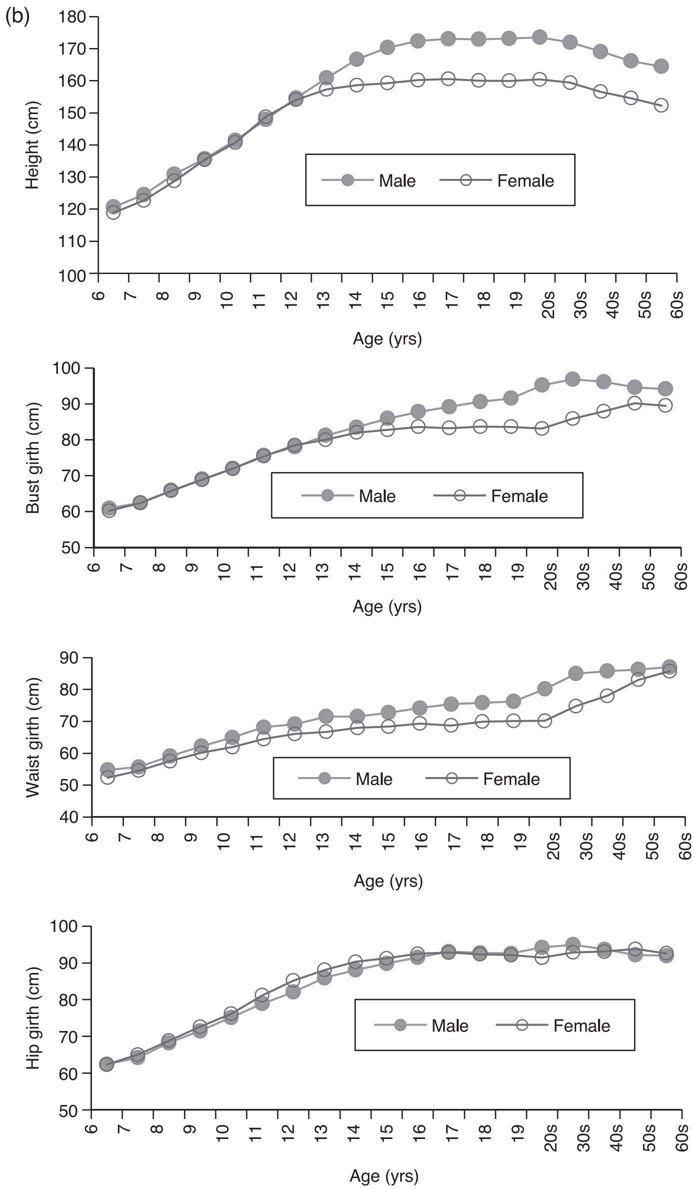
height, fingertip height, span and maximum shoulder breadth (Fig. 8.13), are considered to be very important parameters for well-fitted balanced design and functionality. The results show 0.93, 0.81, 0.38, 0.99 and 0.26 times the height in eye height, shoulder height, fingertip height, span and maximum shoulder breadth, respectively. These values can be used in work space and accessories design to predict the body length of each part (Hans *et al.*, 1990).

Total body height is clearly of primary importance for all growing children for clothes-fitting purposes, and this has been recognized in many national standards (ASTM D 6458, 2012; KS K 9403, 2009; KS K 9402, 2009; Lee, 1999e). In the body development features of the population group represented by the height, girl subjects are shown to grow upward rapidly during the height range 104–135 cm (approximately 4–10 years) thus remaining slim, whereas in the latter years, they tend to become stouter or broaden.



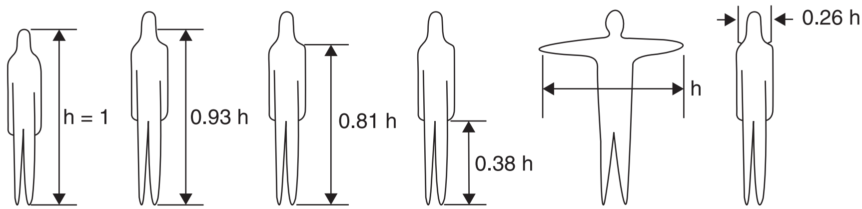
8.12 (a) Comparison of the growth curve in both sexes using the 1997 survey data set.

(*Continued*)



8.12 Continued. (b) Comparison of the growth curve in both sexes using the 2010 survey data set.

Upwards from the height value of 134 cm, a choice of two or more values in girth dimensions can be provided for a better garment fit, as in the following extract from Fig. 8.9. Increasing annual growth in bust, waist and hip girth, with 3.80 cm, 3.11 cm and 3.70 cm respectively at age 9–10 (with height of 134 cm) corresponds to female



8.13 Proportion ratio of the dimensions to total height (h). From left to right, panels show: total height, eye height, shoulder height, figure tip height, span and maximum shoulder breadth.

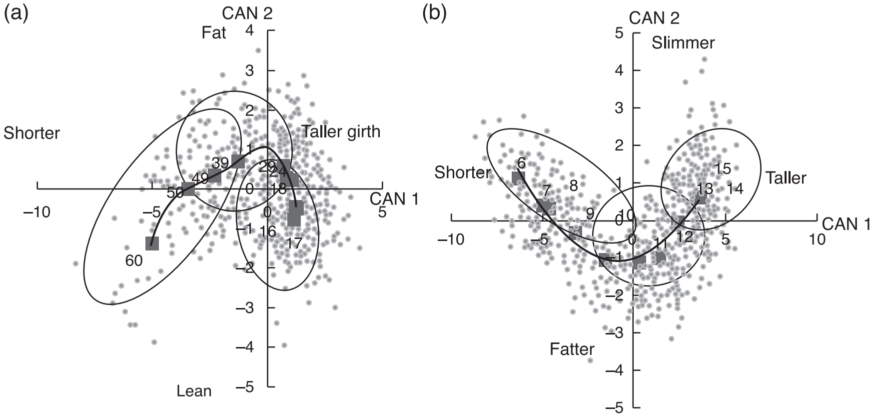
child-adult transformation in body shape. There is evidence of the effect of a superior social environment on body growth. There have been increases in growth rates in the more recent period compared to 1986, and there is a definite trend toward earlier maturation and greater total body build. A number of studies have been carried out on the growth stages of puberty (Marshall and Tanner, 1986; Tanner 1962, 1978; Duke, 1980). These reports showed that the puberty stages for boys appear at the age from 9.1 to 12.5 years, while girls reach the stages as early as 10.0 years. The growth stages are highly correlated to height growth as shown in Figs. 8.11 and 8.12.

As shown in the survey results, small differences in body proportions at birth are continuously multiplied by differential growth rates up until maturity, after which body shape changes are influenced by age, quality and quantity of food intake, exercise and social conditions. With advancing age, waist girth shows a considerable rise in subjects in their thirties. Hip girth and the overall body weight also show a sharp increase in subjects in their thirties.

8.3.2 Grouping of samples by age using canonical analysis

In order to analyze the characteristics of each body shape with respect to advancing age, factor analysis and canonical analysis were conducted on 60 measurement items in the group of subjects aged 6–15 years and in the group of subjects aged 16–70 years (see Fig. 8.14). Hammond (1957) stressed the importance of factor analysis of metric data and somatotype in body type research. He observed that the former, without preconceived ideas about what types might exist, allowed the data to demonstrate whatever clusters or groups there might be.

The use of one basic pattern for a group of persons greatly facilitates the manufacture of clothing. In order to accomplish this task and to make pattern grading possible, age grouping of persons sharing similar body shape characteristics is necessary. Grouping of samples by canonical analysis are conducted on 60 items in the group of subjects aged 6–15 years and that of 16–70 years. This method of analysis implements two variables: CAN 1 and CAN 2 corresponding to height and fat levels. The group of subjects aged from 6 to 15 years can be divided into three categories: the 6 to 9 years group, the 10 to 12 years group and the 13 to 16 years group, which are respectively referred to as girls, girls during puberty and



8.14 Canonical coefficients at two age groups: (a) age 16 to 70 years and (b) age 6 to 15 years.

young ladies. Each group corresponds to a morphological type of Korean women sharing the same growth pattern. In effect, the results showed that children in the 6 to 9 years group have a tendency to get slimmer during their growth, and in the following period (the 10–12 years group) the tendency is reversed with enlarging breasts, waist and hips. During the pre-adolescent period, body size undergoes a steep change in length and girth with broadening longer limbs and girth.

In the 16 to 70 years adult group, four categories that share the same growth pattern emerge. These four categories are referred to as ladies of ages 17–25, women of ages 25–40, middle aged women of ages 40–55 and women over 60. The analysis confirms that young Korean women in their twenties (16–25) have a tendency to be thin and elongated, whereas their torsos and waists get larger in width during their thirties (25–40 years). Moreover, the results show that Korean women continue to see their size in width get larger during their forties and fifties (40–55 years), but this trend reverses itself, in height as in width, in their sixties (60~). Elderly subjects are thinner and shorter and thus include undersized subjects.

8.3.3 Classification of body proportions of Korean women

Body size changes and body shape classification based on drop value between hip and bust girth

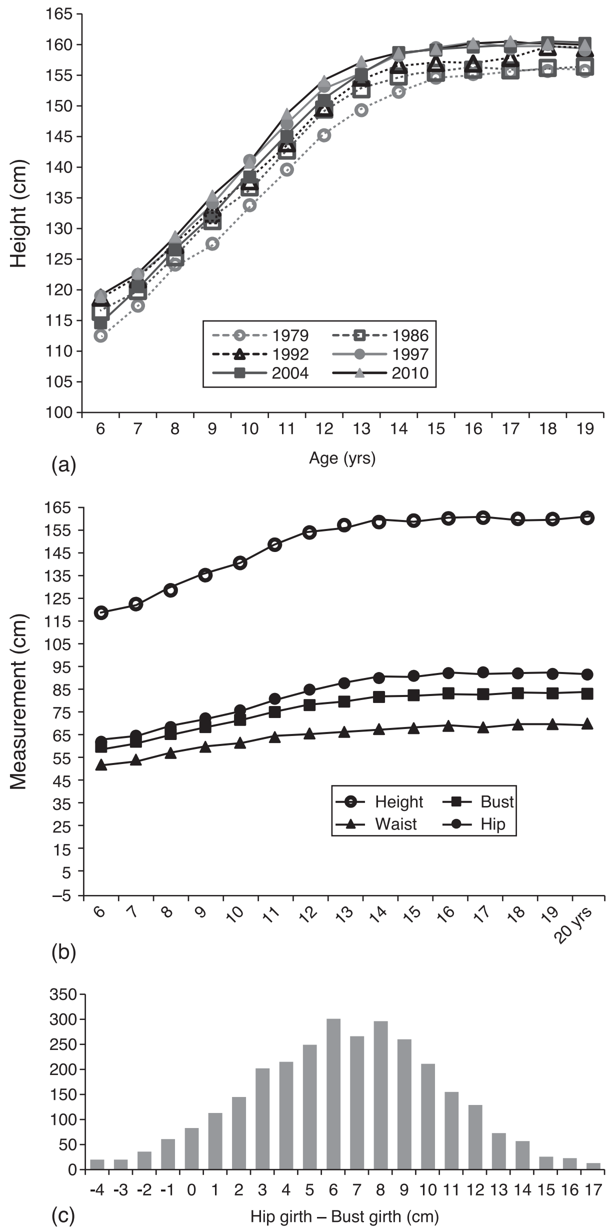
Figure 8.15 illustrates the changes of body size in subjects from 6–20 years. Figure 8.15(a) is an example showing a secular change in mean height of female subjects' samples taken from 1979–2010 aged from 6–20 years. In Korea, like many other countries, the mean height has been increasing in the last several decades. In such countries anthropometric data will be outdated sooner or later. The information on the speed of the secular change in height in the last several decades is useful to judge if the database is still representing the intended target population or to judge how long the latest database will serve as the reference data (Kouchi and Mochimaru, 2005). As shown in Fig. 8.15(a), the mean height value of women aged 18 years is 155.7 cm in 1979, 156.2 cm in 1986, 160 cm in 1997, 160.2 cm in 2003, and 160 cm in the 2010 data. Compared to 1979, the mean height of 1997 and 2010 increased about 4 cm to 5 cm. The mean height of adults remains almost the same in the surveys of 1997 and 2010. However, the mean height of girls aged from 8–9 years increased about 1–2 cm from 1997 to 2010 which shows the early fast maturing somatotype. Also, the mean height of girls aged from 8–9 years increased 7–8 cm in last several decades from 1986 to 1997. Figure 8.15(b) shows the change of mean values for height, bust, waist and hip of women aged from 6–20. The means of height, bust, waist and hip are respectively 160.2 cm, 83.6 cm, 69.3 cm and 92.8 cm at 19 years. These sizes can be regarded as the standard young adult female body shape in Korea as shown in Fig. 8.16.

Figure 8.15(c) suggests the drop value between bust girth and hip girth based on the data of women's body dimension taken in 2010 ($N=2978$). The drop values are concentrated in the range from 6 cm to 9 cm which approximately represent 40% cover rate of women. Data are divided into three zones corresponding to different body types of Korean women. The three body shapes range in descriptive titles from N (regular), H (slim hips) and A (broad hips) as follows: Type N, whose drop value ranges from 6 cm to 10 cm, can be defined as the standard type for Korean women. Women who have a drop value between 10 cm and 16 cm belong to type A. This type indicates that she has a well-developed hip compared to that of Type H (drop value of −1 cm–6 cm reflects a woman with a well-developed bust and slim hips). Figure 8.17 shows an example of body shape modeling of Korean women in their twenties using body size data plotting. This sort of figure realizes a comparison of existing shapes with the desired virtual ones (i.e. a well-proportioned body figure in which height corresponds to eight times the height of the head) and consequently determines the position of what is, on average, considered as a harmonious body shape by a given or targeted population.

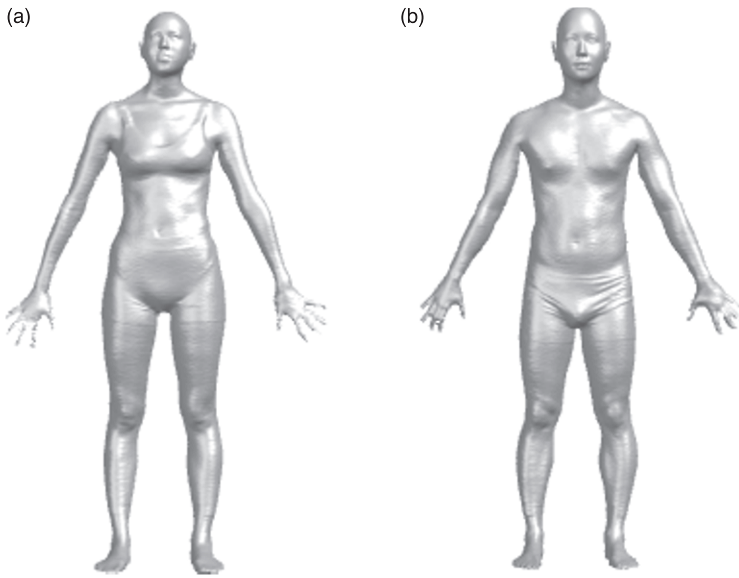
Body proportion information from 3D analysis

To obtain more accurate classification of body shape and body silhouette, a cross-sectional three dimensional shape data analysis of human body is essential. For this, a 3D body scanner, silhouetter, and sliding gauge are generally used to obtain the three-dimensional characteristics of the human body (Paquette and Brantry, 2000; Rioux, 2000; Robinette, 2000). Morphological information showing a three dimensional body shape and silhouette has been reported by Lee (2002). At the same time, indices between breadth measurements were also used to verify the simulation of the body shape group.

Figure 8.18 shows examples of body shapes (form front and form side) illustrated from the data measured with a sliding gauge and the plaster method.



8.15 Body size comparison of subjects from 6 to 20 years (2010 data): (a) comparison of 6 surveys shows that the mean height values of 1997 and 2010 are similar; (b) the size changes of women by age (2010 data); (c) the drop value distribution from 2010 data of Korean women (N=2978) aged 16 to 70 years.



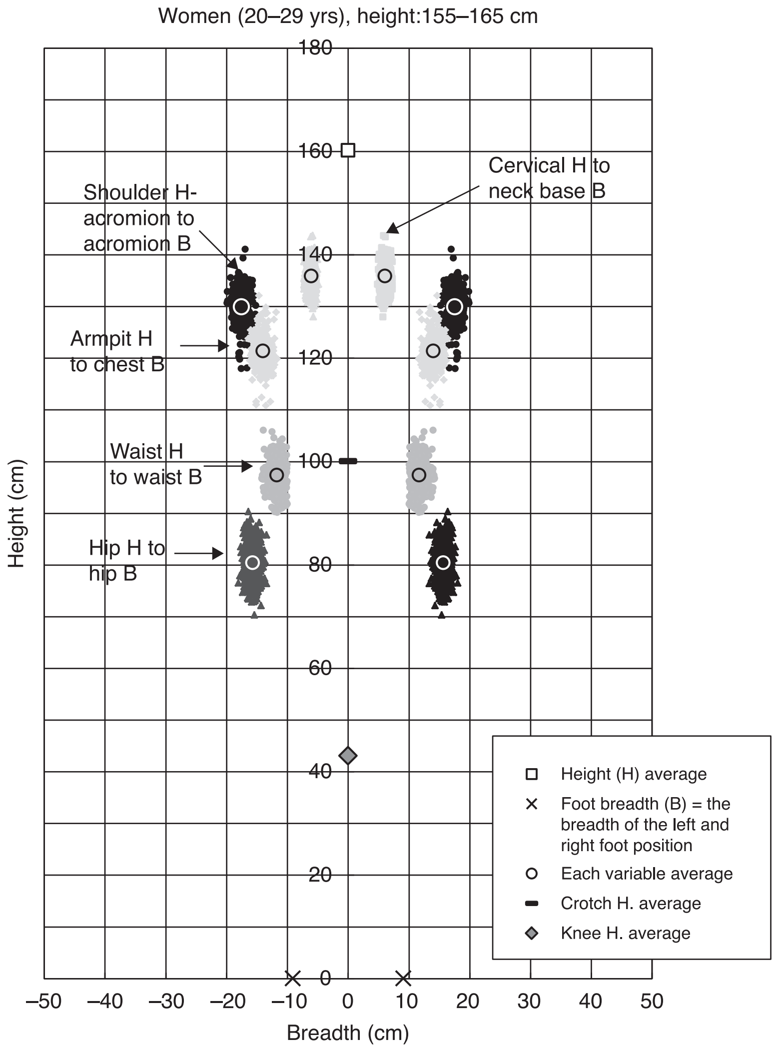
8.16 Standard Korean: (a) female standard type in twenties (height-bust-waist-hips (cm): 160-84-70-93) and (b) male standard type in twenties (height-chest-waist-hips (cm): 173-93-77-94).

Thus, according to Fig. 8.18, for subjects in their twenties belonging to the body type N and body type A, and on the assumption that the waist breadth from the form front view is valued at 1.00, their bust, bust point (nipple) and hip breadth rate values against waist breadth are as follows:

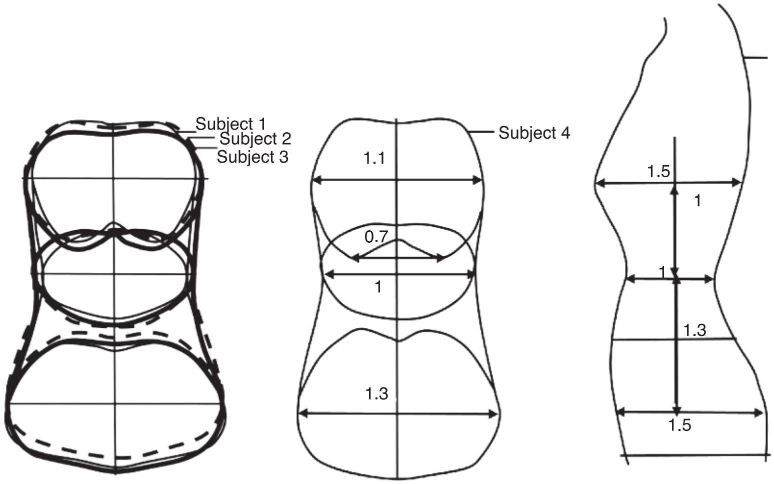
	Body type N	Body type A
Bust breadth	1.1	1.1
Bust point (nipple) breadth	0.7	0.6
Waist breadth	1.0	1.0
Hip breadth	1.3	1.4

These results may also be compared to the form side silhouette data of the body type N and body type A subjects in their twenties, assuming a value of 1.00 for waist depth; bust depth at the bust point (nipple) level and hip depth rate values respectively are as follows:

	Body type N	Body type A
Bust point (nipple) depth	1.5	1.4
Waist depth	1.0	1.0
Hip depth	1.5	1.4



8.17 Modeling of Korean women's body proportion using data plotting. Comparison between existing shapes with the desired virtual ones (i.e. an 8 × head-tall-well-proportioned body), and with body shapes from 235 women from 20 to 29 years selected as having harmonious body shape. According to the 8 × head-tall-well-proportioned body, the waist height position should be at 100 cm high for a woman being 160 cm high (see the horizontal line). The figure shows that the selected subjects' waist height ranges from 90 to 102 cm. Thus, the range is wide due to the diverse body shapes that we observed.

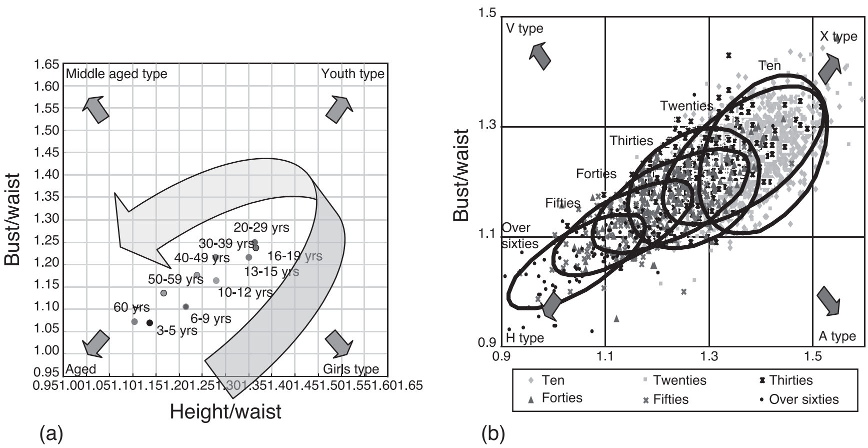


8.18 Body silhouette shape form front and side view (body type N).

Body type N presents the most beautiful proportioned and balanced S Line body silhouette from the front and side views compared to other body types, with a 1.3–1.4 ratio in hip breadth, a 0.6–0.7 ratio in nipple breadth, a 1.1–1.2 ratio in bust breadth and a 1.4–1.5 ratio in hip and bust depth.The calculated index data using girth measurements (values of B/W, H/W) were also presented as an element of body shape comparison. The distribution of the indices of Korean female subjects, according to their body shapes based on bust to waist and hip to waist indices is plotted in Fig. 8.19. The A body type refers to women with large hips, the X body type to women with large hips and a bust, the V type to women with a large bust and the H type to women with a large waist. The body shape of a woman changes from type X to type H as she ages. As shown in Fig. 8.19, the classification of four body shapes helps to understand the tendency of body shape changes of subjects from their teenage years to their sixties.

8.4 Human-centered product design for elderly women

To ensure the design technique and to develop the sizing system for aging women whose body shape changes in girth and depth, a number of studies (Lee, 2002, 2003) have been carried out on body shapes (form front and form side, 3D silhouette) and comfort feelings including physiological responses, using the already existing databases or constructing new ones. However, this is not an easy distinction to make using our present information, and much more work is needed on human comfort emotions for garments (especially, foundation garments produced for reshaping of



8.19 An example of body shape index plotting by calculation of the bust/waist and hip/waist values. (a) The tendency of body type changes by age: the index of B/W and H/W in women in their twenties ranges from 1.50 to 1.66. For women in their thirties and forties the index moves to the range 1.30–1.20; and then decreases to 1.00 in the fifties and sixties. (b) Data plotting: the cluster of both index B/W and H/W moves from index 1.55 to 1.0 according to body shape. From these data we can suggest that the oldest groups are undergoing the biggest change in waist size, with a smaller bust and a lean body.

the body) and physique. In this section, the results present the anthropometric features and comfort feelings of Korean women, especially middle-aged women (in their forties and fifties) who begin to express a stronger dissatisfaction with their body shape and expect clothes to correct their body shape.

8.4.1 Body size information of older women

An analysis of physical characteristics of middle-aged Korean women concerning their body shape was performed. The anthropometric data included stature, bust height, waist height, hip height, crotch height, bust circumference, waist circumference and hip circumference. Body measurements from the front form and side form views and calculated index values using the breadth and depth measurements of bust, waist and hip level, were used as elements for body shape comparison (Lee, 2003). The results from this study can be effectively used to design better-fitting clothes and improve the standards for products and sizing systems in order to maximize user satisfaction.

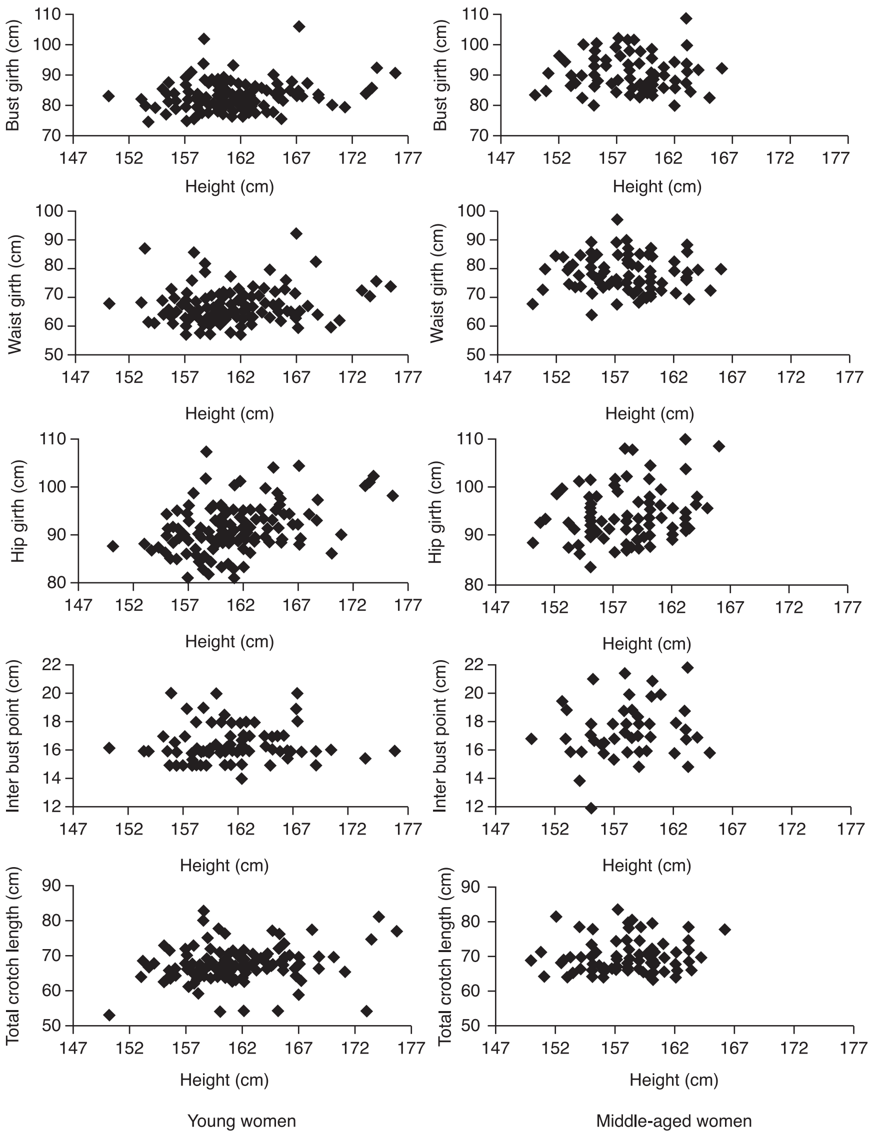
Here, anthropometric data variations showing the different physical features by age are compared in order to identify some changes in the body shape of Korean women who are primarily in their twenties or in middle-age (Table 8.8 and

Table 8.8 The comparison of the physical features in different age groups

Measurements (cm)	Age (years)				
	Twenties	Thirties	Forties	Fifties	Sixties
Height	160.0	157.8	156.7	153.4	151.2
Span	157.4	155.8	154.0	151.4	150.8
Shoulder height	129.7	128.0	127.1	124.6	123.0
Waist height	97.3	95.8	94.8	93.1	91.9
Iliospinal height	88.7	87.7	86.1	84.2	84.2
Gluteal furrow height	71.3	69.8	68.5	66.9	67.3
Hip height	80.2	78.4	76.5	74.4	73.2
Acromion to acromion breadth	35.1	35.4	35.2	35.0	33.8
Maximum shoulder breadth	40.2	41.3	41.8	41.4	40.2
Chest breadth	28.1	29.2	29.1	29.6	28.9
Waist breadth	23.4	24.8	26.1	27.2	28.4
Hip breadth	31.3	31.6	32.4	32.3	32.1
Chest depth	21.1	21.8	23.0	23.6	24.2
Waist depth	16.5	17.8	19.1	21.1	22.8
Abdominal depth	18.9	20.2	21.6	23.0	24.2
Hip depth	20.4	20.9	21.3	21.2	21.8
Chest girth	80.9	84.0	85.8	86.7	84.7
Bust girth	81.8	86.4	87.5	90.2	90.7
Waist girth	65.3	70.7	74.6	79.2	82.4
Underbust girth	71.8	75.8	78.0	80.4	80.5
Abdominal girth	76.4	80.8	85.2	89.5	90.6
Hip girth	89.1	90.0	91.7	91.7	91.4
Thigh girth	51.9	51.8	52.6	51.6	50.0

Fig. 8.20). For women whose stature is in the range of 160 – 164 cm, middle-aged women showed the most increase (11.4%) in waist girth, followed by increases in inter-bust point breadth (8.7%) and hip girth (3.4%) compared to women in their twenties.

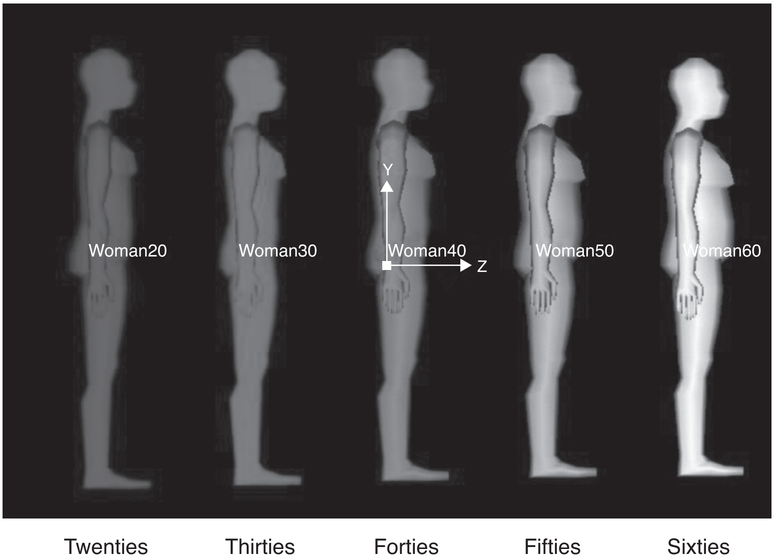
For women whose stature ranges from 154–159 cm, middle-aged women revealed the most increase (18.1%) in waist girth, followed by an increase in inter-bust point breadth (10.6%) compared with women in their twenties. The drop value between hip girth and bust girth was 7.3 cm for women in their twenties, 3.6 cm for women in their thirties, 4.2 cm for women in their forties, 1.5 cm for women in their fifties and 0.7 cm for women in their sixties. Regarding the front form and side form shape examination, assuming a value of 1.00 for waist breadth and waist depth, the results for middle-aged women were 0.7 and 1.2, respectively, in bust and hip breadth, and 1.1 and 1.1, respectively, in bust and hip depth. As women become older, changes in body shape become more obvious and differ in a wider range. Figure 8.21 also presents the changes of the mean body shape analyzed from the national data by different age groups with computer modeling.



8.20 Size comparison between young women and middle-aged women.

8.4.2 Emotional analysis of older women

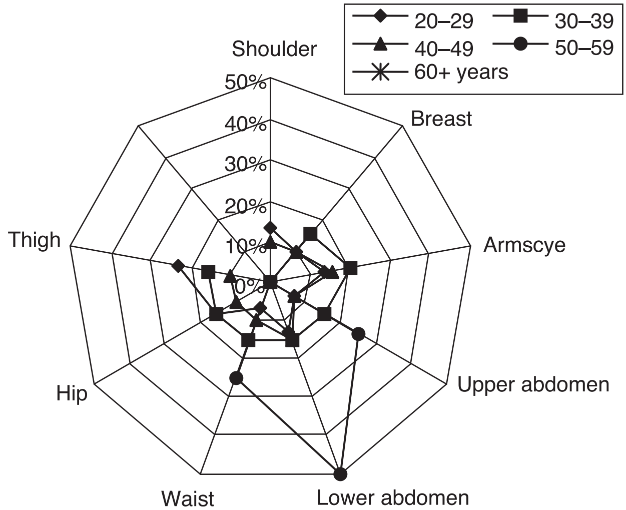
Since humans seek to achieve a beautiful, attractive body shape as a tool for enhancing human to human communication, developing a foundation garment must lead toward an improved body silhouette. To maximize consumer satisfaction, broad statistical information about the human body is of great concern (Lee,



8.21 3D modeling of body shape at five different age groups.

1999f). To achieve a human-centered product system based on comfort sensibility, including size suitability, our research will be centered on morphological information, such as harmony, satisfaction, comfort and fitting problems as well as the human mind.

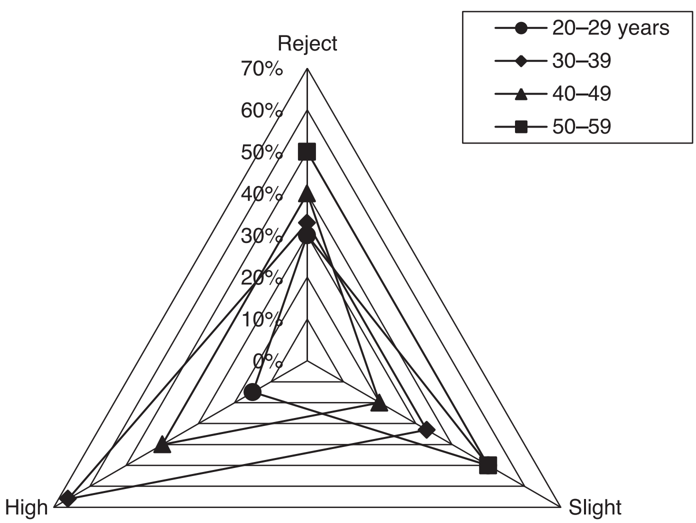
Product design should be paired with the following elements: the human body, human physiological capabilities, human mind, culture and social considerations which are even more essential for older women. In order to fulfill these needs, an anthropometry survey must not only provide the user with simple body size information but also offer 3-D body shape information, including body silhouette, body lines, body contour shape, etc.We proposed here a research concept for a human-centered product system based on comfort sensibility defined on life style and body features. Simultaneously, in order to obtain information regarding the emotional needs of older women for clothes, a questionnaire survey was administered to 100 women (Lee, 2003). The participants were asked to indicate their body parts that they were most dissatisfied with and wish to correct if they can, as well as the preferred level of tightness of clothes for correction. The body parts included shoulder, breast, arm, upper abdomen, lower abdomen, waist, hip and thigh.The emotional needs related to body shape resulting from the survey can be summarized as follows (see Fig. 8.22). For women in their twenties, the body parts that they are not satisfied with were thigh (25%), shoulder area (18%) and breast (15%). For women in their thirties and forties, complaints were mostly about their arm (24%), breast (17%) and abdomen (15%). In particular, for women in their fifties, the body parts that they were



8.22 Level of dissatisfaction with body shape according to age.

most dissatisfied with were lower abdomen (55%), followed by waist (28%) and upper abdomen (24%).

The preferred methods for correcting body shape are exercise and wearing special clothes. Middle-aged women preferred using customized innerwear or shaped-clothes to correct their body shape. Even though women in their fifties



8.23 Desired pressure comfort feelings in brassiere.

were not satisfied with their breasts due to loss of elasticity, they did not like the feeling of pressure from their brassiere. However, women in their thirties, who expressed a strong complaint about their breasts, preferred to use brassieres to correct their breasts regardless of the feeling of pressure, as shown in Fig. 8.23.

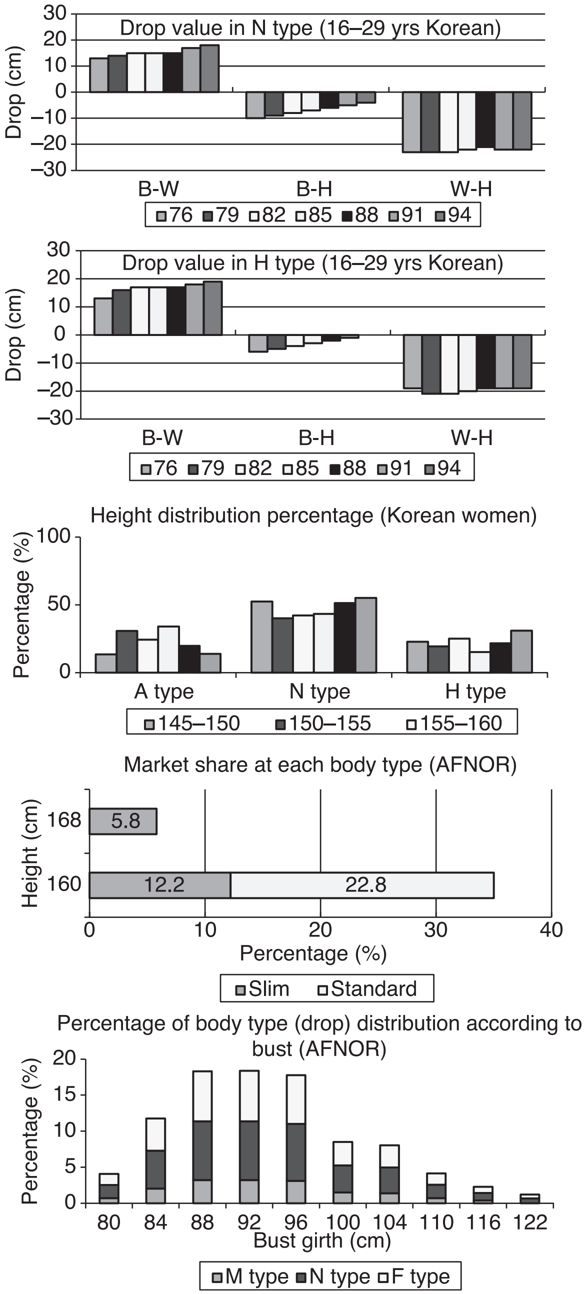
8.5 Korean Standard (KS) sizing systems for women's garments

In order to determine the women's garment sizing system KS, we analyzed 50 items related to garment construction and body shape changes. The most important features for the sizing system were as follows:

- Grouping of samples by age classes. Classes were defined by a community of body shape characteristics. To this end, we analyzed our data using factor and canonical analysis. Categories entitled 'girls', 'young ladies' and 'women' related to subjects aged between 5 and 13 years, 14 and 17 years and 17 and 60 years, respectively.
- Body shape grouping. For body shape grouping, we adopted the bust-hip drop value for women in order to distinguish the existing body types, thus utilizing methods used by ISO (ISO 3637, 1977) and many other standards (JIS L 4005, 2001; AFNOR NF G 03–002, 1977; ASTM D 5585, 2011). Three body shapes are presented as below.
- Size intervals. Body size designations for bust and hip girth are presented at inter-size intervals of 3 cm, and of 5 cm for height dimension.
- Key dimensions. Tables are based on the three basic (control) dimensions specified by ISO, namely bust, hips and height.

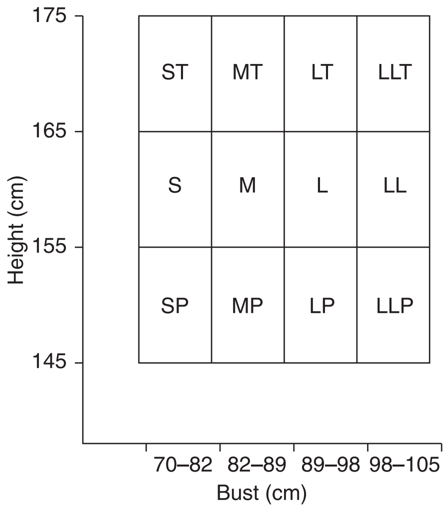
One of the aims of the above work and analysis has been trying to minimize the number of sizes to be defined while maximizing their cover rates in order to facilitate the production work of the industry. The drop values distribution under each body type and cover rate are shown in Fig. 8.24. Body type is classified into three groups according to the drop value of bust and hip measurements. Type N whose drop value is 6 cm, falling in the size range 4 cm to 10 cm, can be defined as the regular Korean women body type. Women whose drop value of 12 cm falls in the 10 to 16 cm range, belong to type A:

Height	Petite 145~155 cm	Regular 155~165 cm	Tall 165~175 cm
Body type			
N type (Drop 6)	Drop 4~10 cm	Drop 4~10 cm	Drop 6~12 cm
A type (Drop 12)	Drop 10~14 cm	Drop 10~16 cm	Drop 12~16 cm
H type (Drop 0)	Drop -4~4 cm	Drop -1~5 cm	Drop 0~6 cm



8.24 Drop values and percentage comparison of three body types.

The size range of the three key dimensions and intervals are determined as follows. Bust dimension ranges from 73 cm to 106 cm, hip dimension from 78 cm to 104 cm and waist girth from 73 cm to 106 cm. Bust and hip measurements are established at intervals of 3 cm and waist dimension at intervals of 2 cm. Height dimension, which ranges from 145 cm to 175 cm, is divided into three groups, referred to as 'petite', 'regular', and 'tall' with an interval of 10 cm. In the case of upper body garments of women in their twenties, the letter code size ranges corresponding to S, M, L and LL are as follows:



The median value of the key dimensions and cover rate of the three body types based on the drop value between bust girth and hip girth are shown in Table 8.9.

Table 8.9 Median values of key dimensions (a) and cover rates of each body type corresponding to height (b)

(a) The median values of chosen variables

	Age			
	18–70 years	18–29 years	30–49 years	Over 50 years
Height (cm)	158.7	159.8	157.4	154.3
Bust girth (cm)	84.9	82.5	86.2	90.1
Waist girth (cm)	70.9	66.2	73.7	80.7
Hip girth (cm)	91.0	90.6	92.6	92.9
Drop(H-B) value (cm)	7.0	8.1	4.1	2.8

(*Continued*)

Table 8.9 Continued

(b) The cover rates of each body type in women

	Height	Body type			
		A type (%)	N type (%)	H type (%)	Total (%)
Petite	145–150 cm	13.4	52.4	22.8	88.6
	150–155 cm	30.8	40.1	19.3	90.2
Regular	155–160 cm	24.4	42.2	25.1	91.7
	160–165 cm	34.1	43.3	15.2	92.6
Tall	165–170 cm	19.8	51.3	21.7	92.8
	Over 170 cm	13.8	55.2	31.0	100

8.5.1 Size chart of Korean women according to height

Size scales between bust girth and hip girth in the 160–165 cm height group are shown in Table 8.10. Relationship between waist girth and height in the 17–70 years group is shown in Table 8.11. By comparison, ASTM size, corresponding to KS, is presented in Table 8.12. KS 55 corresponds to ASTM 4, with bust, hip and height size of 85-92-160 cm. Thus, KS size is slightly smaller regarding hip girth compared to ASTM size.

8.5.2 Sizing systems in the KS K 0051 (2009)

In KS K 0051(2009), bust and hip measurements are established at intervals of 3 cm and 5 cm for height dimensions ranging from150 cm to 165 cm. Body type is classified into three groups according to the drop value between bust girth and hip girth. Type N whose drop value is 6–9 cm, can be defined as the standard (regular) Korean women body type. The general size chart of Korean women in KS K 0051 (2009) is shown in Table 8.13. The cover rates accomplished in each type according to age groups are shown in Table 8.14. Letter codes S, M, L, and XL representing size ranges of bust girth, waist girth and hip girth in each size code are shown in Table 8.15. Cover rate (%) of each size code S, M, L, and XL in bust and hip girth, according to age group, is shown in Table 8.16.

In Table 8.16, the medium size code is essentially based on subjects in their thirties, and the distribution of subjects in their twenties is concentrated in the small size section. This sizing system may diminish the efficiency of good fitting. By comparison with the 1998 data, a review of the key dimensions of 44, 55 and 66 sized subjects shows that waist girth has increased by 2–3 cm. Generally, the body shape of subjects in their twenties has increased in girth at the levels of waist and hip.

Table 8.10 Size category between bust girth and hip girth of women of 160–165 cm height

Hip	78 cm	80 cm	82 cm	84 cm	86 cm	88 cm	90 cm	92 cm	94 cm	96 cm	98 cm	100 cm	102 cm	Total (%)
Bust														
67 cm		0.14		0.14	0.14									0.41
70 cm	0.14	0.41	0.41	0.41	0.55	0.14								2.07
73 cm	0.14		1.8	1.24	1.8	1.38	0.14	0.14						6.63
76 cm	0.14		0.83	2.87	4.97	3.59	2.07	0.55	0.14		0.14			14.5
79 cm		0.14	0.83	2.35	3.59	5.94	5.11	2.21	0.69	0.28				21.13
82 cm		0.28	0.14	1.1	2.62	2	5.52	4.97	3.45	0.97	0.28	0.14		22.38
85 cm			0.14	0.14	0.89	2.76	3.45	3.31	3.31	2.21	1.24			17.27
88 cm					0.28	0.14	1.52	2.85	2.49	0.83	0.69		0.14	8.43
91 cm					0.14		0.28	0.83	1.24	0.55	0.97	0.41		4.42
94 cm						0.14		0.14	0.83	0.41	0.41			1.93
97 cm							0.14		0.28		0.14			0.55
100 cm											0.14			0.14
103 cm														0.14
106 cm														
109 cm														
Total %	0.41	0.97	4.14	7.48	14.78	16.99	18.23	14.5	12.43	5.25	4.01	0.55	0.28	100

Table 8.11 The distribution (%) between waist girth and hip girth of women aged 17–70 years

Waist	52 cm	55 cm	58 cm	61 cm	64 cm	67 cm	70 cm	73 cm	76 cm	79 cm	82 cm	85 cm	88 cm	91 cm	94 cm	97 cm	103 cm	Total (%)
Hip																		
72 cm									0.04									0.04
74 cm																		
76 cm		0.04	0.08		0.08													0.19
78 cm		0.39	0.43	0.12	0.04		0.04											1.01
80 cm	0.08	0.47	0.47	0.82	0.19	0.08		0.16										2.26
82 cm	0.12	0.54	1.79	1.71	1.17	0.19	0.16	0.04		0.04	0.04							5.80
84 cm	0.08	0.19	2.37	3.19	2.61	1.01	0.62	0.12	0.08									10.27
86 cm	0.04	0.23	1.95	4.82	4.63	1.75	1.28	0.70	0.27	0.16		0.19	0.04	0.08				16.15
88 cm	0.04	0.12	1.25	4.28	4.44	2.92	1.71	0.89	0.66	0.19	0.08	0.12	0.04	0.04		0.04		16.81
90 cm		0.04	0.23	1.91	4.01	4.12	2.33	1.09	0.82	0.39	0.51	0.43	0.08	0.08	0.04	0.04		16.11
92 cm			0.23	1.17	2.02	3.35	2.57	1.52	1.05	0.70	0.27	0.27	0.19	0.12	0.04	0.12		13.62
94 cm				0.31	0.86	1.91	1.56	1.87	1.01	0.54	0.35	0.39	0.23	0.08	0.16	0.08		9.34
96 cm				0.08	0.43	0.58	1.28	1.01	0.47	0.35	0.35	0.12	0.04	0.12				4.82
98 cm				0.08	0.19	0.35	0.35	0.35	0.43	0.19	0.31	0.19	0.08	0.04	0.04		0.04	2.65
100 cm						0.04	0.08	0.04	0.12	0.12	0.08		0.08	0.04	0.04	0.04		0.66
102 cm								0.04	0.08		0.04				0.08	0.04		0.27
Total (%)	0.35	2.02	8.79	18.48	20.66	16.30	11.98	7.82	5.02	2.68	2.02	1.71	0.78	0.58	0.39	0.35	0.04	100

Table 8.12 Comparison of KS size designation system corresponding to ASTM (units: cm)

	Code				
	KS44=ASTM2	55=4	66=6	77=10	88=12
Size	82–88–155	85–92–160	88–96–160	94–100–165	97–106–165
Height	155	160	165	165	168
Bust	82	85	88	94	97
Waist	64	68	71	75	79
Hip	88	92	96	100	106

Table 8.13 General size designation for upper body garments by KS K5001, 2009

Dimensions		Measurement reference for size codes:		
		44	55	66
		S	M	L
Key dimensions (cm)	Bust girth	82	85	88
	Hip girth	88–91	90–95	94–97
	Height	155	160	165
Secondary dimensions (cm)	Waist girth	63–68	65–72	70–77
	Back length	37	38	39
	Arm length	53	54	55
Drop (hip girth – bust girth, cm)		6–9	5–10	6–9

Table 8.14 Cover rate (%) at each body type and waist type according to age groups

(a) Cover rate (%) at each body type according to age groups

Body type	Drop value (hip – bust girth)	Age (years)				Total (%)
		18–29	30–39	40–49	50–59	
N type	3–9	19.00	14.43	7.54	3.79	44.76
A type	9–21	21.28	6.72	2.37	0.65	31.02
H type	–14–3	3.02	7.24	6.12	7.84	24.22

(b) Cover rate (%) at each waist type according to age groups

Waist type	Drop value (hip – waist girth)	Age (years)				Total (%)
		18–29	30–39	40–49	50–59	
Regular waist	14–22	12.45	16.29	9.31	3.79	41.84
Slim waist	22–38	29.60	7.50	2.11	0.47	39.68
Broad waist	–4–14	1.25	4.61	4.61	8.01	18.48

(*Continued*)

Table 8.14 Continued

(c) Cover rate (%) of the three body types against waist type

Waist type	Body type			Total (%)
	N type	A type	H type	
Regular waist	27.10	5.51	9.22	41.84
Slim waist	14.05	25.33	0.30	39.68
Broad waist	3.62	0.17	14.69	18.48
Total (%)	44.77	31.02	24.21	100.00

Table 8.15 Size range of the bust girth, waist girth and hip girth in letter codes S, M, L, XL

(a) S, M, L, XL size range of the bust girth in each size code

Size code	Key dimension (cm)	Secondary dimensions (cm)		
	Bust girth	Height	Waist girth	Hip girth
S	72–82	155	64.9	88.3
M	82–89	160	71.4	91.7
L	89–98	165	78.8	94.9
XL	98–109	170	87.2	99.4

(b) S, M, L, XL size range of the waist girth in each size code

Size code	Key dimension (cm)	Secondary dimensions (cm)	
	Waist girth	Height	Hip girth
S	58–69	155	88.7
M	69–77	160	92.4
L	77–88	165	95
XL	88–101	170	99.6

(c) S, M, L, XL size range of the hip girth in each size code

Size code	Key dimension (cm)	Secondary dimensions (cm)	
	Hip girth	Height	Waist girth
S	80–88	155	66.8
M	88–95	160	71.6
L	95–100	165	77.5
XL	98–106	170	86.4

Table 8.16 Cover rate (%) of each size code S, M, L, XL according to different age groups

Bust girth, code (cm)	Hip girth, code (cm)	Age (years)				
		18–29	30	40	50	Total (%)
S (72–82)	S (80–88)	11.57	5.05	1.36	0.48	18.46
	M (88–95)	8.84	2.21	0.59	0.18	11.82
	L (95–102)	1.51	0.48	0.04	–	2.03
	XL (102–110)	0.07	–	–	–	0.07
M (82–89)	S (80–88)	2.73	3.28	1.69	1.51	9.21
	M (88–95)	7.55	5.49	3.43	1.29	17.76
	L (95–102)	5.16	2.73	0.88	0.37	9.14
	XL (102–110)	0.55	0.15	0.11	0.04	0.85
L (89–98)	S (80–88)	0.11	0.33	0.44	0.70	1.58
	M (88–95)	1.07	1.95	2.36	2.65	8.03
	L (95–102)	2.25	3.24	2.50	2.58	10.57
	XL (102–110)	1.36	0.63	0.44	0.26	2.69
XL (98–109)	S (80–88)	–	–	–	–	–
	M (88–95)	0.04	0.07	0.11	0.66	0.88
	L (95–102)	0.22	0.74	0.59	1.66	3.21
	XL (102–110)	0.96	0.77	0.63	1.36	3.72

8.6 Compatibility of sizing systems

ISO standards include the ISO/TC 133 norm pertaining to clothing that is applied in most European countries. As member states, European countries respect ISO standards when establishing their clothing size standards and size labeling system. However, despite ISO's efforts, the countries could not neglect consumers' preference for a national clothing sizing system with which they are familiar, and thus, still continue to use the former national sizing system. Therefore, clothing based on the same physical features follows different sizing systems. Even when following the same sizing system, in practice, the corresponding measurements are different and cause confusion to consumers who seek imported products or products from abroad. For instance, 92 cm bust girth clothing is labeled differently in different countries as shown below:

Japan	France	UK	Italy
15	40	14	44

Moreover, measurements in various countries corresponding to the identical size code 40 are as indicated overleaf:

Size designation system in the case of size code 40

	France	Germany	Italy
Bust (cm)	92	92	84
Waist (cm)	69	76	62
Hip (cm)	96	100	90
Height (cm)	160	168	164

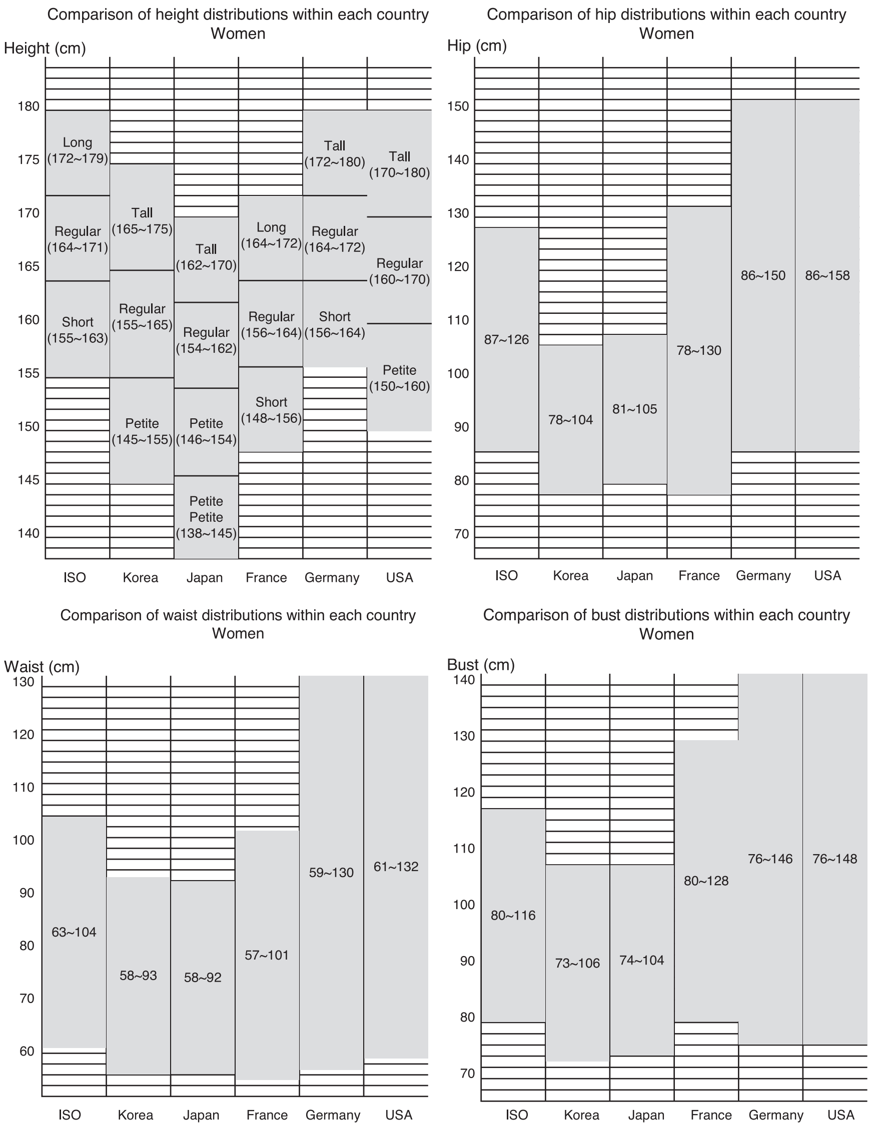
Thus, comparing the national sizing systems and existing body types would improve the compatibility between national sizing systems and facilitate the application of ISO standards (see Table 8.17).

Table 8.17 Drop value and height group comparison by standards ISO, AFNOR, ASTM, JIS, KS

<table>
<tr><td colspan="5">(a) Drop value comparison</td></tr>
<tr><td>ISO</td><td>AFNOR</td><td>ASTM</td><td>JIS</td><td>KS</td></tr>
<tr><td rowspan="2">A type 12</td><td rowspan="2">M type</td><td>Miss Petite
(151–159 cm)</td><td>AB type
Hip (A type+4 cm)</td><td rowspan="2">A type 12</td></tr>
<tr><td>Miss
(159–170 cm)</td><td>B type
Hip (A type+8 cm)</td></tr>
<tr><td rowspan="2">M type 6</td><td rowspan="2">N type</td><td>Miss tall
(169–177 cm)</td><td rowspan="2">A type
Bust 74–94 cm (3 cm)
Hip 92–104 cm (4 cm)</td><td rowspan="2">N type 6</td></tr>
<tr><td>Adult Missy
(161–173 cm)</td></tr>
<tr><td rowspan="2">H type 0</td><td rowspan="2">F type</td><td>Women
(162–170 cm)</td><td rowspan="2">Y type
Hip (A type-4 cm)</td><td rowspan="2">H type 0</td></tr>
<tr><td>Half
(152–163 cm)</td></tr>
<tr><td colspan="5">(b) Height group comparison</td></tr>
<tr><td>ISO</td><td>AFNOR</td><td>ASTM</td><td>JIS</td><td>KS</td></tr>
<tr><td rowspan="2">Short 160</td><td rowspan="2">Short 152</td><td>Miss</td><td rowspan="2">Petite 150</td><td rowspan="2">Petite 145–155</td></tr>
<tr><td rowspan="2">Short 151–159
Regular 159–170
Tall 169–177</td></tr>
<tr><td>Regular 168</td><td>Regular 160</td><td>Regular 158</td><td>Regular 155–165</td></tr>
<tr><td rowspan="2">Long 176</td><td rowspan="2">Long 168</td><td>Adult</td><td>Tall 166</td><td rowspan="2">Tall over 165</td></tr>
<tr><td>Regular 161–170
Short 152–163</td><td>PP 142</td></tr>
</table>

8.6.1 Size distribution of height, bust girth, waist girth and hip girth by country standards

The basic measurements used in national clothing industries, i.e., bust girth, hip girth and height, are compared in this section. Waist girth measurements in different countries are also mentioned for reference (Fig. 8.25). Regarding



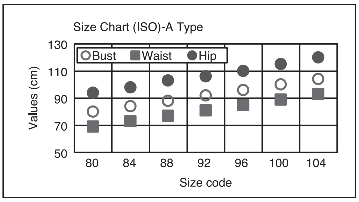
8.25 Key dimensions size range comparison by ISO, Korean, Japanese, French, German and American standards.

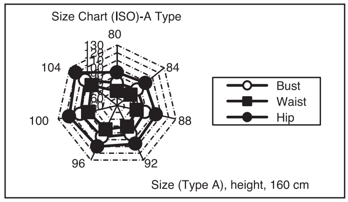
Asian women, bust size ranges from 73 cm to 106 cm. In the case of Occidental countries, French women's bust size ranges from 80 cm to 125 cm. The range of German and American women's bust sizes is wider, including an extra bust size of 150 cm. ISO indicates that the majority of women in the world fall into the 80–116 cm size bracket.With regard to hip size, hip girth ranges from 79 cm to 105 cm for Korean and Japanese women, and from 78 cm to 130 cm for French women. Just like bust girth, the range of German and American hip sizes is wider, including a hip girth of 150 cm; therefore, the body type drop value based on hip size presents stronger utility in this case. ISO indicates that a range of 87 cm to 120 cm hip size covers the average Asian and Occidental women hip girth. Concerning height, it ranges from 145 cm to 175 cm, extending over 30 cm in Korean and Japanese women. French women are between 148 cm to 172 cm tall and thus show the same scalability with Asians. Korean subjects fall into higher height brackets than Japanese women. As for German and American subjects, height range is wider including those whose height range extends over 40 cm. Regarding waist girth, Asians' waist girth ranges from 58 cm to 93 cm, from 57 cm to 100 cm for French women and from 60 cm to 130 cm for Germans and Americans with coverage that is twice as wide. ISO suggests a range of 63 cm to 104 cm, which is a wider range than the one considered in Korea, Japan and France.

8.6.2 Drop value comparison between different standards: KS, JIS, ISO, AFNOR, DIN and ASTM

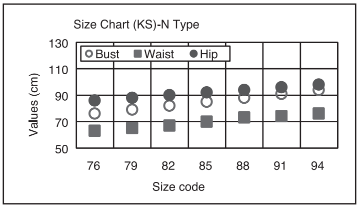
This section reviews the comparison of drop values (B-W, B-H, W-H) established on bust girth basis. Bust size based on drop value distribution between reciprocally bust-waist-hip girths is analyzed in Fig. 8.26. According to ISO's standards, bust-waist drop value is 17 cm–12 cm, bust-hip drop value is 7 cm–5 cm and the difference between waist and hip extends over 24 cm to 17 cm for the M body type (regular body type). The H body type shows similar bust and hip sizes, but presents a difference of 20 cm between bust and waist, which is twice as important compared to that of the A body type. Korean A (with large hips), N (regular body type) and H (with small hips) body types match with those of ISO, as indicated in Table 8.17. As a result, the N body type's bust-hip drop value ranges from 9 cm to 6 cm. The H body type, under ISO standards, may be considered as Korean H body type (small hips) with slightly more volume.

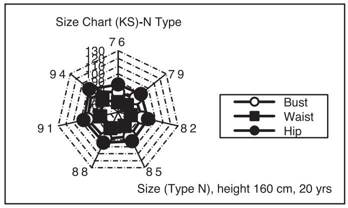
Japanese A body type's (regular body type) bust-hip drop value is 9 cm. This matches with the Korean N body type of a 6–9 cm drop value and ISO's M body type of a 7 cm drop value. Japanese standards also distribute the drop value on a bust-girth size basis.The regular body typed French women's drop value between bust-hip ranges from 4 cm to 2 cm, from 21 cm to 25 cm between bust-waist and from 25 cm to 26 cm between waist-hip. In comparison with the Korean N type women, the bust-hip drop value is smaller in French women. Thus, the average



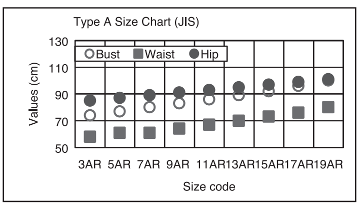


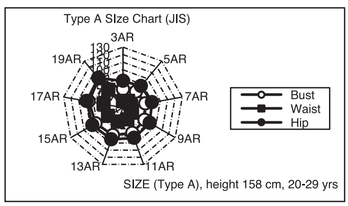
Size code	80	84	88	92	96	100	104
Bust girth (cm)	80	84	88	92	96	100	104
Waist girth (cm)	69	73	77	81	85	89	93
Hip girth (cm)	94	98	103	106	110	115	120



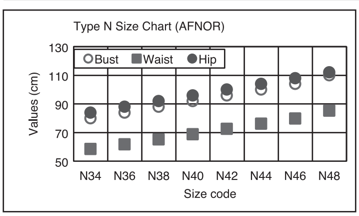


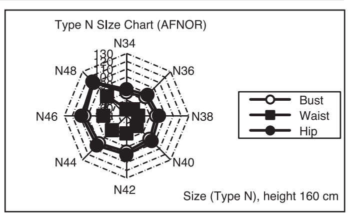
Size code	76	79	82	85	88	91	94
Bust girth (cm)	76	79	82	85	88	91	94
Waist girth (cm)	63	65	67	70	73	74	76
Hip girth (cm)	86	88	90	92	94	96	98





Size code	3AR	5AR	7AR	9AR	11AR	13AR	15AR	17AR	19AR
Bust (cm)	74	77	80	83	86	89	92	96	100
Waist (cm)	58	61	61	64	67	70	73	76	80
Hip (cm)	85	87	89	91	93	95	97	99	101

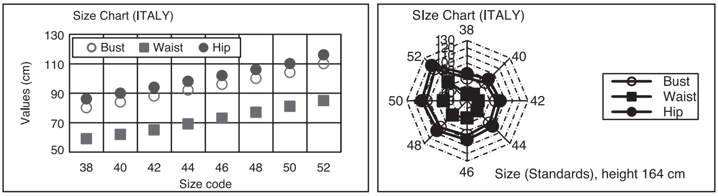




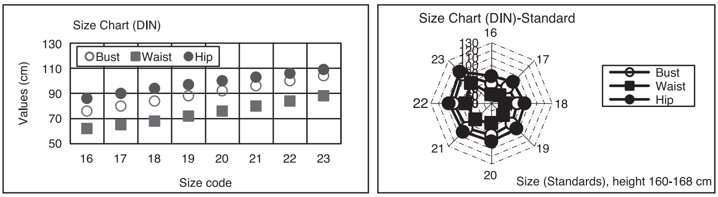
Size code	34n	36n	38n	40n	42n	44n	46n	48n
Bust (cm)	80	84	88	92	96	100	104	110
Waist (cm)	58.6	61.8	65.2	68.8	72.6	76.25	79.85	85.3
Hip (cm)	84	88	92	96	100	104	108	112

8.26 Key dimensions size distribution by ISO, KS, JIS, AFNOR, Italy, DIN and ASTM.

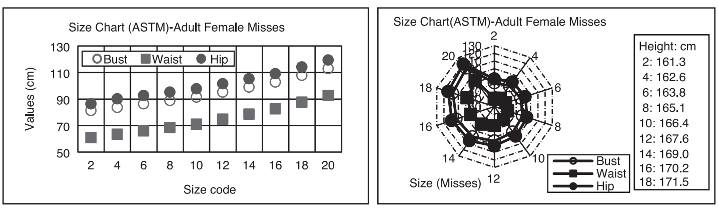
(*Continued*)



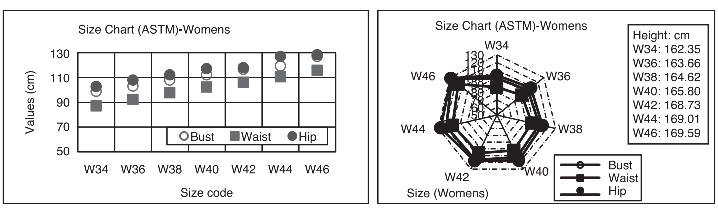
Size code	38	40	42	44	46	48	50	52
Bust (cm)	80	84	88	92	96	100	104	110
Waist (cm)	59	62	65	69	73	77	81	85
Hip (cm)	86	90	94	98	102	106	110	116



Size code	16	17	18	19	20	21	22	23
Bust girth (cm)	76	80	84	88	92	96	100	104
Waist girth (cm)	62	65	68	72	76	80	84	88
Hip girth (cm)	86	90	94	97	100	103	106	109



Size code	2	4	6	8	10	12	14	16	18	20
Height (cm)	166.3	166.3	166.3	166.3	166.4	166.4	166.4	166.4	166.4	166.4
Bust girth (cm)	83.8	86.7	89	92.1	94.6	98	102.5	107	112	116
Waist girth (cm)	64.4	66.4	67	71.1	74	78	82.6	87.6	94	99
Hip girth (cm)	91	94.3	97	99.7	102	106	109.8	114.3	119	124



Size code	W34	W36	W38	W40	W42	W44	W46	W48
Height (cm)	162.35	163.66	164.62	165.8	168.73	169.01	169.59	168.78
Bust girth (cm)	98.87	103.09	107.96	112.08	116.46	119.18	126.97	129.5
Waist girth (cm)	87.03	92.28	97.66	102.22	106.07	110.54	115.72	126.06
Hip girth (cm)	102.78	107.87	112.09	117.04	117.84	126.94	128.25	136.44

8.26 Continued.

Occidental women body type follows the 8 cm head-tall proportion with a 6 cm bust-hip drop value and a 25 cm waist-hip drop value. The German N body typed women's drop value for bust-hip is 10 cm to 5 cm, for bust-waist is 14 cm to 16 cm, and for waist-hip is 24 cm to 21 cm. These figures show similarities with ISO body type distributions. However, slight differences appear in the waist-hip drop value. The bust-hip drop value of American women ranges from 12 cm to 4 cm for Misses, 10 cm to 6 cm for Miss Tall, 11 cm to 6 cm for Junior, 9 cm to 6 cm for Miss Petite, 5 cm to 8 cm for Junior Petite, 5 cm to 6 cm for Adult female, 1 cm to 7 cm for women and 2 cm to 5 cm for Half. Waist-hip drop value with a 22 cm range includes Adult female body type (25–26), Misses body type (22–14), Miss Tall body type (22–15) and Junior body type (20–17). Junior Petite and Misses Petite waist-hip drop value extends over 18 to 15. Women and Half waist-hip drop value ranges from 16 to 10 cm. The body type which matches the ISO M type is the Adult female Misses body type. The size compatibility chart is shown in Tables 8.18 and 8.19.

Table 8.18 Size chart of each size code by ISO, KS, JIS, AFNOR, Italy, DIN and ASTM standards

	80	**84**	**88**	**92**	**96**	**100**	**104**	**108**	**112**
ISO									
Size code	80	84	88	92	96	100	104		
Bust	80	84	88	92	96	100	104		
Waist	63	69	74	79	83	87	92		
Hip	87	92	96	99	103	106	109		
Height	160	160	160	160	160	160	160		
KS									
Size code	79	84	88	91	94	100			
Bust	79	84	88	91	94	100			
Waist	65	67	73	74	76	80			
Hip	88	90	94	96	98	102			
Height	160–164	160–164	160–164	160–164	160–164	160–164			
JIS									
Size code	7YR	9YR	13YR	15Yr	17YR	19YR			
Bust	80	83	89	92	96	100			
Waist	61	64	67	70	73	76			
Hip	85	87	91	93	95	97			
Height	158	158	158	158	158	158			

(*Continued*)

Table 8.18 Continued

	80	**84**	**88**	**92**	**96**	**100**	**104**	**108**	**112**
AFNOR									
Size code	34n	36n	38n	40n	42n	44n	46n	48n	
Bust	80	84	88	92	96	100	104	110	
Waist	58.6	61.8	65.2	68.8	72.6	76.25	79.85	85.3	
Hip	84	88	92	96	100	104	108	112	
Height	160	160	160	160	160	160	160	160	
Italy									
Size code	38	40	42	44	46	48	50	52	
Bust	80	84	88	92	96	100	104	110	
Waist	59	62	65	69	73	77	81	85	
Hip	86	90	94	98	102	106	110	116	
Height	164	164	164	164	164	164	164	164	
DIN									
Size code	17	18	19	20	21	22	23		
Bust	80	84	88	92	96	100	104		
Waist	65	68	72	76	80	84	88		
Hip	90	94	97	100	103	106	109		
Height	160	160	160	160	160	160	160		
ASTM									
Size code	2	4	8	10	12	14	16		
Bust	83.8	86.7	92.1	94.6	98.4	102.5	107.0		
Waist	64.4	66.4	71.1	73.6	78.1	82.6	87.6		
Hip	91.14	94.3	99.7	102.2	106.1	109.8	114.3		
Height	166.3	166.3	166.3	166.4	166.4	166.4	166.4		

8.7 Conclusions

The topic of anthropometry has benefited from multidisciplinary research. With regard to collation, many different scanning technologies are available and are currently being used, as are many different tools to extract information from the scans. Yet verification and documentation of these differences are limited. The

Table 8.19 Compatibility of sizing by drop value (bust-hip) by country standards for women's garments

Drop(cm)	–8	–6	–4	–2	0	2	4	6	8	10	12	14	16	18	20
ISO									Broad hips	A	A	A	A		
							M	M	M	Standard hips					
			H	H	H	H	Slim hips								
KS									Broad hips	A	A	A	A		
							N	N	N	N	N	Standard hips			
				H	H	H	H	Slim hips							
JIS						Standard hips	A	A	A	A					
				Slim hips	Y	Y	Y	Y							
									Broad hips	AB	AB	AB			
											Extra broad hips	B	B	B	
AFNOR				M	M	Mince									
						N	N	Normal							
								F	F	F	Forte				
DIN				N	N	N	N	N	N	N	Standard hips				
	S	S	S	S	S	S	S	Slim hips							
							B	B	B	B	B	B	B	Broad hips	
ASTM									Junior	J	J	J	J		
								Junior petite	JP						
						Misses	M	M	M	M	M				
						Miss petite	MP	MP	MP						
							Miss tall	MT	MT	MT					
						Adult female misses	AM	AM							
						Womens	W	W	W	W					
					Half	H									

database with traditional type survey and 3D scan survey needs to allow the user to accomplish good quality assurance across different surveys or studies in order to be effective. Physical features of the human body include many 'parts' that we use: garments, spaces design, machines etc.

Theories abound for explaining and predicting such human body characteristics. The importance of higher level information processing and control of standardization and accuracy are commonly recommended as size construction variables in studies of human body growth continue to develop.

As we have discussed in this chapter, providing correct data solutions for the task at hand, however, should give an appreciation of the field and its potential for product design applications, and permit the user to acquire the correct information quickly. This also may at least give some impression of the problems of control and standardization of size data according to race and countries and arrange many components of systems so as to simplify the trade demands of the people involved and enhance the likelihood of satisfactory design performance.

8.8 Future trends

Because the making and availability of statistics for general public information has long been studied in Korea, the main purpose of anthropometric data gathering and surveys in the country tended to rely mainly on the traditional methods and did not sufficiently take notice of their possible beneficial use by various industries. New 3D technologies are opening new horizons, and more detailed analysis based on 3D information would allow for designing better-fitting products for a targeted population (or segments of population showing common features). We also present our additional view that surveys, taking into account the desires of a population, its general sensibility to different elements of a product (textile used, shape, pressure on the skin, etc.), must be welcomed, thus conducting us, besides the analysis of existing body shapes, to the analysis of virtual body shapes.

The clothing sizing system is a recurrent problem which requires further research and improvement regarding sizing system standards, body measuring system and size labeling system in association with clothing manufacturers, consumers and researchers. Moreover, in order to improve the conformity of clothing to the body, manikins reflecting each body type's characteristics must be developed in addition to the development of size standards and uniform labeling systems. The manufacture of standardized dummies is an important task for the future. Exchanges of information and technology with consumers are important, as are online exchanges between the manufacturer and the consumer, which may help to take consumer preferences, into consideration.

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9
Apparel size designation and labelling

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Abstract: With the arrival of ready-to-wear, retailers desiring to help customers to find garments that suited them best, attached a size designation (single number 8, 10, etc.) initially underlying body measurements. As helpful as it seems, nowadays western women have difficulty finding the right size with this information alone, for which the meaning has been lost. Now that companies are distributing worldwide to different ethnicities, with different shapes and sizes, the challenge is even bigger. The solution may reside in a detailed size designation. Based on the North American size designations, this chapter presents an interesting global size designation and a method for its implementation.

Key words: size label, apparel, 3D body scanner, anthropometry, vanity sizing.

9.1 Introduction

Ever since people began wearing ready-to-wear clothes, retailers have desired to help customers in finding the garment that would suit them best. One common way of doing this was to attach to the garment what is called today the size designation. As helpful as it could be, it seems that size designation doesn't provide consumers that much help anymore. According to some researchers, women, particularly in western society, have a hard time finding the garment that suits them best with the sole information of the actual size designation. One reason is because size designation, which provides a single number 8, 10, 12, etc., was initially supported by underlying body measurements and body shapes, but the meaning seems to have been lost over the years. Additionally, at the beginning of the ready-to-wear era, women knew that ready-to-wear garments didn't exactly mean 'ready-to-wear', but also meant that it may require alterations which most women knew how to do at the time.

This being mentioned, it seems obvious that the garment industry needs to adjust for three major reasons. First, it appears that people have lost knowledge of what the measurements behind the size number are. Second, women nowadays take for granted the meaning of ready-to-wear and only a few are able and willing to alter their garments. Lastly, many companies are now distributing worldwide, which makes it even more challenging for both parties: retailers/brands from different parts of the world and consumers from different ethnicities, with different shapes, or living in a different geographic area. The solution may reside in a more detailed size designation. This chapter will start by covering briefly how size designations were developed particularly in North America and what is the perceived value today. Then it will present what could be, according to our research, an interesting global size designation and how it could be implemented. This goes without mentioning one of the most important challenges: what it should look like and what should be written on the size designation.

9.2 The importance of size designations

It is not rare nowadays to read that size designations in the United States have not evolved properly to serve their intended purpose, to help consumers find garments that suit them best. The same is true in Canada where those apparel size designations were defined based on the anthropometric database of the United States of America. One couldn't argue that when garment specification measurements are done using forcing data it is not surprising that there are unhappy shoppers. But why is it so in America? To get a better understanding, we reviewed the evolution of sizing and the size designation systems from the United States of America (USA) and those of its neighboring country, Canada. We provide details as to why Canadians' sizing system was calqued on US anthropometric data. Moreover, we provide information such as the time period when the national survey was conducted and the sample used.

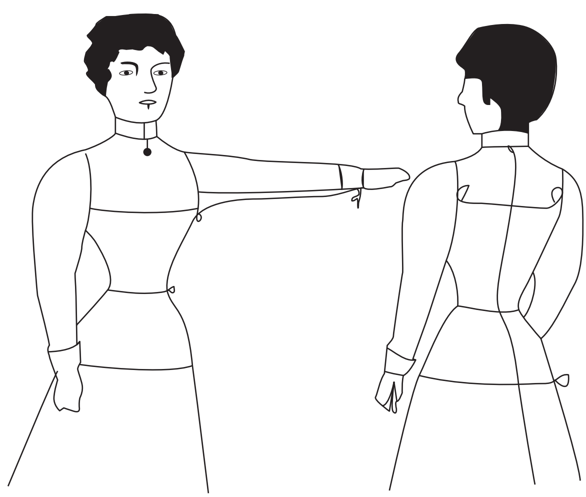
9.2.1 The development and evolution of size designations in North America

Until the eighteenth century, women's garments were custom-made (Fan *et al.*, 2004). The fit was personalized (Workman, 1991). The first nested patterns for women's wear appeared in 1820–1840 (Kidwell, 1979) and the grading systems years later (Bryk, 1988). Ebenezer Butterick and James McCall were the first to market nested patterns in the 1860s, initiating the ready-to-wear industry (Burns and Bryant, 2002). The key measurement points were defined then as the bust, selected because it had proven to be useful for Europeans (Workman, 1991), and the waist line. Paper patterns were graded on the bust circumference for blouses and dresses and, the waist line was used for the skirts (Kidwell, 1979 as cited in Schofield and LaBat, 2005). Most bodice measurements were based on the bust. In that era, patterns used a proportional grading system to create different sizes. Workman (1991) shows that the basic sample was graded at '36', which meant that it was suitable for a 36 inch (91.44 cm) woman's bust. It was then adjusted with 2 inch (5.08 cm) linear decrements or increments (Ashdown, 1998). The proper fit of the finished garment depended on the dressmaker's skill (Schofield and LaBat, 2005).

9.2.2 Size designation according to the identification numbers in catalogs

Among the first to offer and distribute garments, having a big impact on today's size designation, were catalog distributors. Thus at the very beginning of the twentieth century, the *Sears Roebuck and Co. Catalogue* offered garments with size designations ranging from 32 to 42. These were referring to 32 inch (81.28 cm) bust circumference to 42 inch (106.68 cm) bust circumference (Workman, 1991). In addition, it stated that a garment with a 32 inch (81.28 cm) bust size designation should be suitable for young ladies of 14 years of age; a 34 inch (86.36 cm) size designation should be suitable for young ladies aged 16 years, and a 36 inch (91.44 cm) size designation should be suitable for young ladies of 18 years (*Sears Roebuck and Co. Catalogue*, 1902). It also specified that these garments were suitable for young ladies since the construction was different from those for women (Workman, 1991). They also associated 14, 15 and 16 inch (35.5 cm, 38.1 cm, and 40.6 cm respectively) neck measurements to the bust measurements. A 14 inch neck for example should be equivalent to a 32–34 inch bust, etc. One should know that ladies skirt size designations varied from a 22 inch (55.88 cm) to a 29 inch (73.66 cm) waist. The size designation reflected one or the other: (1) the critical body measurement points and the age of the wearer (Swearingen, 1999 in Fan, 2004) as was the case for young children; or (2) the associated neck size. The idea was to make sure a woman at home would measure herself and compare her measurements with the ones shown in the catalog index (see Fig. 9.1).

In the USA, besides the *Sears Roebuck and Co. Catalogue,* ready-to-wear was also sold through catalogs such as *Montgomery Ward* as well as in the nascent urban brick and mortar department stores. Canadian retailers followed the trend and also distributed millions of their catalogs throughout Canada (Bernier *et al.*, 2003: 77).



9.1 An illustration from the 1902 *Sears Roebuck* catalog.

9.2.3 The need for size designation for ready-to-wear clothing

The decades following World War I saw the introduction of department stores selling ready-to-wear all through North America. In the cities like Philadelphia, New York or in Montreal, department stores such as Macy's (NYC), Wanamaker (Philadelphia), or Dupuis Frères, T. Eaton or Simpson (Montreal, Canada) started to introduce ready-to-wear, impacting on people's shopping habits. According to Kidwell (2001) the modern age of apparel production and the democratization of clothing had begun. Burns and Bryant (2002) stated that 'separates for women' worn by young girls (two-piece outfits combining a blouse and a skirt) created by Gibson, became very popular and thus had a large influence on the women's ready-to-wear industry. Although ready-to-wear was a cheap interpretation of the current fashion trend, women followed this trend even if, as mentioned earlier, they knew they would need to alter these garments to obtain an appropriate fit (Cooklin, 1990). Each manufacturer did its best to develop its grading system, but lacking adequate scientific data made it difficult for everyone (O'Brien and Shelton, 1941). Schofield and LaBat's (2005) studies reveal that each manufacturer reinvented the process although one point seems to have been consistent: the key position where to measure. Most of them agree on the bust, waist, and hips. Because there were no size designations developed yet, manufacturers used their own which were based on their predecessors' (Gould-Decauville *et al.*, 1998).

9.2.4 Mass production and the establishment of standards

At the end of the 1930s, mass production for armed forces' uniforms triggered the establishment of standards in many areas (O'Brien and Shelton, 1941). According to O'Brien and Shelton (1941: 1) 'no scientific study of body measurements used in the construction of women's clothing has ever been reported. As a result, there were no standards for garment sizes'. Meanwhile merchandise returns in the stores, due to poor fit were high and it was not unusual for the necessary alterations to increase the cost of a ready-to-wear garment by as much as 25% of its original cost (Winks, 1997). Mass production, variations in measurements, and size designation, in addition to the ones presented in the catalogs, all led to a high percentage of returns and the need for a standardized sizing system (O'Brien, 1939; Yu, 2004). Therefore the *Women's Measurements for Garment and Pattern Construction* (WMGPC) was conducted. Indeed, between July 1939 and June 1940 more than ten thousand women were measured (14 698 women exactly) (WMGPC, 1941). The survey took place in eight states. And only White Caucasian women were used for this anthropometric survey. The results were then published by the *United States Department of Agriculture* in 1941. The WMGPC reported the objective was 'to provide measurements which could be used for improving the fit of women's garments and patterns'. For the first time anthropometric measurements were used to help the apparel industry standard sizes and size designation (O'Brien and Shelton, 1941; Goldsberry *et al.*, 1996; Chun-Yoon and Jasper, 1996; Ashdown, 1998; Workman and Lentz, 2000; Burns and Bryant, 2002; Fan *et al.*, 2004; Schofield and LaBat, 2005). More importantly, the survey report stated that the data would best be used for sizing charts divided, among other things, into 'short', 'regular' and 'tall'.

9.2.5 Development of size designations

Body measurements of the national survey were compiled in order to develop size designation and to facilitate commercial communication. These resulted from the cooperation of various interest groups which fulfilled a perceived need within the industry (Kadolph, 1998). Furthermore, in 1945, the *Association for Mail-order Sales* recommended a standard way for labeling size designations for the garment industry. It was in 1958 that The US Department of commerce published the *Body Measurements for the Sizing of Women's Patterns and Apparel*, The commercial standard '*CS215-58'*. Although interesting and useful, the statement was as follows: 'The adoption and use of a Commercial Standard is voluntary'. Then, its primary and secondary goals were:

1. to provide standard classification, size designations, and body measurements for consistent sizing of women's ready-to-wear apparel (Misses', Women's, Juniors', etc.) for the guidance of those engaged in producing or preparing specifications for patterns and ready-to-wear garments. The measurements given in this standard are body, not garment, measurements; and
2. to provide the consumer with a means of identifying her body type and size from the wide range of body types covered, and enable her to be fitted properly by the same size regardless of the price, type of apparel, or manufacturer of the garment. (US Dept. of Commerce, 1958: 1.)

The CS215-58 reports the scopes as follows. Four classifications of women: 'misses', 'women', 'half-sizes' and 'junior'. This was followed by groups defined as: 'short', 'regular' and 'tall'. Then again with four sub-groups within each of these groups: 'bust-hip', 'slender', 'average' and 'full'. The report itself proposed various possible applications, definitions of the measurement points, measuring methods, sizing charts and the percentage of women in each of these classes. The size number and symbols were combined to make the complete size designation. For example: '14T–' would refer to a size 14 bust, T for tall in height and '–' for slender hip type whereas a size designation of '14R' would mean: size 14 bust (with its underlying measurements), R for regular in height and an average hip type or again '14S+' which would refer to a size 14 bust, S for short in height, and '+' for full hip type. One last detail of the report was that the junior classification was based upon interpolations of portions of the data used in the development of the misses' classification and therefore has traditional odd numbers for size designations. So instead of referring to a size 14 as for misses, it would be a junior size 13. It was then recommended that in order to assure purchasers that garments conform to this system, such garments be identified by a sticker, tag, or a hanger or other label carrying the type of information presented above: 14T– or 14R or 14S+. Soon after the CS215–58 was developed, several countries built their sizing standards or published reports on the subjects. The *BS1345* of the *British Standards Institution* was published in 1945; a survey by the *British Board of Trade* stated the need for 126 sizes to cover its female population. In 1950, the *DS923* of the *Denmark Standards Association* came out with similar recommendations. In 1954 an anthropometric study was conducted by the *Polish Academy of Science.* Between 1954 and 1959, the United Kingdom provided its report on the anthropometric measurements of military personnel. In 1957, the USSR conducted a survey, etc. Canada was no exception in publishing its report but it was based on the American population survey. In 1968, 17 countries formed the *International Organization for Standardization (ISO)* and implemented the TC133 'technical committee' entitled 'Sizing Systems and Designations'. They believed that commercial standards would better serve their purpose if common to all countries. Back in the United States, the *Voluntary Product Standard (PS 42–70)* for pattern development and grading (with increments of 1 inch in circumference and 1½ inches in height measurements for each size) was updated and published in 1971 'as a revision of the CS215-58' (US Dept. of Standards, 1971: 1). At the very beginning it states (par. 1) that:

> The objective of a Voluntary Product Standard is to establish requirements which are in accordance with the principal demands of the industry and, at the same time, are not contrary to the public interest.

Therefore the classifications that were defined earlier such as 14S+ or 13T- were now modified/simplified. The new standard included body measurements for four classifications as follows: juniors', misses', women's and half-sizes for shorter women and sub-classifications as detailed below.

- Juniors' petite sizes ranging from 3P to 15P.
- Juniors' sizes ranging from 3 to 7.
- Misses' petite sizes ranging from 8P to 18P.
- Misses' sizes ranging from 6 to 22.
- Misses' tall sizes ranging from 10T to 22T.
- Women's sizes ranging from 34 to 52.
- Half sizes ranging from 12½ to 26½.

In addition it was written that standards were subject to review at any time and that it remained the responsibility of the users to judge its suitability for their particular purpose. Let's now have an overview of what happened in Canada.

9.2.6 Canadian General Standards Board (CGSB)

The Canadian General Standards Board (CGSB) has, over the decades, also produced size designations linked to data charts. It is stated at the very beginning of the report that:

> The principal objects of the Council are to foster and promote voluntary standardization as a means of advancing the national economy, benefiting the health, safety and welfare of the public, assisting and protecting the consumer, facilitating domestic and international cooperation in the field of standards. (CAN/CGSB-49.203-M87; p. 1)

The CGSB also wrote that:

> This standard describes the abridged Canada Standard sizing system which may be used as a guide in choosing the sizes of women's wearing apparel. The standard contains a selection from the complete system of sizes which is of greatest commercial interest. The sizes are identified by code numbers that correspond as closely as possible to current trade practice. Size identifications based on size indicator body dimensions are also given. (CAN/CGSB-49.203-M87; p. 1)

One can also read in the CAN/CGSB-49.201-92 that the source measurements of the database that served to do the Canadian women apparel size designations were taken 'a few years ago on a population of about 10,000 American women aged between 18 years old and 80 years old'. In the footnote it is written that the body measurements were taken in 1939 and 1940 in the USA, Miscellaneous Publication No. 454, *United States Department of Agriculture* in 1941. Basically the subjects who served for the establishment of the Canadian size designations were the female sample that served to generate the American size designation.The CGSB added that a label with size number could be accompanied with a few key measuring points such as bust and waist and that these girth measurements should be in centimeters. It also promoted the use of a pictogram to support the size designation with specific body measurements. It proposed horizontal measurements for garments such as: bust girth, waist girth and hip girth and, in addition to inseam pants.

9.2.7 Pictograms, body chart standards and other proposed size designation systems

In the 1970s, ISO developed and proposed a new way of presenting size designations. Again it was based on key body measurements, but this time it included a body pictogram. One of the biggest challenges of the time was which system should be used for size designation: centimeters or inches? This question was never answered and the adoption of the pictogram never came to life. Years later, other developed countries came up with their own body chart standards: Switzerland in 1972; *PC3137* and *PC3138* in the USSR (1973). Not long after, similar systems were proposed in Germany (1983); measurements of 9402 subjects were taken and they concluded that 57 sizes were needed to cover 80% of their population. Such standard body charts would have been too cumbersome to be useful (Yu, 2004). Since then, from time to time, surveys were updated. It was the case in the USA as the relevance of sizing charts for market segments such as women aged 55 and over was questioned. Six thousand American women aged 55 and older were measured, which served to develop the *ASTM D5586* in 1995.

9.2.8 Updated anthropometric data

More recently many people working in the industry started to feel a need to update national anthropometric data. Several major initiatives begun in the 1990s using the new *3D body scanner* technology to accomplish this task. Thousands of volunteer subjects of all ages were scanned in Asia, Europe and America. Between 1992 and 1994 many subjects were scanned in Japan. From 1999 to 2002 many were scanned in the UK. At the beginning of the new century the same was done in the USA. Some participants/sponsors who funded the project used the database to update their own internal specific size designations. Although numerous studies have been done and many articles have been written over the past century to understand garment size designation, its satisfaction or dissatisfaction, and although many argue that the actual size designation needs to be designed to be suitable for everyone, the consensus is not here yet. While major corporations focus on their target market, many of them do not desire a specific size designation. Why? Some argue it is because manufacturers/brands use their size designation as a marketing tool, well known today as 'vanity sizing' to flatter their consumers. Some argue that vanity sizing makes women feel good about themselves, puts them in a better mood for their shopping experience, increases loyalty.

9.2.9 Retrospective

In retrospect, it appears that few manufacturers used the numerous anthropometric surveys and size charts issued from 3D national campaign. Some set their own size designation to serve their own target customers (Burns and Bryant, 2002); since adhesion to standards is voluntary, recall Workman and Lentz (2000), some continuously reinvent their own. Finally, notwithstanding the methods used to define size designations, manufacturers use the same key body measurements to size their garments (e.g. waist girth, hip girth and crotch height) (Beazley, 1997) and most of them use the same numerical size designation system (6, 8, 10, . . . 24 or even 0 and 00) yet making it problematic today since they all refer to their own size charts. It is clear that size designation should help the consumer identify a well-fitting garment but because of the tremendous variations currently existing in database analysis and actual population measurements the actual size designation is questionable. Moreover, because of the dissatisfaction it creates, some steps need to be taken to provide a comprehensive size designation that would satisfy manufacturers/brands and be suitable for consumers. On this point of view, we believe that the size designation, as it was initially proposed, combining size number, letter and symbols such as shown above 14T–, added to the idea presented by CGSB and ISO e.g. showing a pictogram specifying to which body measurements it should suit best, would probably be the best combination. Manufacturers, brands or retailers could continue to serve one specific target market's shape and size. They would just need to add more details on their size designation label, making it more universal.

9.3 The key elements for an international size designation

As shown before, the initial idea of size designation was based on different clusters defined by similar underlying measurements taken at different points on the body; bust, waist and hip, for example. As also presented above, it appears that manufacturers didn't adhere to these standards and did their size designations preferring to define their own for their target market. Yet, Ashdown (1998) argued that manufacturers and retailers try to fit as much as possible into a small number of sizes. Keeping this in mind, in a previous study Faust and Carrier (2009) validated and defined body key points for size designations. Their results, although providing information mostly for the lower body of the female population, were based on a 3D body scanner and anthropometric data from a national survey conducted in the USA. Their analysis was done clustering a multitude of measurements (over 200 body measurements) extracted from 3D body scans of more than six thousand women. Results of their analysis first showed correlations between weight and girth circumferences of the individuals of the sample. Weight was highly correlated with waist girth, hip girth and thigh girth; each of them with a Pearson's correlation coefficient of respectively 0.91, 0.95 and 0.87. Total height of women was highly correlated with high hip height (Pearson's correlation coefficient of 0.81) and high hip height highly correlated with waist height (Pearson's correlation coefficient of 0.98). Girth circumferences were also highly correlated. As for example, waist girth and hip girth had a 0.96 Pearson's correlation coefficient. Then waist girth and the high hip girth were correlated with a Pearson's correlation coefficient of 0.90. Interestingly, no significant correlation was found between the height and weight. Thus, no significant correlations were found between any height and the girth measurements. Results showed a Pearson's correlation coefficient of 0.29 between height and weight, whereas the results of the hip height and the hip girth showed a 0.17 Pearson's coefficient. In other words one can be tall and big or tall and slim or again short and big or short and slim. Table 9.1 shows some of these Pearson's correlations. Variables are as follows: *h*

Table 9.1 Pearson's correlation coefficient: height, weight and circumferences correlation matrix

	h	*w*	*g*B	*g*W	*g*HH	*g*H	*g*HT	*g*T	*h*W	*h*HH	*h*H	*h*C
h	1,00											
w	0.29	1.00										
*g*B	0.11	0.91	1.00									
*g*W	0.10	0.91	0.94	1.00								
*g*HH	0.09	0.92	0.91	0.96	1.00							
*g*H	0.18	0.95	0.87	0.90	0.94	1.00						
*g*HT	0.24	0.86	0.76	0.75	0.80	0.90	1.00					
*g*T	0.20	0.87	0.73	0.72	0.76	0.85	0.96	1.00				
*h*W	0.79	0.35	0.17	0.12	0.14	0.29	0.34	0.29	1.00			
*h*HH	0.81	0.39	0.22	0.17	0.17	0.30	0.37	0.31	0.98	1.00		
*h*H	0.52	0.59	0.58	0.58	0.58	0.51	0.40	0.34	0.62	0.67	1.00	
*h*C	0.80	0.08	−0.08	−0.12	−0.14	−0.03	0.10	0.06	0.85	0.87	0.49	1.00

refers to height, *w* refers to weight, *g* refers to girth. Then B refers to bust, W refers to waist, H refers to hip and HH high hip, and HT refers to high tight whereas T refers to tight and lastly C refers to crotch. Then, when letters are put together as it is the case for *h*HH, it refers to height of the high hip.

As mentioned in the literature, to be effective, size designation needs to provide a small number of sizes so manufacturers/brands would use it. At the same time, it needs to be distinguishing enough that consumers could find the appropriate garment that suits them best. Taking only those mostly related to the lower part of their body, with the use of software such as SPSS and Statistica, Faust and Carrier (2009) clustered these individuals into 11 groups. The number of groups was based on a reasonable amount of size designations defined by one retailer/brand. These size designations on the market run from: 4 to 22 with a size 16 and one 16W for a total of 11 designated sizes. When clustering into only 11 linear sizes, Faust and Carrier (2009) argue that while the amount of numbered sizes may be interesting it provides no indication of the underlying shape. To be effective it needs to be split into two or three shapes/groups similar to the original sizing system where + and – were added to the size number. Moreover since there is no correlation between height and weight or height and any girths and since women today wear pants, they argue that it is important to provide the length onto the size designation. According to Rasband and Lietchy (2006) the best way to provide the length of a pant is by measuring the inseam.

9.3.1 Clustering according to similar height, size and shape

By observation, one can see that people differ in size and shape (Rasband and Lietchy, 2006). According to Patterson (2012) Afro Americans differ in size and shape from their White Caucasian American counterparts.

Patterson (2012) argues that even if Afro Americans would try, there is no way that they could be close in size and shape to their White counterpart. ‘Of course, the way fat is treated in the black community only reflects how fat is treated in mainstream culture and the fashion community. However, as “curvy” – not too fat, now – is becoming more acceptable in the fashion world, it’s clear the main shade of acceptable curvy is White’ (Tasha Fierce in Patterson, 2012). With this in mind the author looked at the relation between ethnicity and body measurements but also at differences between age groups.

Difference in height according to ethnicity and age groups

Faust and Carrier’s (2009) research found differences between the average size and shapes of White Caucasian American, African American, Hispano-American and Asian American. While almost 50% of White Caucasian American and African American height measurement is between 5′4″ (164 cm) and 5′7″ (173 cm) this percentage drops to only 25% for Hispano and Asian American. Although when looking at what is commonly called petite (less than 5′4″ or again 164 cm) the percentage of these last two rises to 71% for Hispano Americans and to close to 70% for Asian Americans compared to only 3% for African Americans. Without any doubts African Americans are on average the tallest. Another interesting difference clearly appeared between age groups. According to this previous study (Faust and Carrier, 2009), it seems that 65% of the women 66 years old and over are shorter than 5′4″ (164 cm). This number drops to 55% for those 56 to 65 years old, to 49% for those 46 to 55 years old, to 47% for those 36 to 45 years old and to 45% for women between 18 to 35 years old. On the other hand, tall which here refers to 5′7″ (173 cm) and more, is in higher percentage in younger women and it decreases as the age group increases. Table 9.2 summarizes these numbers.

Since there is a high correlation within heights and because there are differences between ethnicities, it appears interesting to show the most common inseam heights per ethnicities and age groups. The most common inseam measurement varies between 27 inches (68 cm) and 31.5 inches (80 cm). More specifically one could argue that an African American’s pants inseam should be longer than those for an Asian.

Referring to Table 9.3, an average inseam length of 30 inches (76 cm) should satisfy 50% of each ethnic group (Caucasian, Hispano and Asian). Moreover one could argue that another 20% of them would just need to have the inseam altered so it could suit them. In those cases a small alteration would be needed; on the other hand this inseam length would serve less than 40% of the African American population. To satisfy a large group of African Americans, as a target market, one would need to offer longer pants legs. A similar phenomenon appears for different age groups where the most common inseam measurement varies between 27 inches (68 cm) and 31.5 inches (80 cm). More specifically one could argue

Table 9.2 Height distributions according to ethnicity

	Ethnicity (percentage per group)				Age groups (percentage per group)					
	Caucasian-American	African-American	Hispano-American	Asian-American/others	18–25 years	26–35 years	36–45 years	46–55 years	56–65 years	66 years and over
Petite $x<5'4''$ (164 cm)	39	37	71	68	45	45	47	49	55	65
Regular 5′4″ (164 cm) ≥ $x \geq 5'7''$ (173 cm)	47	47	25	27	43	43	41	41	36	27
Tall $x>5'7''$ (173 cm)	13	15	3	4	11	11	11	9	8	7

Table 9.3 Comparison of Afro-American and Asian American inseam distribution

	Ethnicity (percentage per group)				Age groups (percentage per group)					
	Caucasian-American	African-American	Hispano-American	Asian-American/others	18–25 years	26–35 years	36–45 years	46–55 years	56–65 years	66 years and over
27 to 28.5 (68 cm – 72 cm)	17	3.26	18	18	9	11	16	18	27	20
28.5 to 30 (72 cm – 76 cm)	50	34	50	50	42	47	48	50	50	45
30 to 31.5 (76 cm – 80 cm)	30	48	26	25	40	36	31	27	22	31
31.5 to 33 (80 cm – 83 cm)	3	13.25	3	2	8	5	4	4	2	1

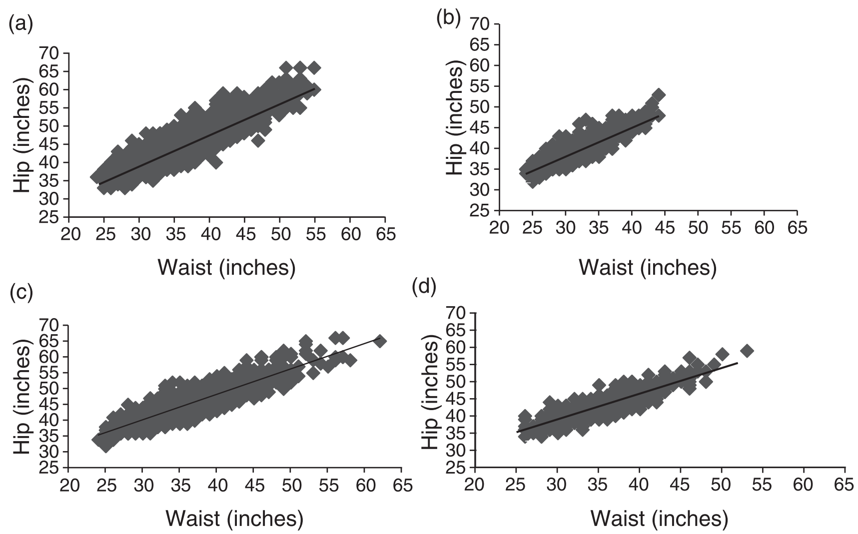
here that youngsters' pants inseam should be longer that those for more mature aged women. An average inseam length of 30 inches (76 cm) should satisfy over 40% of each age group. Again one could argue that another 15% to 20% of them would just need to have the inseam altered so it could suit them. However, this percentage varies when looking at the 18- to 25-year-olds whereas the majority would need pants with longer inseams.

Difference in girth measurements according to ethnicity and age groups

The same analysis was done with girth measurements. When comparing the sample used for Size USA, the tendency of the waist and hip measurements appear to be different according to ethnicity. Figure 9.2 shows waist and hip measurements for each ethnicity and its average as discussed before.

The results present a clear distinction between each group. If one compares the African American female population living in USA versus the Asian female population living in the USA, the range of girth sizes and shapes are obviously different. Figure 9.3 compares each one with the percentage associated to each waist and hip measurement: the darker the cells, the higher the percentage.

Similar to the different ethnic groups we found the same types of results for the different age groups. Although the purpose of this chapter is not to do the analysis of Size USA anthropometric national survey, it was important here to clarify that since different target markets are oftentimes associated with one specific ethnicity or age group, the size designation should be more valuable if it provides more information than the single one or two digits.



9.2 Female waist and hips measurements according to ethnicity. (a) White Caucasian; (b) Asian American; (c) Afro American; (d) Hispanic.

(a)

Count of survey_ID Hip Arr	Waist Arr 25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	(Blank)	Grand Total
32	0.09																			0.09
34	0.09	0.19																		0.28
35		0.09																		0.09
36	0.28	0.09	0.56	0.56	0.19	0.19	0.09													1.96
37	0.09	0.09	0.47	0.37	0.47	0.47	0.19													2.14
38	0.09	0.19	0.47	1.21	1.12	0.65	0.47	0.47	0.28											4.94
39		0.19	0.56	1.03	1.21	1.12	0.84	0.28	0.28	0.09	0.09	0.09								5.78
40			0.37	0.93	1.49	1.58	1.03	0.56	0.37	0.84	0.09	0.00	0.09							7.36
41		0.09		0.37	0.75	1.03	1.03	1.21	0.84	0.37	0.65	0.19	0.19							6.71
42			0.09	0.37	0.65	1.12	1.49	1.86	0.93	0.75	0.93	0.19	0.56	0.19	0.19					9.32
43					0.09	0.37	1.30	0.75	1.12	1.12	0.65	1.12	0.65	0.65	0.56	0.09				8.48
44					0.09	0.28	0.75	1.12	1.30	0.65	1.03	0.65	0.47	0.84	0.47		0.09			7.74
45				0.19			0.09	0.56	0.75	0.47	0.75	1.58	0.84	0.75	0.75	0.37	0.28	0.09		7.46
46							0.09	0.19	0.37	0.65	1.21	0.75	0.09	0.56	1.03	0.28	0.47			5.68
47							0.28	0.09	0.09	0.19	0.47	0.93	0.93	0.75	0.93	0.19	0.28	0.56		5.68
48									0.09	0.09	0.0.28	0.28	0.37	1.12	0.28	0.37	0.47	1.12		4.47
49									0.09	0.09	0.09	0.09	0.37	0.19	0.75	0.56	0.37	0.65		3.26
50									0.09			0.19	0.19	0.19	0.19	0.28	0.47	0.19		1.77
51									0.09			0.09	0.19	0.19	0.19	0.37	0.56	0.37		2.05
52										0.09	0.09		0.09			0.28	0.19	0.09		0.84
53															0.19	0.19	0.19	0.19		0.75
54																0.09	0.28			0.37
55																	0.09			0.09
Grand Total	0.65	0.93	2.52	5.03	6.06	6.80	7.64	7.08	6.71	5.41	6.34	6.15	5.03	5.41	5.50	3.08	3.73	3.26	0.00	87

(b)

Count of survey_ID Hip arr	Waist arr 25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	Grand Total
32	0.20																		0.20
33	0.20	0.20																	0.40
34	0.20	0.61	1.21																2.02
35	0.20	0.81	0.81	0.81	0.61	0.20													3.44
36		0.81	1.82	3.04	1.21	0.81	1.01												8.70
37	0.20	1.42	2.02	2.63	2.02	2.02	2.02	0.81	0.20										13.36
38		0.61	0.40	2.23	3.85	3.44	3.24	2.83	0.81	0.20	0.20								17.81
39			0.40	2.23	2.02	2.63	2.43	2.83	1.21	0.40	0.40								14.57
40			0.20	0.40	0.20	0.61	1.42	3.04	1.01	2.02	0.81	0.20	0.40						10.32
41				0.20	0.40	1.21	1.21	2.23	1.21	1.42	0.81	1.82	0.20						10.73
42								1.42	0.61	1.82	1.62	0.61	0.40		0.40				6.88
43					0.20	0.20		0.20	0.61	0.40	1.42	0.81	0.20	0.20	0.81				5.06
44								0.20		0.20	0.40	1.42	0.20	0.20		0.20			2.83
45										0.20	0.40	0.20	0.40		0.61	0.20	0.61	0.20	2.83
46								0.20		0.20			0.20	0.20					0.81
Grand total	1.01	4.45	6.88	11.5	10.5	11.1	11.3	13.8	5.67	6.88	6.07	5.06	2.02	0.61	1.82	0.40	0.61	0.20	100.00

9.3 Comparison of Afro Americans (a) and Asian Americans (b) waist and hips measurements (inches) distribution.

9.3.2 Summarizing the key elements

The results presented above clearly validate that some differences exist between sizes and shapes. They also demonstrate that these could also vary between ethnic groups and age groups. Without mentioning that ethnicity or age groups need to be written, we are convinced that length is an important variable and should be written/specified on garment size designations. We are also convinced that some girth measurements should also be written on the size designation. Although we discuss height and weight, we do not consider that these two variables would provide additional necessary information; on the contrary they may have a negative impact on consumers' minds.

To summarize we believe that for pant size designation the waist, the hip and in some cases the thigh girth and the inseams should be mentioned. In addition, since previous studies have shown that people like the visual of a pictogram, we conclude that these measurements should be shown on a pictogram. At this point many pictograms have been tested and the perfect one has not yet been found. Having a pictogram with three or four key point measurements as described above should provide sufficient information so consumers could recognize themselves. It should serve the purpose to help consumers find the garment that suits them best. It would provide all of the essential information as it was suggested half a century ago such as the 14R- or 12T+, etc. in a way that citizens from around the world could have a good understanding of the designated size. The only and biggest dilemma is which system should be used? The metric system, centimeters, or the use of the imperial system, inches? Thus, this question is not solved and neither is it clear which type of pictogram should be used.

9.4 Designing international size designations and methods of implementation

When the metric system became the new measurement system its purpose was to facilitate all types of transactions that used measurements. In 1788, in the *Cahiers de Doleances*, people called for the reform of weights and measures. They were asking for 'one law, one king, one weight and one measure'. As a result, the metric system, which is the equivalent to the quarter of a meridian divided by ten million, became mandatory starting on 1 July 1794. This modern system of measurement, equivalent to near the length of three feet or an *aune* (described below) allowed objects to be express in abstracted, commensurable units that relate to an absolute standard (Alder, 2002). It contrasted with the ancient system where measurements were inseparable from the object being measured and customs of the community which performed the measurement. At that time not only did the physical standards differ from community to community, but the technique of measurement depended on local custom.

9.4.1 A parallel with the apparel industry

A parallel could be done with the actual non-conformity and the absence of a specific system from the apparel industry. Nowadays manufacturers/brands may have a same size designation although as mentioned earlier their measuring points may differ from one another. As a result, one may use the waist at its narrow point to define its sizing whereas another may use the waist where the garment is in position when worn, which could be one inch lower than the narrowest point of the waist. Or again, different manufacturers/brands may use the exact same measuring point, associated with the same size number but this may be based on different underlying measurements. As a result, both could use the waist at the same position, both can use the same size designated number such as 12, but one could refer to a size 12 as being 28 inches (71 cm) waist and the second could consider a size 12 for a waist of 32 inches (81 cm). Therefore the measurements themselves are different. Some manufacturers/brands use this to their advantage as a marketing strategy and others just size the items as it was done by their predecessors. Although consumers seem to be unhappy with the actual size designation, making it mandatory to be installed on a garment may have a negative impact on retailers and manufacturers.

9.4.2 Introduction of a uniform size designation

The author believes that to enhance the consumer's shopping experience the size designation should ensure a meaningful and comprehensible garment size (the key measuring points), its shape and maybe its type of fit (loose, tighter, etc.). This size designation should bear a definitive relationship to a garment's key measurements and convey adequate information to consumers of any target market. It would eliminate this discrepancy that plagues the apparel industry. By instituting a new uniform size designation, this new system would provide a standardized way of communicating the size, the shape and the fit of various garments without requiring a change in garment construction. Manufacturers, distributors, retailers worldwide will use the same system (pictogram with common key points writing their own measurements) to ensure consistency. The question to raise now is: How to get the best designed label? By initiating a design contest!

A design contest

To initiate this uniform way of communicating sizing, a design competition needs to be held. Design students and industry professionals worldwide could be invited to submit their designs for a new size designation. The winning design should then be tested in various countries before being used throughout the industry as the basis of an international campaign. If a new size designation is appealing it would at first be adopted *de facto* by interested apparel manufacturers and all other interested parties. Then if it becomes unbeaten, meaning it pleases consumers, retailers and manufacturers/brands and it is suitable for worldwide use, it may become *de jure*.

9.4.3 Benefits of a uniform size designation

The whole apparel industry, designers, manufacturers, wholesalers, distributors, retailers, government and trade associations, academicians, and consumers should all benefit from it. For consumers it would:

- Help in finding and selecting the proper garment suitable for their size and shape;
- Reduce wasted time when shopping (i.e. fitting room);
- Improve the shopping experience;
- Increase satisfaction;
- Reduce returns/exchanges;
- Eliminate their confusion since they understand the information on the label.

For retailers it would:

- Facilitate ordering correct sizes and shapes for target market(s);
- Increase consumers' loyalty;
- Reduce returns/exchanges;
- Reduce workload at the fitting rooms;
- Reduce end of season left over inventories (mark-downs, garbage);
- Enable employees to work *a priori* with consumers and not *a posteriori*.

For designers and manufacturers it would:

- Improve target market(s) selection decision;
- Facilitate communication with retailers and consumers;
- Enable better quality control;
- Improve communication/relations with sub-contractors.

For government, trade associations and academicians:

- For academicians it would offer a common sizing and fit research language.
- For trade associations it would improve communications with members; reduce legal/quasi-legal problems.
- For governments it would facilitate consumer education; facilitate relations with the industry; enable possible links with other areas of concern (i.e. population fitness, eating habits, etc.).

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10
International apparel sizing systems and standardization of apparel sizes

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Abstract: With the increasing globalization of trade, the importance of size designation of clothing has increased. Consumers' body build and sizes are different according to gender, age, and body type. In this study standard garment sizing systems published in the USA, the EU, Germany, China, Japan and Korea were compared and the ways of defining body types, the key dimensions and the range were analyzed.

The body measurement range covered by systems differs by country and key dimensions control the variability of body size and provide the framework for size categories. The key dimensions differ by garment type but those used most often are chest girth for men's garments and bust girth for women's garments. Height measurements are used as the secondary key dimension for adults' garments, but as the first key dimension for infants' or children's garments. Changing consumer demands are guiding new approaches to sizing. Apparel companies need to define their target customers and to integrate consumers' needs into their product development processes. The sizing standard will play a significant role in the ready-to-wear garment business and will provide guidelines for manufacturers and consumers.

Key words: body type, key dimension, sizing system.

10.1 Introduction: the role of international sizing systems

Consumers try to find garments that are suitable for their body dimension. The goal of the sizing system is to satisfy consumers' needs for apparel that fits (Schofield and LaBat, 2005). Size labels in apparel provide guidance for consumers to locate garments that fit their body. However, each apparel manufacturer has its own sizing systems based on its target market. Consumers' body builds and sizes are different according to gender, age, and body type. Garment sizing systems vary from country to country because the physical body of consumers varies. Each government has developed their unique sizing standard for their own people. With the increasing globalization of trade, the importance of size designation of clothing has increased significantly (Chun-Yoon and Jasper, 1993, 1995, 1996). Apparel manufacturers and retailers, who have their national consumer group as a target, have difficulties targeting consumers in other countries. With these difficulties, apparel manufacturers and retailers have desired to have an international sizing system. A solution that overcomes those challenges is one using garment size labeling, expressed in terms of body measurements. It gives information about the targeted consumer's body build or size. Many standard garment sizing systems are used in the world such as US, British, European, Japanese, Korean and Chinese sizing systems, and so on. These systems identify the sizes and body types in the majority of their targeted population.

In this chapter, standard garment sizing systems which are published in the USA, the EU, Germany, China, Japan, and Korea were compared. The international sizing standards for men's garments, women's garments, and children's garments were compared including infant garment sizes. Most of these standards classified consumers into several body types to give appropriate garment fit for them. In the way of defining body types, the key dimensions and the range of measurements in the standards were analyzed. Populations were divided into several groups that had similar body measurements. Allowing all individuals in a specific size group to use a garment with dimensions specific to that size group in this way was the objective of body sizing for the clothing industry. A key aspect is the body dimension that was used to classify the population with respect to the type of garments under consideration (Petrova, 2007). The body types in the garment standards were classified by the index value. For example, the system for men's garment sizing is the chest-waist drop value for constitution of body type classification. Women's body types were often classified by hip-bust drop value. The garment sizes were defined with body measurement of key dimension. For example, chest or bust dimension is the key dimension for men's or women's garment size.

10.2 Body types in global garment sizing systems

Consumers' body types are diverse. Regular size is for a person who is neither tall, short, stout nor thin, but someone who has a good posture. Regular size takes care of approximately 50% of possible customers. In the 1970s the women's apparel industry considered an average figure as someone who had a difference of 7 to 8 inches between the bust measure and waist measure, and hips about 3 inches larger than the bust. However, in a global market, we can easily meet various figure types. For men's garment sizes most of the standards used chest-waist drop value to define body types. The global sizing systems have similarities and dissimilarities in their approach to define body types.

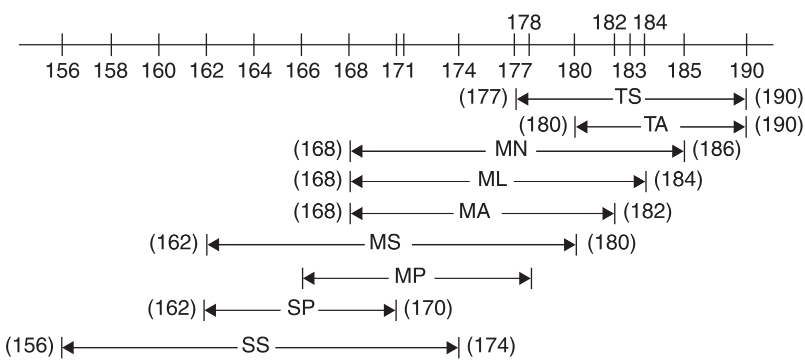
Standard garment sizing systems have been developed in many countries. Anthropometric sizing for clothing is based on the concept of dividing the population into subgroups of individuals who are more or less similar in certain relevant body size dimensions (McConville *et al.*, 1979). They developed it based on their consumers' body measurements range or body shapes. The body shapes can differ by ethnicity and age. Consumers in various countries show diversity in their body shapes which is based on their life environments. Recently, consumers' body shapes have significantly changed. More consumers nowadays have a larger waist size than consumers of the 1970s. Researchers continually traced the change of consumers' body shape, and garment manufacturers and retailers and governments revised their garment sizing tables to provide good fit with ready-to-wear garments. Most of the countries re-regulated their national standard garment sizing systems based on the analysis of anthropometric data. The purpose of revising their standard sizing systems is to improve the fit of ready-to-wear garments. To give a good garment fit, the garment sizing system classifies consumers into three to ten body types. Some systems classify body type by height or index value while others define body type as compared to an average build. In terms of body type, the word *regular* has been used for many years to state the body type close to the average body measurement of the key dimension. For better understanding of women's figure types, Douty (1968) developed two scales: the *Body Build Scale* (*BBS*) and the *Posture Scale* (*PS*). *BBS* classified women's figure types by body mass and suggested five body build scales: *thin, slender, average, stocky*, and *heavy*. Douty (1968) measured the relation among all body segments to each other in terms of body size and weight. Posture was also used to classify women's body type. The five body posture scales that were used were *bad, poor, average, good*, and *excellent. PS* value was measured by the alignment of the body segments. However, most of the garment sizing systems consider body build scale while posture is not yet considered in the garment sizing system.

10.2.1 ISO garment sizing system

The garment sizing system of the International Organization for Standardization (ISO/TR 10652: 1991) suggests five body types for men's garment sizing: *Athletic* (*A*), *Regular* (*R*), *Portly* (*P*), *Stout* (*S*), and *Corpulent* (*C*) types, defined by the chest-waist drop value (International Organization for Standardization, 1991). The chest-waist drop value ranges from −6 cm to 16 cm. The athletic body type (A) has a 16 cm drop value. The regular body type (*R*) has a 12 cm drop value. The full body types (*P, S* and *C*) have 6 cm, 0 cm, and −6 cm drop values respectively. All body types have five height sizes: 164 cm, 170 cm, 176 cm, 182 cm and 188 cm. Women's garment sizes are given for three body types: *A, M* and *H* types. Women's body types were defined according to the hip-bust drop value. The average body type (*A*) has 12 cm drop value. Woman's hip girth in body type *A* exceeds bust girth by at least 9 cm. Body type *M* has a 6 cm drop value. The hip girth of women in body type *M* exceeds bust girth by 4–8 cm. Body type *H* has a 0 cm drop value which means that the hip girth is approximately equal to the bust girth. All body types are sized for three height groups: 160 cm (*S*, short), 168 cm (*R*, regular) and 176 cm (*L*, long) (International Organization for Standardization, 1991).

10.2.2 German garment sizing system

In the German men's garment sizing system, body types are classified with three height groups and five body-build types. Height range is from 156 cm to 190 cm and it is divided into three groups: *Short* (*S*), *Medium* (*M*), and *Tall* (*T*). Five body build types are *Athletic* (*A*), *Normal* (*N*), *Slim* (*S*), *Large* (*L*), and *Stocky* (*S*). Nine body types are given by the combination of height and body-build index terms: *TA, TS, MA, MN, ML, MS, MP, SS*, and *SP*. The chest-waist drop value ranges from −8 to 16 cm. The chest-waist drop value is different according to body types: 16 cm for *Medium Athletic* (*MA*) and *Tall Athletic* (*TA*) body types, 12 cm for *Tall Slim* (*TS*) and *Medium Normal* (*MN*) body types, 6 to 8 cm for *Medium Stocky* (*MS*) and *Medium Large* (*ML*) body types, and 4 to 6 cm for *Short Stocky* (*SS*). It means that the relatively heavy body types, *Medium Stocky* (*MS*) and *Medium Large* (*ML*), have 6 to 8 cm larger chest measurements than their waist measurements. The full figures, *Medium Portly* (*MP*) and *Short Portly* (*SP*), have 4 to 8 cm larger waist girths than their chest girths. The chest size ranged from 88 cm to 116 cm with a 4 cm interval. The waist size ranged from 72 cm to 120 cm with a 4 cm interval. For each chest size 4 to 5 waist sizes are available (Table 10.1). The tall body types (*TS* and *TA*) are made for men's height from 177 cm to 190 cm. The medium height body types (*MN, ML, MA, MS*, and *MP*) are for men's height from 162 cm to 184 cm. The short body types (*SS* and *SP*) are for men's height from 156 cm to 174 cm. It shows that the height type in the German men's garment sizing system is different from other countries' sizing systems: the named height group compared with the body builds. For example, a man whose height belongs to the 168 cm to 174 cm group can be classified as either the medium height group or the short height group by his body build. A man whose height varies from 177 cm to 190 cm can be classified as tall height or medium height by his body build (Fig. 10.1). German men's garment size does not cover extremely large body build compared to US or European standard. German men's garment



10.1 Height range (cm) of men's body types in the German garment sizing system.

sizes start from 88 cm and end at 116 cm of chest girth measurement. The interval size for chest girth is 4 cm. The waist size starts from 72 cm and ends at 120 cm. The size interval for waist girth is 2 to 6 cm. The waist girth size range is different by body type. For athletic body types (*TA* or *MA*) the waist sizes start at 72 cm and end at 92 cm. The body types *MN, MS*, and *SS* have a very wide range of waist sizes: the waist size of *MN* starts at 76 cm and ends at 108 cm; the *MS* size starts at 80 cm and ends at 110 cm; and the *SS* size starts at 82 cm and ends at 112 cm. For the full figure types (*MP* or *SP*) the waist size starts from 96 cm and ends at 120 cm. For each body type, five to eight sizes are available. Fifty-nine sizes are proposed in total (Table 10.1).

The German women's garment sizing system (DOB-Verband, 1983) has nine body types: *SL, SM, SS, RL, RM, RS, TL, TM*, and *TS*. They are classified by height and hip proportion. The first letter stands for height group and the second letter represents hip proportion type. The height groups are classified by short height (*S*, 160 cm), regular height (*R*, 168 cm), and tall height (*T*, 176 cm). The hip proportion types are defined with the hip-bust drop value. The large hip type (*L*) has an 8 to 14 cm drop value and the medium hip type (*M*) has a 2 to 8 cm drop value. The small hip type (*S*) may have a smaller hip measurement than bust measurement. The drop value is −4 cm to 2 cm. The small hip type may have a larger waist girth than the chest girth. Each body type has 6 to 10 sizes. Seventy-three women's garment sizes are available in total (Table 10.2). The body types with regular height and medium hip proportion (*RM*) or the regular height and large hip proportion (*RL*) have 10 sizes each. The body type with tall height and slim hip proportion (*TS*) has only six sizes. The bust size starts from 84 cm for all body types. The very large bust sizes (126 cm to 136.5 cm) are available for the regular height group (Table 10.2).

10.2.3 European garment sizing system

The European standard men's garment sizing system (BS EN 13402-3:2004) provides a wide range of body build. Fourteen chest sizes are given from 84 cm to 144 cm with a 4 cm interval. Fourteen waist sizes are given from 72 cm to 132 cm with a 4 cm interval (British Standards Institution, 2004). The European standard men's garment sizing system does not specify body types. However, it gives two to four different waist sizes for each chest size. Seven chest-waist drop values are offered: 24 cm, 22 cm, 20 cm, 12 cm, 4 cm, 0 cm, and −4 cm. Forty-eight chest and waist combination sizes are available in total (Table 10.3). Men's garment sizes are available with various height groups. Nine height sizes are available from 160 cm to 192 cm with 4 cm intervals.

The European standard women's garment sizing system provides a wide range of bust, hip, and height sizes. Sixteen bust sizes are given from 76 cm to 152 cm with 4 cm intervals. Eighteen hip sizes are given from 76 cm to 147 cm with a 4 to 5 cm interval. The European standard women's garment sizing system does not declare

Table 10.1 Distribution of men's figure types and chest–waist drop value in the German garment sizing system

Waist size (cm) \ Chest size (cm)	88	92	96	100	104	108	112	116
72	*MA/TA* (16)							
76	*TS/MN* (12)	*MA/TA* (16)						
80	*MS/ML* (8)	*TS/MN* (12)	*MA/TA* (16)					
82	*SS* (6)							
84		*MS/ML* (8)	*TS/MN* (12)	*MA/TA* (16)				
86		*SS* (6)						
88			*MS/ML* (8)	*TS/MN* (12)	*MA/TA* (16)			
90			*SS* (6)					
92				*MS/ML* (8)	*TS/MN* (12)	*MA* (16)		
94				*SS* (6)				
96		*MP* (– 4)			*MS/ML* (8)	*TS* (12)		
98					*SS* (6)	*MN* (10)		
100			*SP/MP* (– 4)			*MS* (8)		
102						*SS/ML* (6)	*MN* (10)	
104				*SP/MP* (– 4)				
106							*MS/SS/ML* (6)	
108								*MN* (8)
110					*SP/MP* (– 6)			*MS* (6)
112								*SS* (4)
114						*SP/MP* (– 6)		
120							*SP/MP* (– 8)	

Table 10.2 Bust girth and hip girth range and number of sizes by body types in the German women's garment sizing system (DOB-Verband)

Hip type / Height	Small hip (–4~2 cm drop)	Medium hip (2~8 cm drop)	Large hip (8 cm drop)	Number of sizes
Short (160 cm)	***SS*** Bust: 84–116 cm Hip: 85–113 cm (7 sizes)	***SM*** Bust: 84–122 cm Hip: 91–125 cm (9 sizes)	***SL*** Bust: 84–116 cm Hip: 97–125.5 cm (8 sizes)	24 sizes
Regular (168 cm)	***RS*** Bust: 84–128 cm Hip: 85–124.5 cm (8 sizes)	***RM*** Bust: 84–128 cm Hip: 91–130 cm (10 sizes)	***RL*** Bust: 84–128 cm Hip: 97–136.5 cm (10 sizes)	28 sizes
Tall (176 cm)	***TS*** Bust: 84–110 cm Hip: 88.5–108 cm (6 sizes)	***TM*** Bust: 84–116 cm Hip: 91–119.5 cm (8 sizes)	***TL*** Bust: 84–110 cm Hip: 97–122 cm (7 sizes)	21 sizes
Number of sizes	21 sizes	27 sizes	25 sizes	73 sizes

Table 10.3 Distribution of chest and waist sizes and chest-waist drop value in the European men's garment sizing system

Chest (cm) / Waist (cm)	84	88	92	96	100	104	108	112	116	120	126	132	138	144
72	12		20											
76		12		20										
80	4		12		20									
84		4		12		20								
88	–4		4		12		20							
92		–4		4		12		20						
96			–4		4		12		20					
100				–4		4		12		20				
104					–4		4		12		22			
108						–4		4		12		24		
114							–4		4		12		24	
120								–4		4		12		24
126									–4		0		12	
132										–4		0		12

Table 10.4 Distribution of bust girth, hip girth, and hip-bust drop value in the European women's garment sizing system

Hip size (cm) \ Bust size (cm)	76	80	84	88	92	96	100	104	110	116	122	128	134	140	146	152
76	0															
80	4	0														
84	8	4	0													
88	12	8	4	0												
92	16	12	8	4	0											
96		16	12	8	4	0										
100			16	12	8	4	0									
104				16	12	8	4	0								
108					16	12	8	4	–2							
112						16	12	8	2	–4						
117							17	13	7	1	–5					
122								18	12	6	0	–6				
127									17	11	5	–1	–7			
132										16	10	4	–2	–8		
137											15	9	3	–3	–9	
142												14	8	2	–4	–10
147													13	7	1	–5
152														12	6	0

specific body types. However, it gives five different hip sizes for each bust size. Women's garment sizes are available with various hip proportions. The hip-bust drop values for bust sizes from 76 to 96 cm are 16 cm, 12 cm, 8 cm, 4 cm, and 0 cm. For the bust size 100 cm or above the range of drop value is increased. From –2 cm to 17 cm drop values are given for bust size 110 cm and -4 cm to 16 cm drop values are given for bust size 116 cm. Body types that have larger bust girths than hip girths are available from bust size 110 cm. Seventy-seven bust and hip combination sizes are available in total (Table 10.4). Three height groups are available for women's garment sizes: 160 cm, 168 cm, and 176 cm with an 8 cm interval.

10.2.4 American garment sizing system

The US standard men's garment sizing system (ASTM D6240-98) gives 27 sizes from 34 to 60. They are simplified to seven letter sizes: *S, M, L, XL, 2XL, 3XL,* and *4XL* (ASTM International, 2006a). The smallest size is size *34*. It is for men with chest girth 86.4 cm and waist girth 71.1 cm. The largest size is size *60*. It is for men with chest girth 152.4 cm and waist girth 157.5 cm. The US men's garment sizing system does not define body types. Seven chest-waist drop values are given in the European standard. However, US men's garment sizes are developed for a very conservative drop value range. US men's garment sizes from *34* to *45* are for men's body type that has good proportion. These sizes have a constant chest-waist drop value: 15.2 to 15.3 cm.

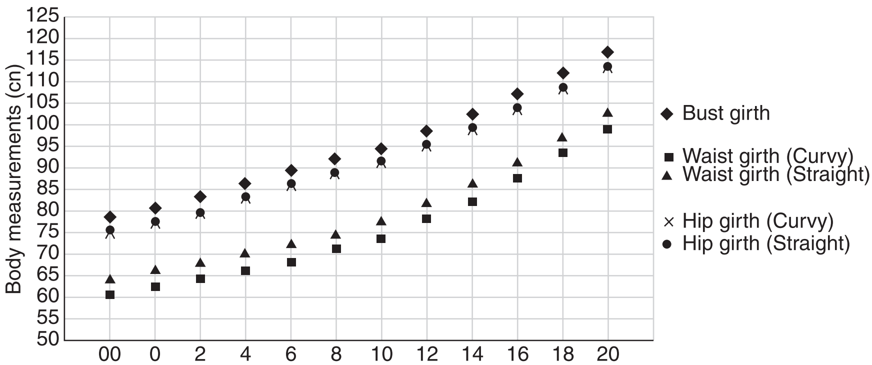
The drop value decreases for larger sizes. Men's sizes from *48* to *50* have a 12.5 cm drop value. The drop values are sharply decreased for extremely large sizes. Size *56* is for men with chest girth 142 cm. Its drop value is 5.1 cm. Chest girth and waist girth for size *58* are same. Sizes *59* and *60* have a 3 to 5 cm larger waist girth than chest girth. Men's size *Small* (*S*) is applicable to size *34* to size *37*. It covers chest girths from 86.4 cm to 94.0 cm and waist girths 71.1 cm to 78.7 cm. Its drop value is 15.3 cm. The men's size *Medium* (*M*) is applicable between size *38* and size *41*. It covers chest girth from 96.5 cm to 104.1 cm and waist girth 81.3 cm to 98.9 cm. Its drop value is 15.2 cm. The men's size *Large* (*L*) corresponds to sizes from *42* to *45*. It covers chest girths from 106.7 cm to 114.3 cm and waist girths from 91.4 cm to 99.7 cm. Its drop value is from 14.6 cm to 15.3 cm. The men's size *Extra-Large* (*XL*) is applicable to sizes from *46* to *49*. It covers chest girth from 116.3 cm to 124.5 cm and waist girth 102.9 cm to 112.4 cm. Its drop value ranges from 12.1 cm to 13.3 cm. The men's size *Two-Extra-Large* (*2XL*) is applicable to sizes from *50* to *53*. It covers chest girths from 127.0 cm to 134.6 cm and waist girths from 115.6 cm to 125.7 cm. Its drop value ranges from 8.9 cm to 11.4 cm. The men's size *Three-Extra-Large (3XL*) is applicable to sizes from *54* to *57*. It covers chest girths from 137.2 cm to 144.8 cm and waist girths from 129.5 cm to 142.2 cm. Its drop value ranges from 2.6 cm to 7.7 cm. The men's size *Four-Extra-Large* (*4XL*) is applicable to sizes from *58* to *60*. It covers chest girths from 147.3 cm to 152.4 cm and waist girths from 147.3 cm to 157.5 cm. Its drop value ranges from −5.1 cm to 0 cm. It means that the size *4XL* is for men whose waist girth is larger than their chest girth.

US sizing systems for women's garments had provided four body types: *Misses, Women's, Half-sizes*, and *Junior*. In the US sizing system women's body types have been clearly defined for a long time. During the 1920s US manufacturers felt the need for a new and younger looking garment which was called '*Misses*' or '*Missy*' size and gave a new size range designation of *10* to *20* (Handford, 1980). The US women's garment sizing system has been developed for each body type. *Misses* sizes are for regular body type. The *Misses* size is made for women with more slender body build than the *Women's* size body type. In 1920 it was considered that *Misses* sizes represented garment size for young ladies whose age was from *14* to *20* years old. However, *Misses* size garments were worn by a considerable proportion of adult women as well.

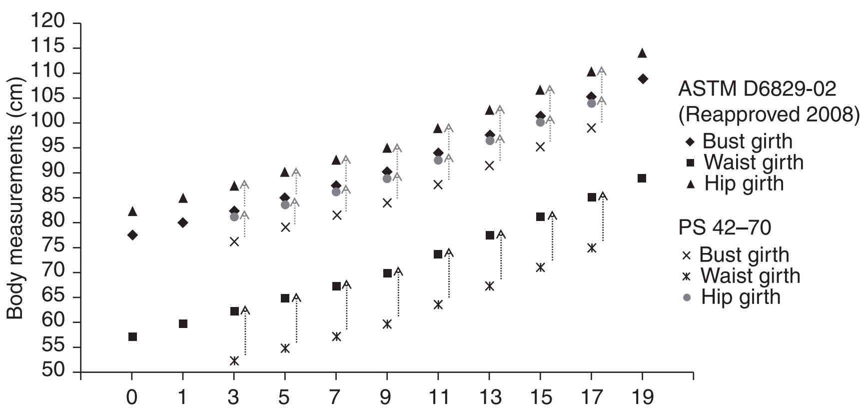
It became a major body type of the women's ready-to-wear garments in the USA. *Women's sizes* became the sizes for women with full body build and normal height. Retailers and manufacturers began to realize that this matured body type consumer group is big enough to be concerned. They realized that the large size garments need to be made not only for adult women but for all age groups (Cook, 1988). The name of that affluent figure type, *Women's size*, was changed into the *Plus size* to appeal to the general consumer group. Height is another index of women's body type in the US garment sizing system. Garment size for short figures is available. Various names for that body type appeared and disappeared in the retail market: *Short, Half-size*, and *Petite*. In these days the *Petite* size takes the place of short or half-sizes. In the American fashion business the *Petite* size was defined as women who stand between 4 feet 8 inches to 5 feet 4 inches. Retailers claimed that women who are under 5 feet 4 inches in height were half of all American women (Ondovcsik, 1981) or over 14 million in 1990 (Mangan, 1990). Retailers claimed that the demand for petites was strong enough and that petite size garments should be totally, completely engineered in proportion (Griffin, 1980). In the 1930s, '*Junior*' size was introduced. *Junior* size was for a young figure with a higher and smaller bust, slimmer hips, and shorter waist length. *Junior* sizes adopted the odd numbers in sizes, and ranged from 3 to 15, to distinguish it from the *Misses* size range (Handford, 1980). The *Junior* size had been designed for girls who still had the physique of children, but for those who desired to have garments which gave them a more grown-up look. The figure type for these garments was rather narrower in the shoulders and more flat-breasted than regular *Misses* sizes. However, *Junior* size garments have been worn by a considerable proportion of adult women (Wallach, 1986).

US women's garment sizes have been coded with numbers. Even numbers are used for *Misses'* sizes and odd numbers are used for *Junior* sizes. The vanity sizes have increased over the past few decades (Chun-Yoon and Jasper, 1993). In 2011 *Misses* sizes were divided into *Curvy Misses* size and *Straight Misses* size in ASTM D5585-11 (ASTM International, 2011). Both body type sizes have the same bust size, but the *Curvy Misses* sizes have 4 cm smaller waist girth and 2 cm larger hip girth measurements than the *Straight Misses* sizes (Figure 10.2). The range of hip-bust drop value for *Misses Curvy* size is from 7.0 to 7.6 cm, while the *Misses Straight* sizes' drop value is from 5.1 to 5.4 cm. The range of bust-waist drop value is from 24.8 cm to 28.6 cm for *Misses Curvy* sizes and from 19.1 cm to 22.9 cm for *Misses Straight* sizes. The range of hip-waist drop value is from 17.8 cm to 21.0 cm for *Misses Curvy* sizes and from 14.0 cm to17.2 cm for *Misses Straight* sizes.

The body type projected in '*Junior*' size has changed as well. *Juniors* size in the previous garment sizing standard issued in the 1970s, PS 42–70, had much smaller body measurements for bust, waist, and hip girths than the current *Junior* size in ASTM D6829-02. For example, the bust, waist and hip girth measurements for *Junior* size 11 were 89.0 cm, 63.5 cm and 92.7 cm respectively in 1970. However, the corresponding dimensions became 94.0 cm, 73.7 cm, and 99.1 cm. Bust measure increased by 5 cm and hip girth enlarged by 6.4 cm. The waist girth measurement enlarged by 10.2 cm. It shows that women's waist girth is getting bigger compared to the past. Also three *Junior* sizes 0, 1, and 19 have been added (Fig. 10.3).



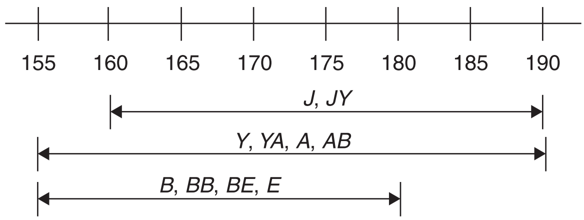
10.2 Distribution of waist and hip sizes of US *Misses* sizes from 00 to 20 in 2011: *Curvy Misses* and *Straight Misses* (ASTM D 5585-11).



10.3 Change of bust, waist, hip girths and body proportion in US *Junior* sizes in 1970s to 2008.

10.2.5 Japanese garment sizing system

In the Japanese men's garment sizing system (JIS L 4004:1997), ten body types are given (Table 10.5). Men's body types are defined by chest-waist drop value. Athletic body types (*J, JY,* and *Y*) have 20 cm, 18 cm, and 16 cm drop values respectively. Average body types (*YA, A,* and *AB*) have 14 cm, 12 cm, and 10 cm drop values respectively. Full body types (*B, BB, BE,* and *E*) have 8 cm, 6 cm, 4 cm, and 0 cm drop values respectively and they show stocky body build with short height compared to the athletic or average body types. *J* and *JY* type sizes are made for people whose heights are between 160 cm to 190 cm. The popular body type sizes, *Y, YA, A* and *AB* sizes, are made for 155 cm to 190 cm in height.



10.4 Height ranges of the men's body types in Japanese national men's garment sizing system.

The full body type sizes, *B, BB, BE,* and *E*, are made for 155 cm to 180 cm in height (Fig. 10.4).

Seventy-four chest and waist combination sizes are proposed in total. Japanese men's garment size covers smaller body build compared to US and European standards. Japanese men's garment sizes range from 86 cm to 104 cm of chest girth measurement. The interval size for chest girth is 2 cm. Waist size ranges from 68 cm to 104 cm. The interval size for chest girth is 2 cm to 4 cm. The waist girth size range is different by body type. For athletic body types (*J, JY,* and *Y*) and average body types (*YA* and *A*) waist sizes start at 68 cm to 74 cm, and end at 86 cm to 88 cm. For the full figure types (*B, BB, BE*, and *E*) waist sizes start from 82cm to 94 cm, and ends at 94 cm to 104 cm. For each body type six to nine sizes are available. Six sizes are proposed for each of *J, JY, BE,* and *E* body type and nine sizes are given for each of *YA* and *AB* body type (Table 10.5).

Table 10.5 Distribution of chest girth and waist girth measurements in the Japanese national men's garment sizing system (JIS L 4004:1997)

Chest size (cm) / Body type	86	88	90	92	94	96	98	100	102	104
J	–	68	70	72	74	76	78	80	–	–
JY	–	70	72	74	76	78	80	82	–	–
Y	70	72	74	76	78	80	82	84	–	–
YA	72	74	76	78	80	82	84	86	88	–
A	74	76	78	80	82	84	86	88	–	–
AB	–	78	80	82	84	86	88	90	92	94
B	–	–	82	84	86	88	90	92	94	–
BB	–	–	–	86	88	90	92	94	96	98
BE	–	–	–	–	90	92	94	96	98	100
E	–	–	–	–	94	96	98	100	102	104

In the Japanese garment sizing system (JIS L 4005:1997) women's body types are defined by hip proportion and height. Four height types (*PP, P, R,* and *T*) are ranged from 142 cm to 166 cm with an 8 cm interval. Even a very short woman would be able to find her garment size in the Japanese women's sizing system. However, a woman who is taller than 170 cm would not be able to find her garment size in the system. The height type *PP* is for 142 cm, *P* is for 150 cm, *R* is for 158 cm and *T* is for 166 cm in height. For hip proportion types, four types (*Y, A, AB,* and *B*) are developed. Type *A* stands for a regular body type. Japanese women's body types are diversified with reference to the regular body type, *A*. JIS defined body type *A* as the most frequently appearing body type. The hip-bust drop value varied within the body type. The larger size has a smaller drop value than the smaller size in each body type (Table 10.6). Body type *A* has eight sizes for very short women (*PP*, 142 cm), ten sizes for short women (*P,* 150 cm), nine sizes for women of 158 cm (*R*) and 166 cm (*T*) in height each and 36 sizes in total. *AB* and *B* types are full hip proportion types. Body type *AB* has 4 cm larger hips than body type *A*. Body type *AB* has six sizes for very short women 142 cm in height (*PP*), 10 sizes for short women 150 cm in height (*P)*, 15 sizes for women 158 cm in height (*R*) and six sizes for 166 cm in height (*T*) and 37 sizes in total. Body type *B* has 8 cm larger hips than body type *A*. Body type *B* has eight sizes for short women 150 cm in height and seven sizes for women 158 cm in height and 15 sizes in total. The very short height (*PP*) and the tall height (*T*) are not available for full hip type (*B*). Body type *Y* has 4 cm smaller hip girth than body type *A*. Body type *Y* has four sizes for very short women (*PP*, 142 cm), seven sizes for short women (*P,* 150 cm), nine sizes for women 158 cm in height and six sizes for women 166 cm in height and 26 sizes in total (Table 10.6).

10.2.6 Korean garment sizing system

In the Korean men's garment sizing system (KS K 0050:2004) men's garment sizes are proposed for four body types: *Y, A, B,* and *BB*. Korean men's garment standards state that those men's body types are for upper-body garment sizes. Men's body types are defined by chest-waist drop value. Athletic body type (*Y*) sizes have 21 cm drop value for 165 cm to 185 cm in height. Body type *A* has 15 cm drop value for 160 cm to 180 cm in height. It is the average body type. Full body types (*B* and *BB*) have 12 cm and 9 cm drop values respectively. Sizes of body type *B* are available for 160 cm to 180 cm height. Garment sizes of body type *BB* are available for 160 cm to 175 cm in height. Korean men's garment sizes start from 85 cm and end up at 103 cm to 109 cm in chest girth measurement. The range of waist girth size varies by body type: waist girth size of the athletic body type (*Y*) ranges from 67 cm to 85 cm. For average body type *A*, waist girth starts from 70 cm to 94 cm. For body types *B* the waist size starts from 73 cm and ends at 97 cm for 160–180 cm in height. The waist size ranges from 82 cm to 97 cm for the full body type (*BB*). The size interval for waist girth or chest girth is 3 cm (Korean Standards Association, 2004a).

Table 10.6 Bust girth and hip girth range, hip-bust drop value, and number of sizes by body types in the Japanese national women's garment sizing system (JIS L 4005:1997)

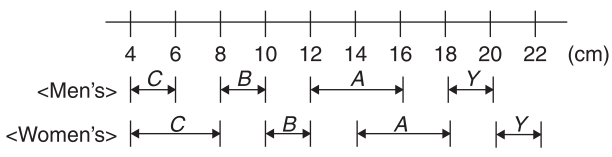
Hip type / Height	Small hip ***Y***	Medium hip ***A***	Large hip ***AB***	Very Large hip ***B***
Very Short (142 cm) ***PP***	***YPP*** Bust: 83—92 cm Hip: 85—91 cm Hip – Bust: 2 to –1 cm (4 sizes)	***APP*** Bust: 77—100 cm Hip: 85—99 cm Hip – Bust: 8 to –1 cm (8 sizes)	***ABPP*** Bust: 80—9 6 cm Hip: 91—101 cm Hip – Bust: 11—5 cm (6 sizes)	Not available
Short (150 cm) ***P***	***YP*** Bust: 77—96 cm Hip: 85—93 cm Hip – Bust: 2 to –3 cm (7 sizes)	***AP*** Bust: 74—104 cm Hip: 83—101 cm Hip – Bust: 9 to –3 cm (10 sizes)	***ABP*** Bust: 74—104 cm Hip: 87—105 cm Hip – Bust: 13—1 cm (10 sizes)	***BP*** Bust: 77—100 cm Hip: 93—107 cm Hip – Bust: 16—7 cm (8 sizes)
Regular (158 cm) ***R***	***YR*** Bust: 74—100 cm Hip: 81—97 cm Hip – Bust: 7 to –3 cm (9 sizes)	***AR*** Bust: 74—100 cm Hip: 85—101 cm Hip – Bust: 11—1 cm (9 sizes)	***ABR*** Bust: 74—124 cm Hip: 89—117 cm Hip – Bust: 15 to –7 cm (15 sizes)	***RP*** Bust: 80—100 cm Hip: 97—109 cm Hip – Bust: 17—9 cm (7 sizes)
Regular (166 cm) *T*	***YT*** Bust: 77—92 cm Hip: 85—95 cm Hip – Bust: 8—3 cm (6 sizes)	***TA*** Bust: 74—100 cm Hip: 87—103 cm Hip – Bust: 13—3 cm (9 sizes)	***ABR*** Bust: 77—92 cm Hip: 93—103 cm Hip – Bust: 16—11 cm (6 sizes)	Not available

In the Korean women's garment sizing system (KS K 0051:2004) three women's body types are defined by hip-bust drop value for upper-body garments: *N, A,* and *H. N* type stands for the regular body type with 3–9 cm drop value. Twenty sizes are available for body type *N*. They are for women 150–165 cm height. Bust size ranges from 79 cm to 91 cm with a 3 cm interval: 79, 82, 85, 88, and 91. Hip size ranges from 85 cm to 97 cm with a 3 cm interval: 85, 88, 91, 94, and 97. Body type *A* has a 3–6 cm larger hip size than the regular body type (*N*). Body type *A* has a 9–12 cm drop value and 10 sizes are available in 160–165 cm height. Bust size ranges from 79 cm to 85 cm with a 3 cm interval: 79, 82, and 85. Hip size ranges from 88 cm to 94 cm with a 3 cm interval: 88, 91, and 94. Body type *H* is for women who have smaller hips than the regular body type. Their bust girth is same as hip girth. Body type *H* size has 0 cm drop value and six sizes are proposed in 150 cm to 160 cm height. Bust size ranges from 88 cm to 94 cm with a 3 cm interval: 88, 91, and 94. Hip size ranges from 88 cm to 94 cm with a 3 cm interval: 85, 88, 91, 94, and 97. Thirty-six women's garment sizes are proposed in total (Korean Standards Association, 2004b).

10.2.7 Chinese garment sizing system

The Chinese garment sizing system (GB/T 1335) defines both men's and women's body types by the chest (bust)-waist drop value (Fig. 10.5). Four body types are proposed for both men and women: *Y, A, B* and *C*. For the men's sizing system, body type *Y* has 20 cm or 18 cm drop values. Body type *A* is the average body type and it has 12 cm, 14 cm, or 16 cm drop values in 155 cm to 185 cm height. Body type *B* has 8 cm or 10 cm drop values in 150 cm to 175 cm height. Body type *C* has 6 cm or 4 cm drop values for 150 cm to 185 cm height. For the women's sizing system, type *Y* has 22 cm or 20 cm drop values in 145 cm to 175 cm height. Body type *A* has 14 cm, 16 cm, or 18 cm drop values for 145 cm to 175 cm height. Body type *B* has 10 cm or 12 cm drop values in 145 cm to 175 cm height. Body type *C* has 4 cm, 6 cm, or 8 cm drop values in 145 cm to 175 cm height.

The Chinese men's garment size ranges from 72 cm to 112 cm in chest size with 4 cm intervals. For each chest size two to nine waist sizes are given (Table 10.7). The range of the chest sizes and the waist sizes are different by body types. The



10.5 Range of chest (bust)-waist drop values for men's and women's body types in the Chinese national garment sizing system.

Table 10.7 Distribution of chest and waist sizes in the Chinese national men's garment sizing system (GB/T 1335)

Chest size (cm) / Body type	72	76	80	84	88	92	96	100	104	108	112
Y	–	56 58	60 62	64 66	68 70	72 74	76 78	80 82	–	–	–
A	56 58 60	60 62 64	64 66 68	68 70 72	72 74 76	76 78 80	80 82 84	84 86 88	–	–	–
B	62 64	66 68	70 72	74 76	78 80	82 84	86 88	90 92	94 96	98 100	–
C	–	70 72	74 76	78 80	82 84	86 88	90 92	94 96	98 100	102 104	106 108

chest size of the athletic body type (*Y*) ranges from 76 cm to 100 cm. Two different waist sizes are given for each chest size and 72 garment sizes are available in 155 cm to 185 cm heights for body type *Y*. Body type *A* is the average body type. Its chest size ranges from 72 cm to 100 cm with three different waist sizes for each chest size. One hundred and seventeen garment sizes are available in 155 cm to 185 cm height for body type *A*. The chest size of the stocky body type (*B*) ranges from 72 cm to 108 cm. Each chest size has two different waist sizes. One hundred sizes are available in 150–185 cm height for body type *B*. Men's garment sizes for the portly body type (*C*) range from 76 cm to 112 cm chest size. Two different waist sizes are available for each chest size. One hundred and six garment sizes are proposed in 150 cm to 185 cm height for body type *C*.

10.3 Key dimensions and classification of garment types

The sizing systems developed in various countries have similarities and dissimilarities in their approach to given key dimensions. Each size code is defined with one to three body measurements. We call these, *control dimension, principal dimension,* or *key measurement*. Applying anthropometric data to the problem of devising an effective ready-to-wear garment sizing system is a long-standing concern. For deriving a garment sizing system from anthropometric data, selection of the key dimensions is a very important step (Green, 1981). Key dimensions control some different aspects of body size variability. They are body dimensions that provide the framework from which size categories will ultimately be generated. The key dimensions most often used are chest girth for men's garments and bust girth for women's garments. Waist girth or hip girth are used as the secondary key dimensions for upper-body garments or whole-body garments. Height measurements are used as the secondary key dimension for adults' garments, but as the first key dimension for infants' or children's garments.

In general, key dimensions are different by garment type. The framework of the international sizing system is that the size designation of garments should be the body measurement which the garment was made to fit. The ISO committee decided key dimensions for each type of garment and it was agreed that the working groups should specify not more than three key dimensions (French, 1975). The ISO system suggested one to three key dimensions for each individual garment type. It seems that the garment type was classified after considering the key dimensions. The ISO classifies garment types into outer-garments, under-garments and others. These three garment types are sub-classified into upper-, whole-, and lower-body garments. Several nations have revised their standard garment sizing systems according to the ISO standard sizing system. Other sizing systems classify garments by item, such as coat/dress, skirt, pants, jacket, shirts, underwear, and pajamas (Chun-Yoon and Jasper, 1993). Most of the standards adopted chest girth as the first key dimension and added height measurements as a secondary key dimension for men's coats or jackets. Sometimes they add height or waist measurement. The ISO sizing system (ISO 3636:1997) and the BSI sizing system (BS 6185:1982) described men's upper-body garment sizes with one or three key dimensions:

- chest girth
- waist girth
- height.

It suggests chest girth as the key dimension for knitted tops. The key dimensions for boys' garments are different from men's garments. In the ISO system the first key dimension for boys' upper-body garments is height, i.e. stature. Hip girth and chest girth are the next. For knitted shirts, the key dimension is chest girth. Two key dimensions are suggested for men's lower-body garments, such as pants, in the ISO standard: waist girth and inside-leg length. For swimwear the waist girth is proposed. Height is the first key dimension for boys' lower-body garments. Hip girth and waist girth are the next. Waist girth is the common key dimension for men's pants. Neck girth and arm length are the key dimensions for formal and uniform shirts internationally. The key dimension for a knitted top is chest girth. Sometimes height is added. The European standard sizing system (BS EN 13402-3:2004) classified garment types and gave key dimensions for each garment type. One or two key dimensions are given and one to three secondary dimensions are added. Height is a secondary dimension for all men's garment sizes. For a loose fit garment, such as a jacket or pajamas, key dimension is chest girth. Height and waist are the secondary dimensions for those garments.

For an overcoat or a knitted top the waist girth is not given as the secondary dimension. Waist girth is the key dimension for pants. The secondary dimensions for men's pants are height and inseam-leg length. The key dimension for formal shirts is neck girth. Sleeve length is listed as a secondary dimension. The key dimensions that are most often used for women's garments are bust girth, waist girth, hip girth and height. Bust girth is the most common key dimension for upper-body garments or whole-body garments. Waist girth is the key dimension for skirts or pants. Sometimes an outside-leg length or hip girth is added as a secondary key dimension. The BSI sizing system (BS 3666:1982) describes women's upper-body garment sizes with one to three key dimensions. The key dimensions for women's outerwear covering upper-body are bust girth, hip girth, and height. Bust girth is a key dimension for knitted tops and underwear covering the upper body. The key dimensions for lower-body outerwear are hip girth, waist girth, and outside-leg length. For underwear covering the lower body, hip girth is the only key dimension. The inside-leg length is used for men's pants size. However the outside-leg length is used for women's pants sizes. For women's garments, height is given as a secondary dimension for all garment types except bras and corsets in the European standard sizing system. Bust girth is the first key dimension for upper-body garments and whole-body garments, such as jackets, overcoats, suits, dresses, and shirts. Hip girth is a secondary key dimension for jacket, pants, skirt, and dress sizes. Waist girth is the first key dimension for women's pants or skirt size. The key dimensions for bras or corset tops are bust girth and under-bust girth. The key dimensions for corset bottoms are waist girth and hip girth. Height is used as a key dimension for pantyhose. Hip girth or weight is the secondary dimensions for pantyhose (ISO 5971:1981). Weight can be a good key dimension because many people know their weight rather than the hip girth measurement. Fit of the pantyhose has a lot to do with stretching. The most common key dimensions for boys' garments in the ISO sizing system (ISO 3636:1977) are height and hip girth. Boys' jackets and coats are sized by height, hip girth, and chest girth. Boys' pants are sized by height, hip girth, and waist girth. For girls' garment sizes, height and bust girth are key dimensions for jackets, coats, or shirts. The key dimensions for girls' skirts or pants are height and hip girth. The British standard (BS 3728:1982) suggested height as the key dimension for infants' garments. The same key dimensions are given for outerwear of boys' and the girls' garments. Height, chest girth, and hip girth are suggested for boys' upper body garments. Height, bust girth, and hip girth are suggested for girls' upper body garments. Height, hip girth, and waist girth were suggested for lower body garments. The Korean standard uses height as a key dimension for boys' and girls' jackets, shirts, knits, and almost all items except formal suit and inner shirts. Height and chest girth are key dimension for formal suit jackets. Height and waist girth are the key dimension for boys' formal suit pants.

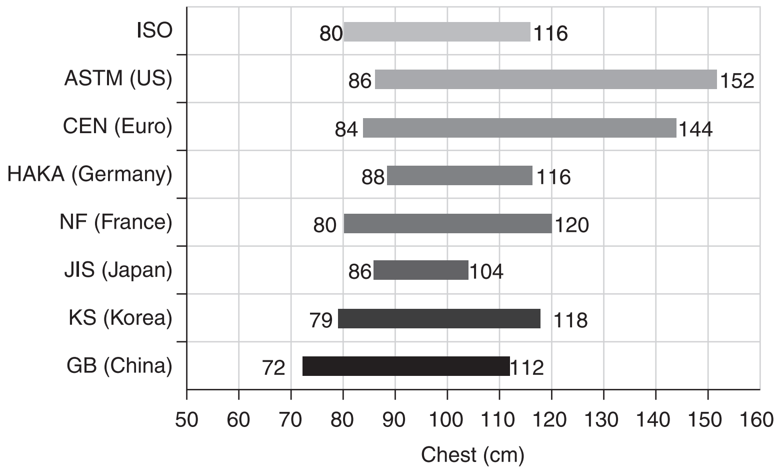
10.4 Range of body measurements

The sizing system shows the range of body measurements for each key dimension. In the anthropometric sizing system, the size chart shows the range of apparel sizes. Body shapes and sizes may differ significantly from country to country. The garment sizing system covers a vast range of human figures. US standards and European standards cover a wider range of chest and waist measurements than Asian garment standards. The body measurements that are covered by standard garment sizing systems differ by country. US and European men's garment sizing standards include larger sizes than Asian standards in chest girth or waist girth. Waist size spread is wider than the chest size in men's garment sizing system. Men's waist size is larger than the chest size in most national standard sizing systems. However, the range of waist sizes does not exceed the range of bust sizes in most women's garment sizing systems.

10.4.1 Body measurements in men's garment sizing systems

The key dimensions that are most often used are chest girth, waist girth, and height for men's garments. The range of these body measurements in the sizing systems has been compared. ISO men's garment sizes cover from 80 cm to 116 cm in chest girth. Most sizing systems cover 88 cm to 104 cm. The US men's garment sizing standard (ASTM D6240-98) includes very large chest sizes and waist sizes. It covers from 86 cm to 152 cm in chest girth. The European standard (BS EN 13402-3:2005) also covers very large chest sizes. It covers from 84 cm to 144 cm in chest size. On the other hand, the Japanese standard does not include large sizes. JIS men's chest size ranges from 86 cm to 104 cm (Japanese Standards Association, 1997c). The standard which starts from the smallest men's chest size is the Chinese standard (GB/T 1335.1:1997). Its smallest chest size is 72 cm. The Japanese men's garment sizing system (JIS L 4404:1997) does not include sizes more than 104 cm in chest girth. The German men's garment sizing system (HAKA) does not include sizes smaller than 88 cm (Fig. 10.6).

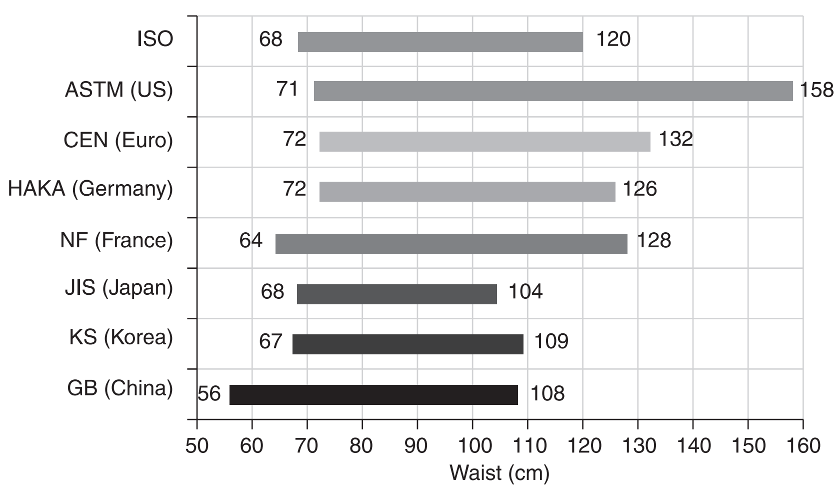
Men's waist size spreads out more widely than chest sizes in most national standard sizing systems. The minimum waist size is 56 cm and the largest size is 158 cm, which means the range of men's waist size is very broad. Those standards present something similar to each other. The men's waist garment size range that is covered by most of the national standard sizing systems is 72 cm to 104 cm. The US standard has a very broad spread in waist sizes. It spreads from 71 cm to 158 cm. The Japanese standard (JIS) gives the smallest range of waist sizes. It ranges from 68 cm to 104 cm. The smallest men's waist size (56 cm) is found in the Chinese standard. The largest waist size (158 cm) is found in the US men's garment sizing standard (ASTM D6240-98). The ISO standard, Euro standard, German standard, and French standard cover relatively similar ranges of waist size. ISO men's garment sizes cover men's chest sizes from 80 cm to 116 cm and



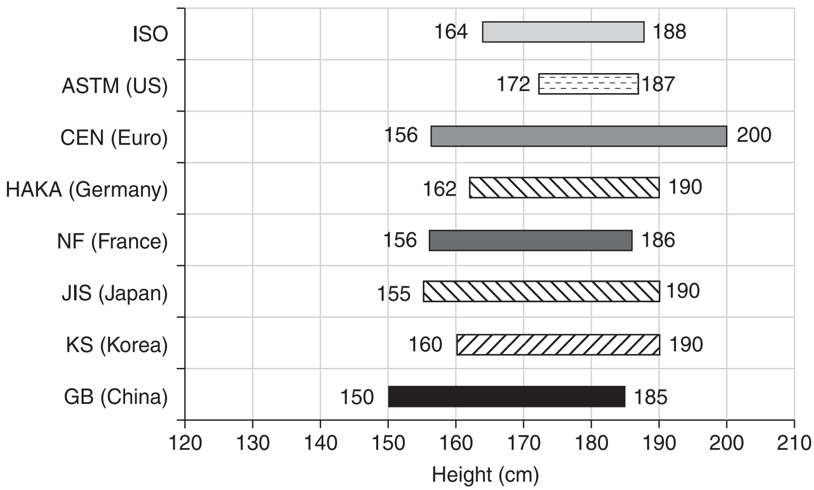
10.6 Range of men's chest size in the global national standard sizing systems.

waist sizes from 68 cm to 120 cm (ISO 3636.1997). The German men's garment standard covers waist sizes from 72 cm to 126 cm while the French standard covers 64 cm to 128 cm. Standards that give a small waist size less than 70 cm are ISO, French and Asian standards (Chinese, Japanese, and Korean). Standards that give men's waist size greater than 120 cm are US, European, German, and French standards (Fig. 10.7).

Men's height sizes also vary among standards. It ranges from 150 cm to 200 cm. The smallest height size (150 cm) is found in the Chinese standard (GB/T 1335)



10.7 Range of men's waist size in the national standard sizing systems.



10.8 Range of men's height size in the national standard sizing systems.

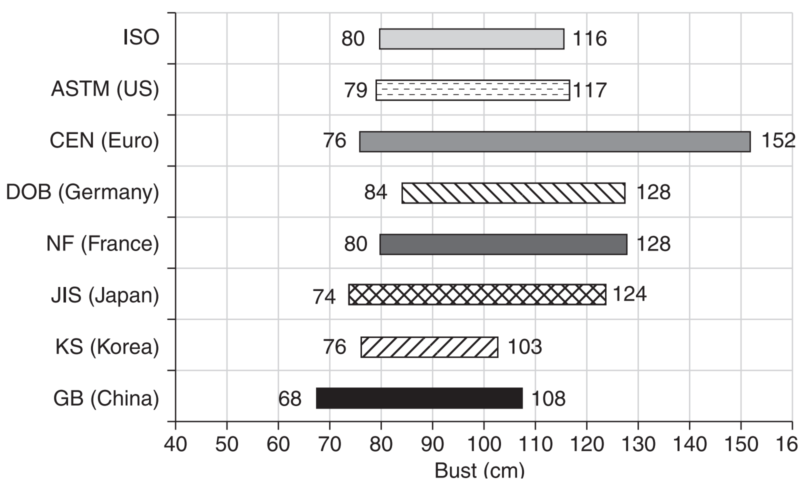
and the largest size (200 cm) is found in the European standard (BS EN 13402–3:2004). Men's height sizes in the ISO standard (ISO 3636:1997) are from 164 cm to 188 cm. The common height size range given in the international garment sizing systems is from 172 cm to 185 cm. Most of the standards provide men's height sizes taller than 185 cm. Standards that covers over 190 cm in height are European, German, Japanese, and Korean standards. The European standard even covers 200 cm in height. Standards that cover sizes shorter than 160 cm are the European standard (BS EN 13402-3:2004), the French standard (NF G 03-003), the Japanese standard (JIS L 4004), and the Chinese standard (GB/T 1335.1). The US standard (ASTM D6240-98) covers from 172 cm to 187 cm tall (Fig. 10.8).

10.4.2 Body measurements in women's garment sizing systems

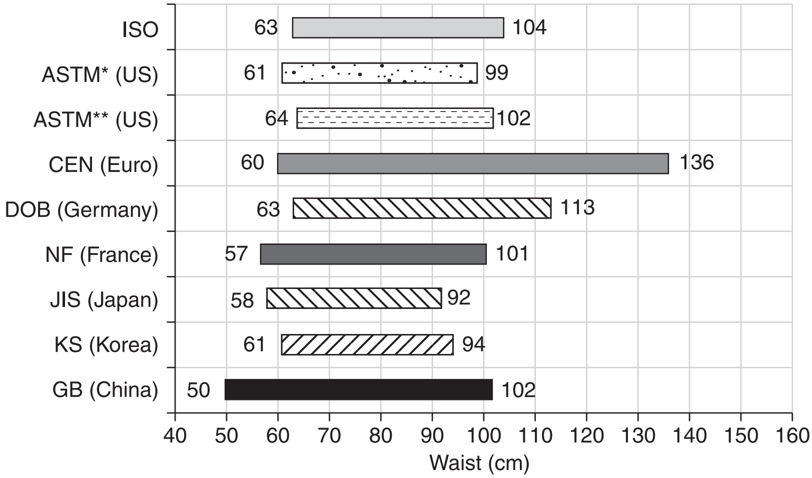
When fashionable clothing for women was first manufactured, sizing was patterned after bust measurement in order to determine the size. The key dimensions that are most often used are bust girth, waist girth, and hip girth for women's garments. The European standard (BS EN 13402-3:2004) covers a wide range of bust girth, waist girth and hip girth. The Korean system (KS K 0051:2004) covers a very limited range of body measurement.

The total range of women's bust girth that is covered by the international sizing systems is from 68 cm to 152 cm. The common bust girth measurement range covered by most international sizing systems is from 84 cm to 103 cm. The smallest bust size is 68 cm and it is found in the Chinese standard (GB/T 1335.2:1997). The largest bust size is 152 cm and it is found in the Euro standard (BS EN 13402-3:2004). The European standard covers a wide range of bust sizes: 76 cm to 152 cm. The US standard covers almost the same range. ISO standard covers from 80 cm to 116 cm. *Misses'* size of the US sizing standard (ASTM D5585-11) covers almost the same size range. It covers from 79 cm to 117 cm. The standard that covers the narrowest range of size is the Korean standard (KS K 0051:2004). It covers from 76 cm to 103 cm. The standard which starts from the smallest bust size is the Chinese standard (GB/T 1335.2:1997). Its bust size starts from 68 cm to 108 cm. The German women's garment sizing standard (DOB-Verband: 1983) does not cover small bust size. It starts from bust size 84 cm (Fig. 10.9).

The women's garment waist size in an international sizing system is relatively indiscriminate. The ISO standard covers from 63 cm to 104 cm. Most of the standard waist sizes range from 57 cm to 64 cm. The European standard (BS EN 13402-3) covers a wide range of women's waist sizes: 60 cm to 136 cm. The smallest waist size is 50 cm and it is found in the Chinese standard (GB/T 1335.2:1997). The largest size (136 cm) is found in the European standard. *Misses* size of the US sizing standard (ASTM D5585-11) covers almost the same range as the ISO standard. *Curvy Misses* sizes' waist sizes are from 61 cm to 99 cm. *Straight Misses* sizes' waist sizes are from 64 cm to 102 cm. Many women's garment standards do not cover waist sizes over 100 cm (Fig. 10.10).



10.9 Range of women's bust sizes in the national standard sizing systems.



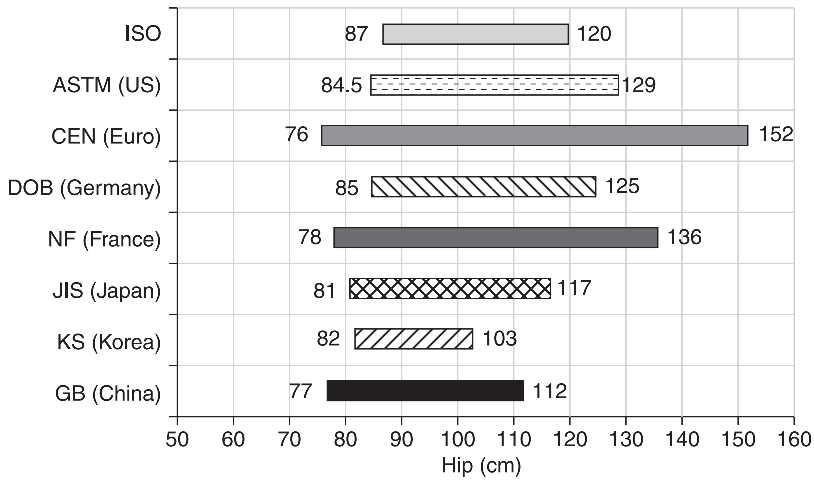
10.10 Range of women's waist sizes (**Curvy Misses*; ***Straight Misses*) in the national standard sizing systems.

Hip size in global standard women's garment sizing standards is relatively diverse. The European system (BS EN 13402-3) shows the widest range of hip size. It ranges from 76 cm to 152 cm. Next is the French standard (NF G 03-002:1997). It covers from 78 cm to 136 cm. The smallest range of hip size is found in the Korean standard (KS K 0051:2004). It ranges from 82 cm to 103 cm. The ISO system starts from 87 cm. ISO does not cover the small hip size. The smallest hip size (76 cm) and the largest size (152 cm) are found at Euro standard (BS EN 13402-3:2004). The range of hip size in the German standard (DOB-Verband: 1983) is very close to the US standard (ASTM D5585-11) (Fig. 10.11).

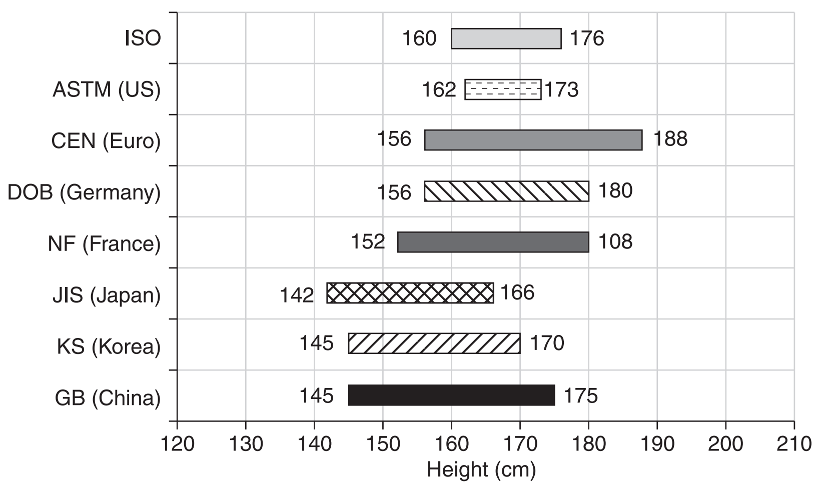
Women's garment height sizes in international sizing standards are relatively diverse. The range of women's height measurements given in the international garment sizing standards is from 145 cm to 188 cm. The common height size range is from 162 cm to 166 cm. The ISO standard ranges from 160 cm to 176 cm. The European standard (CEN) gives sizes for the widest range height. It is from 156 cm to 188 cm. The US standard (ASTM) gives women's sizes for the smallest range, from 162 cm to 173 cm. The shortest height size (142 cm) is found in the Japanese standard (JIS); and other Asian standards (KS K 0051:2004 and GB/T 1335.2:1997) have height sizes shorter than 150 cm (Fig. 10.12).

10.5 Garment sizing systems for children

International children's garment sizing standards classified children's sizes by age and gender: *Infants*' sizes, *Boys'* sizes, and *Girls'* sizes. US garment standards have additional categories for children's garments: *Toddlers*' size and *Children*'*s* sizes. Apparel sizes for children are designated by height or age.



10.11 Range of women's hip size in the national standard sizing systems.



10.12 Range of women's height measurements in the national standard sizing systems.

10.5.1 Infants' garment sizes

The designation systems of *Infants'* garment sizes have similarity among standards. Most of the standards designate *Infants'* size with height or age (month). Designating an infant size by age is easy to remember. However, children's physical growing rates vary by individuals. Therefore, ISO standards and many countries' national standards use height as a key dimension for *Infant* size. Most global *Infants'* garment standards are focused on babies who are younger than 2 years old. The height range of *Infant* size is different among standards. The ISO defines *Infant* as a baby whose height is 104 cm or less (International Organization for Standardization, 1991) while the US standard (ASTM International, 1999) covers infants as babies who are under 90 cm in height. The Japanese and Korean *Infants'* sizing systems are for babies whose height is under 125 cm.

The ISO standard gives ten infant sizes from size *50* to size *104* with 6 cm intervals. Fifteen *Infant* sizes are proposed in the Korean standard (KS K 0052:2004) from size 55 to size 125. Size *70* (height 70 cm) is a size for a 6 month old baby. The US standard (ASTM D 4910-95) gives six *Infant* sizes for babies under 2 years old. Their sizes are designated with age: *0 to3M*, *3 to 6M*, *6 to 9M*, *9 to 12M*, *12 to 18M* and *18 to 24M* months. These sizes cover the height groups from 60 cm to 88 cm. The size *3 to 6M* is for a baby 60 cm to 68 cm in height. *Toddler* sizes are for children from 18 months to approximately 3 years of age, and sizes are *2T* to *4T*. Japanese infants' garment sizes are designated by height. Six infant sizes are given from size *50* to *100* with 10 cm interval in height. It gives three more *Infant* sizes: *75*, *85* and *95* (JIS L 4001:1998).

10.5.2 Boys' and girls' garment sizes

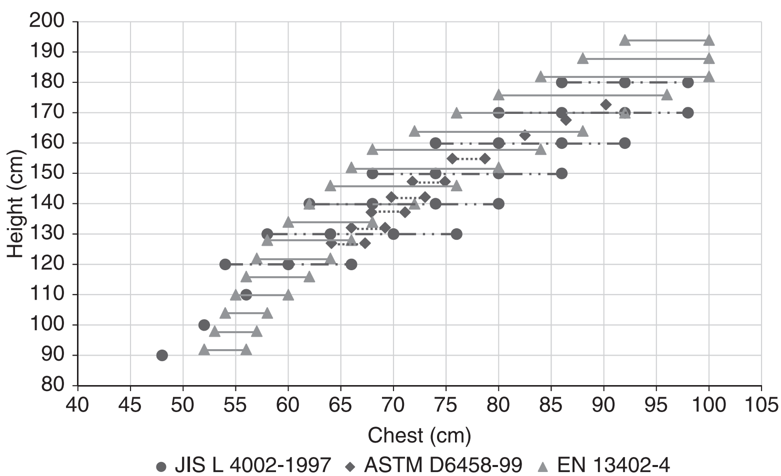
Children's sizes in the US sizing system, which are also known as preschool or little boys' and little girls' sizes, are designed to fit children who are approximately 3 to 6 years old. Six sizes are suggested for boys or girls. The sizes are from *2* to *6X/7* (ASTM D 5826-95). These sizes are for boys and girls whose stature is from 84 cm to 125 cm and the chest girths range from 51 cm to 63 cm. The chest–waist drop values of *Children* sizes are 0 cm for size *2*, 2.6 cm for size *4*, and 5.1 cm for size *6*.

For boys and girls older than 7 years, the US sizing system gives two body types for *Boys* and *Girls* sizes: *Regular* and *Slim*. US *Boys* sizes are for 7- to 17-year-old boys. US *Regular Boys'* size has ten sizes. It starts from *8R* to *20R. Regular Boys* sizes are for boys whose body sizes are from 127 cm to 173 cm in height and from 67 cm to 90 cm in chest girth. *Slim Boys* size category has six sizes. The sizes are from *8S* to *14S. Slim Boys* sizes are for boys whose body sizes are from 125 cm to 155 cm in height and from 64 cm to 76 cm in chest girth. The chest–waist drop value for *Regular Boys'* sizes is smaller than the *Slim Boys'* sizes. It is 7.6 cm for size *8R*, 8.9 cm for size *10R*, and 11.4 cm for size *14R*. It is 9.5 cm for size *8S*, 10.8 cm for size *10S*, and 13.4 cm for size *14S* (ASTM D 6458-99).

Japanese *Boys'* size contains four body types: *A, Y, B*, and *E*. Body type *A* indicates a regular body type and type *Y* means a slim body shape. *B* and *E* types are for full figures. The *Boys* category has sizes from *90* to *180* with 10 cm height intervals. The sizes are designated by the height. Sizes *90, 100*, and *110* are available only for the *A* type. *Y* and *B* type sizes starts from *120* to *180*. *E* type sizes are given only from *130* to *170* (JIS L 4002-1997).

The European sizing standard (BS EN 13402-3:2004) gives *Boys'* sizes from *92* to *194* with 6 cm interval in height. These size designations indicate boys' height. European *Boys'* sizes have a greater height range than US *Boys'* sizes. US *Boys'* sizes are available from 127 cm to 173 cm in height. The European *Boys'* size is available for *Slim* and *Regular* body types. *Boys'* size *140* is for a 140 cm tall boy. For *140 Boys'* size four chest sizes are available in the Japanese sizing system: 62 cm, 68 cm, 74 cm, and 80 cm. Two chest sizes are available in the European sizing system: 62 cm for *Slim* and 72 cm for *Regular*. The US *Boys'* size *11* is for a boy whose height is 142 cm with a chest girth of 70 cm or 73 cm (Fig. 10.13). The chest size 70 cm is for *11S* and 73 cm is for *11R*. It shows that Japanese *Boys'* sizes cover a very wide range of chest sizes. The European *Slim Boys'* size is for very slim body types. On the contrary the US *Slim Boys'* sizes are for those with a relatively slim body build.

US *Girls* sizes are for 7- to 16-year-old girls. Each size gives two body type sizes: *Slim Girls* and *Regular Girls*. It has six different sizes: *7S* (*7R*), *8S* (*8R*), *10S* (*10R*), *12S* (*12R*), *14S* (*14R*), *16S* (*16R*). The height ranges from 130 cm to 159 cm. The bust girth for *Slim Girls'* size ranges from 62 cm to 80 cm. The bust girth of the *Regular Girls'* size ranges from 66 cm to 84 cm. The bust–waist drop value of *Girls'* size increases with size and the *Slim Girls'* size has a larger drop value than the *Regular Girls'* size. The drop value for the *Slim Girls'* size is 10.1 cm for size *7S*, 12.7 cm for size *10S*, and 15.2 cm for size *14S*. It is 8.9 cm for size *7R*, 11.4 cm for size *10R*, and 14.0 cm for size *14R*. The hip–bust drop value for *Girls'* sizes is

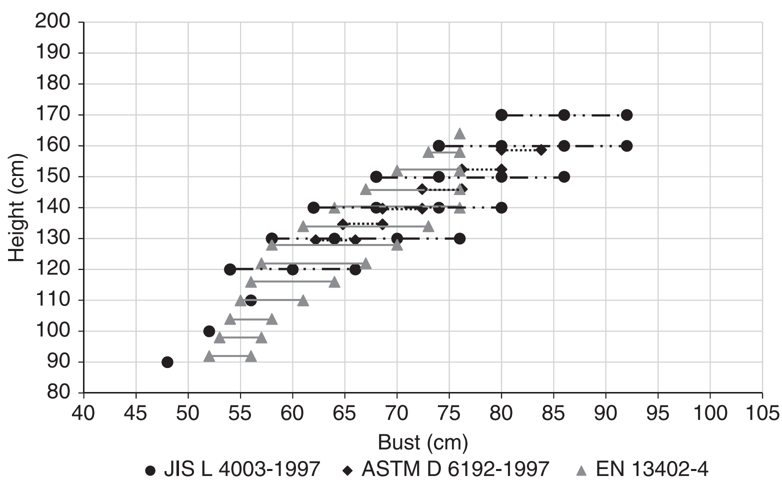


10.13 Distribution of height and chest sizes in the US, Japan, and EU standard sizing systems for boys' garments.

increased with size and *Slim Girls'* size has slightly larger drop value than *Regular Girls'* size. The hip–bust drop values for *Slim Girls'* sizes are 3.2 cm for size *7S* and *10S*, and 5.7 cm for size *14S*. For *Regular Girls'* size it is 3.8 cm for size *7R* and *10R*, and 6.4 cm for size *14R* (ASTM D 6192-97).

Japanese *Girls'* sizes are given for four body types: *A, Y, B*, and *E*. Body type *A* is defined as a regular body type and body build of type *Y* is slimmer than body type *A*. Girls' garment sizes for body types *B* and *E* are for a plump body shape. Japanese *Girls'* sizes range from size *90* to *170* with 10 cm intervals. The size indicates the height of a girl. The small sizes, *90, 100*, and *110*, are available only range for regular body type *A*. *Girls'* sizes for *Y* and *B* body types are available from sizes *120* to *170*. Garment sizes for body type *E* are from sizes *130* to *160* (JIS L 4003-1997).

The European sizing system provides *Girls'* sizes from *92* to *164*. The size designation number indicates the height in centimeters. The sizes are increased in 6 cm intervals. Each size is available for slim and regular body types. For a girl who is 140 cm in height the bust sizes 64 cm and 76 cm are available in the European sizing system. These bust sizes are 2 cm to 4 cm larger than the European *Boys'* size of the same height, 140 cm. US *Girls'* sizes for 140 cm in height are bust size 68.6 cm and 72.4 cm (Fig. 10.14). It shows that the European sizing system gives garment size for a very slim or regular body build, while US *Girls'* sizes are for girls with relatively slim or regular body build. The US *Girls'* sizing system are available for girls whose height ranges from 130 cm to 159 cm. A girl whose height is 140 cm can find her size from bust size 62 cm, 68 cm, 74 cm, and 80 cm in the Japanese sizing system. It shows that the Japanese girls' sizing system covers a wide range of body shapes.



10.14 Distribution of height and bust sizes in the US, Japan, and EU standard sizing systems for girls' garments.

10.6 Future trends

Comparing international sizing systems has an unavoidable limitation that the issued dates of the standards are not aligned. Some countries revise their standards every five years while other countries do not revise their standards so often. The goal of the sizing system is to satisfy consumers' needs for apparel that fits their body dimension. Consumers demand informative size information and some importers offer the size conversion table on the garment tag or the website to make shoppers choose the garment that will fit them best. With technological advances, online shopping is spreading rapidly and 3D body scanners are replacing the tape measure. Customers may enjoy the personalized service like mass customization. Three-dimensional body scanning data might be useful today and in the near future as 3D data could enhance the current size and shape database. Virtual garment design and fit could also be offered. Although one challenge is to provide clothing that fits diverse populations, nowadays the consumers' morphological feature in a specific geographical area has changed with immigration, aging, and lifestyle change. Demands of changing consumers are guiding new approaches to sizing. Regardless of the changes that the consumers are bringing in the industry, apparel companies still need to define their target customers and to integrate consumers' needs into their product development processes. Whether or not sizing will be selected in the future using a computerized system sizing standards will play a significant role in the ready-to-wear garment business. They will provide guidelines for manufacturers and consumers.

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11
Computer design and digital fit of clothing

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Abstract: This chapter discusses clothing design and fit based on the development of computer-related technology and its use for designing and improving the fit of clothing. The chapter first reviews the role and application of computer technologies in clothing design and fit assurance, such as computer-aided design (CAD), three-dimensional (3D) body scanning, virtual simulation and the use of sizing systems. The chapter then describes ways of integrating computer-related technologies with clothing design processes to resolve current design and/or fit issues and promote sustainability in the fashion industry for the future.

Key words: clothing fit, computer-aided design (CAD), 3D body scan, virtual simulation, sustainable product design.

11.1 Introduction: the role of computer technology in clothing design

Designers and manufacturers in the fashion industry are increasingly using computer technology in product development processes, in diverse ways. It is therefore important to know how to use these applications consistently and effectively. The rapid development and spread of computer-related technology has convinced many retailers and designers that the future of the whole industry depends on its successful implementation in clothing design (Collier and Collier, 1990; Istook, 2002; Sayem *et al.*, 2010).

The use of modern computer technology can guarantee competitive advantages such as a high and stable garment quality, improved productivity and flexibility, and the ability to respond quickly to the requirements of the fashion market, which allows manufacturers to save on materials and cut production costs (Istook, 2002; Pechoux and Ghosh, 2002; Sayem *et al.*, 2010; Meng *et al.*, 2010). Computer technology is widely used to ensure effective information flow as well as in the design and production of garments, for example using Computer-Aided Design (CAD), three-dimensional (3D) body scan, or virtual try-on (Gill and Kaplas, 2009; Loker *et al.*, 2008). The influence of computer technology begins at the textile design stage and continues through manufacturing, marketing and the eventual sale of the product to the consumer. Clarke and O'Mahony (2006) state: 'CAD has revolutionized the design process, introducing a sense of 3D space into two-dimensional design and bringing with it a whole new visual aesthetic' (p. 33).

Consequently, the clothing industry has been transformed from a traditional, labour-intensive industry into a highly automated and computer-aided one (Loker *et al.*, 2008). However, despite the advantages of computer technology, there are still some questions that must be thought through. It is important to consider, for example, the reliability and stability of a computer system and its components, or whether or not a computer system can be adapted to actual production conditions and requirements, or whether a system is compatible with other traditional clothing design processes. Many of the technological systems that have been made available to the apparel industry have already accounted for many of these potential problems. For example, OptiTex data exchange can read and convert information from competitors such as Gerber, Investronica, or Lectra, and supports over 20 different file formats for importing and exporting information (OptiTex, 2012).

11.2 Using sizing systems in clothing design simulation

It is best both for companies and for consumers to include as many people as possible in the size ranges provided by apparel companies. However, current sizing systems do not guarantee optimum conditions, which sometimes results in poorly fitting clothes. This section will discuss potential solutions that have been applied or are being developed to improve fit in clothing design.

The goal of creating a sizing system is to find the optimum number of size groups, which will describe as many shapes and sizes encountered in the population as possible, in order to provide as many individuals as possible with a well-fitted garment, and also to allow the manufacturer to make a profit (Bougourd, 2007; Yu, 2004a). One major source of apparel fit problems is pattern grading and sizing systems, which tend to assume that proportionally graded sizes can fit most of the population. The ready-to-wear sizing systems that different companies adopt for their own target markets have the potential, cumulatively, to fit all body proportions in the population (Ashdown and Dunne, 2006). This shows that it is not lack of information or resources, but lack of focus and proportion information within specified target markets that creates the problem. Poor fit can also be due to problems with garment construction, rather than being purely a result of unsuitable sizing (Ashdown and O'Connell, 2007; Petrova and Ashdown, 2008).

Automated custom fit can be one potential solution to provide better fitting clothing for the population. Technological advances such as 3D body scanning for body measurement and automated CAD programs for custom pattern generation can make customization a possible option for apparel manufacturers. Body scanners capture data that can be used to generate a 3D image of the human form. This image can be visualized on the computer screen and analysed using software designed to automatically find body landmarks and generate body measurements. Complicated CAD patternmaking systems have been continuously developed by various companies for efficient and effective apparel patternmaking, grading, and marking (Ashdown and Dunne, 2006). Use of a preliminary test garment constructed using a less expensive fabric is another possible solution to provide better fitting clothing. Most important are the reliability of body measurement data and the accuracy of body chart data (Ashdown and Dunne, 2006).

In recent years, several countries have conducted anthropometric surveys using 3D body scanners to find the relationships between body measurements, optimal fit requirements, and sizing systems. The United Kingdom created the organization SizeUK in 2001, utilizing both manual and scanning technology and focusing on integrating scan data, advanced CAD and commercial applications in production, standards development and virtual try-on shopping (Bougourd, 2007). Following SizeUK, other countries have conducted similar anthropometric data surveys using 3D body scanning technology (e.g., SizeUSA, SizeJapan, SizeKorea, SizeMexico, SizeThailand, SizeAustrailia, SizeCanada, SizeMalaysia). These surveys provide necessary data for the development of an internationally compatible sizing system (Bye *et al.*, 2006).

In the near future, apparel companies will have access to sizing data from a range of different countries, which will enable the production of garments that accurately meet a target market's specific needs in terms of size. The company saves the data, with ID numbers but not names, and may give collective information to retailers as feedback. Customers will be able to measure their sizes overseas and then send the data over the Internet to the sizing database, which will produce 3D drafts and accurately determine sizes for customers to custom-make clothes.

11.3 Analysis of apparel fit preferences using 3D body scan data

Three-dimensional surface scanning technology has evolved as an industrial tool to measure and compare three-dimensional objects at varying stages of assembly for the product development process (Ashdown *et al.*, 2004). The 3D pattern generation method is an innovative means by which optimum-fitting patterns can be obtained easily without traditional trial-and-error-based grading methods (Kim *et al.*, 2010). Visual fit analysis using 3D scans is similar in many ways to fit analysis with a live model, but with some extra benefits (Ashdown *et al.*, 2004). The body scanner eliminates colour, texture, and background distractions, which makes it easier to focus solely on the fit issues. It is also advantageous to be able to view the minimally-clothed body simultaneously with the fully-clothed scan, in order to identify where a garment presses on certain areas of the body and to determine body configuration factors contributing to fit problems (Ashdown *et al.*, 2004). Body scans can also be used to evaluate the style and fit of clothing on the basis of size specifications, structural design details, and fabric parameters (Lee *et al.*, 2012; Loker *et al.*, 2008).

Scanners are currently used for custom-fit garment production by various companies – Brooks Brothers, Saint Laurie, C&A, etc. – and for customized pattern generation for home sewing by companies such as Unique Patterns (http://www.uniquepatterns.com). Scanners are also used for size selection by the US Army, the Canadian Armed Forces and organizations such as Me-Ality, which is a free body-scan service offering consumers' free scans and size prediction advice (http://www.me-ality.com).

Body scanning technology is proving to be an invaluable tool in apparel product development and several retailers have begun to incorporate it into their business. The international retailer Target has invested US$ 1 million in a sizing study utilizing 3D body scanners in selected stores to gather size and shape information about its customers in order to improve the fit of its store brand apparel (Stafford, 2012). Malls across the US have begun to install body scanners for use by customers (Me-Ality, 2012). Currently, 72 malls have scanners installed, with many more planning to install them in the near future (Me-Ality, 2012). A mall customer can quickly obtain his or her current measurements at the scanning booth while remaining fully clothed, and can use the results to choose the correct size at a variety of stores. This eliminates the need to try on items before purchase (Canberra Times, 2012). A wide range of target customers have access to this service, as numerous apparel brands (e.g. Aeropostale, Alfred Dunner, Banana Republic, Coldwater Creek, DKNY) are among the Me-Ality scan data subscribers (Me-Ality 2012).

11.4 Ensuring good fit in the design of new clothing

The fit of clothing is regarded by customers as the most significant aspect of clothing appearance (Lee *et al.*, 2012). To ensure a perfect fit for consumers, the term 'fit' should first be correctly understood. Some experts divide it into two different concepts: subjective fit and objective fit (Lee *et al.*, 2012; Yi, 2001; Yu, 2004a). Both should be considered by designers and manufacturers. Subjective fit involves the 3D body shape and the fabric properties which influence garment drape and appearance and contain a social norm; it also involves body cathexis, and physical dimensions of clothing. Live models and dress forms are common standards used to test clothing fit in trials judged by experienced judges (Yu, 2004a). The second type of fit assessment, objective fit, is difficult to achieve, but necessary. Objective techniques, attempting to depend less on personal assessment and experience, are important for the industry in comparing clothing appearances obtained using different pattern constructions and methods of assembly (Yu, 2004b).

In practice, definitions of fit vary according to industrial standards and personal perception. According to Yu (2004a): 'Elements of fit are commonly categorized as ease, line, grain, balances and set' (p. 38). Pechoux and Ghosh (2002) state that fit 'affects comfort, as well as wear life or durability of a garment' (p. 1). According to Yi (2001): 'Garment fit provides the space allowance for skin strain, which is affected by the ratio of garment size to body size and the nature of garment design' (p. 105). With such a variety of definitions, it is evident that clothing fit is a complex issue. Fit can make the difference between a humble T-shirt and a luxury garment (Greene, 2011). Yu (2004a) argues that physical comfort, psychological comfort, and appearance all affect a consumer's perceived satisfaction with the fit of a garment.

Fit assessment is an important step in the process of developing and assessing the success of a sizing system. Typically, fit assessment within the apparel product development process occurs at the end of garment pre-production stage on a company's fit model in a specified size. Fit assessment also occurs during the purchase process by an individual consumer. Both processes can be very subjective. 3D body scanning technology can provide the means to automatically create custom-fitted patterns. Instead of deriving simple linear measures from the data, the method builds a comprehensive garment shape using data at every level of the body. This is moving towards providing customized apparel that accurately reflects an individual's body shape (Griffey and Ashdown, 2006). Several applications of body scanning technology are already commercially available, for example virtual try-on, virtual fit, and Virtual Reality, including virtual fabric drape and movement that simulates fabric worn on the body (Loker *et al.*, 2008). Dress forms can help ensure a good fit for consumers – retailers can customize dress forms based on 3D scanned data from live fit models.

11.5 Application of virtual simulation in product design

Working with live models for fitting is known as one of the most tedious processes in clothing design. However, with the development of virtual simulation technology, it is possible to simulate garments, designs, and human models called avatars. By using this design simulation software, designers can create accurate samples called prototypes and consequently cut costs and save time. For these reasons, many apparel companies already use or are in the process of adopting virtual visualization software in their product development process.

Fashion software is a very useful tool for designers, pattern makers, and product developers to simulate garment fit and design (e.g., Tukatech, OptiTex, Lectra, NedGraphics). By creating virtual samples before physical samples (prototypes), designs can be modified more easily and sample approval time can be significantly reduced (Meng *et al.*, 2010; Nantel, 2004). For example, the Tuka3D™ software produced by Tukatech takes a digital CAD pattern and a set of fabric values (e.g., stretch, weight) and creates a digital sample of the garment, draped on a 3D virtual fit model, using the latest in cloth simulation technology (http://tukatech.com/content/tuka3d). According to Tukatech's official website, users of Tuka3D™ provide the software with the pattern, the type of fabric and the measurements and shape of the fit model, from which the software will accurately create the sample.

OptiTex fashion design software also facilitates design solutions for the apparel and related industries. OptiTex also provides an adjustable, 3D fit model from body scan data for clothing representations on a computer screen (http://www.optitex.com/). Various apparel companies (e.g., Land's End, Target, Patagonia, Victoria's Secret) have already started to use this software for 3D virtual prototyping in the product development process. The company is currently developing clothing simulation for animated clothed figures based on fabric properties. OptiTex's products seek to simplify processes, minimize production costs and, most importantly, shorten the garment production cycle in designing.

NedGraphics has also been integrated into businesses in the fashion industry. They provide solutions for design and creation, workflow optimization and integration, production interfacing and virtual sampling (http://ng.nedsense.com/). Lectra provides innovative solutions for fashion companies to reduce time-to-market, and offers its own CAD application software for product design, pattern making, and 3D prototyping, which can be used in the development of fashion collections from the drawing board to the cutting room. Lectra has developed partnerships with more than 850 schools and universities in 60 countries (e.g., Central Michigan University, Donghua University, Esmod International, Fashion Institute of Technology, Parsons New School for Design, Manchester University, Hong Kong Polytechnic University).

According to Lectra's official website, Modaris V7 (the latest version of Modaris, released in February 2012) uses cutting-edge 3D technology to verify garment fit and validate design and silhouettes by combining avatars, flexible fabric rendering, and fitting tools. Modaris allows brands, retailers, wholesalers, manufacturers, and contractors to visualize the same concept, resulting in less guess work and more savings. Virtual models allow all-size testing and visualization. Capitalizing on the power of 3D simulations for virtual prototype and style review, Modaris V7 facilitates style and collection validation while ensuring the designer's original intention is respected, even before the first physical prototype is created. The process starts with the creation of a flat pattern that can immediately be modelled in 3D and then adjusted. Modifications are visible in real time in both modes. Fabrics, patterns, and colours as well as logos and trims can then be applied to preview style and proportions in any or all sizes.

Virtual fit from 3D scans is the most advanced form of virtual try-on. Body scans can be used to evaluate the style and fit of clothing on the basis of size specifications, structural design details, and fabric parameters (Loker *et al.*, 2008). Virtual visualizations can be used to evaluate fit for pattern development using target market members' body scans in selected clothing styles (Loker, 2007). Fit analysis from 3D images can be conducted at any time, anywhere, providing both flexibility and opportunity within a global industry (Loker *et al.*, 2008). Online apparel firms are already using virtual showrooms to present their apparel to businesses (http://www.lashowroom.com), and cooperatives such as Gen Art (http://www.genart.org) are using websites to showcase emerging designers' new fashions.

Online fitting room technology aims to help online retailers reduce returns and increase sales. Three-dimensional software helps estimate how a garment fits a consumer when shopping online. By replacing a generic avatar with a customized consumer avatar, consumers can try a garment on their own body before they commit to buying it online (Clarke and O'Mahony, 2006). They can also see what they would look like wearing a certain garment in a certain setting (Loker *et al.*, 2008).

In sum, 3D garment design makes it possible to adjust garments to fit potential customers who might not conform to the target group's normal size and shape. By choosing from the database of virtual bodies, standardized sizes can be easily modified to accommodate an individual's size requirements. As a growing trend this has increasing significance, as the implication is that customers can purchase any garment they desire, fitted to size.

11.6 Future trends

Mass customization and automated design processes are at the core of developments in the global fashion industry. Design and product development processes will continue to focus on cutting-edge technologies.

The industry is moving towards a product-on-demand environment based on quick response. This requires that the time gap between determining body measurements and delivering an accurately fitting garment be reduced (Pechoux and Ghosh, 2002). Once the process of mass customization becomes extensively automated, costs should decrease in terms of manufacturing, labour, and overheads, removing the need to stock occasionally requested sizes (Pechoux and Ghosh, 2002). Customer satisfaction should increase with better fitting garments, particularly for people outside the normal size range (Pechoux and Ghosh, 2002). Many companies are providing digital solutions for fashion designers and retailers, helping to cut labour costs and improve responses to customers but also to establish sustainability in product design and the development process.

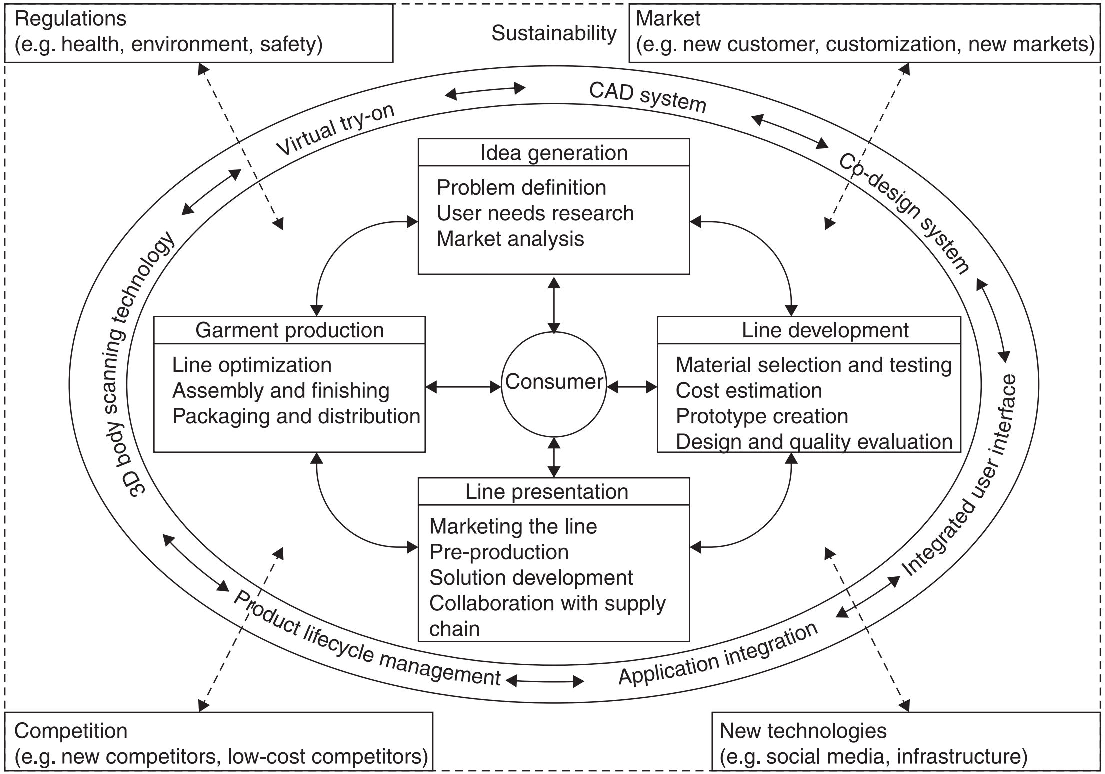
It is difficult for most designers to achieve sustainability and profitability at the same time. Designers are continually looking for ways to enable more cost-efficient business decisions while lessening their impact on the environment. To save money without compromising product quality or garment reliability, cutting unnecessary production stages is generally the best option for designers and manufacturers in pursuit of both sustainability and profitability. In the globally growing fashion market, a more systematic approach may be needed to meet economic, social, and environmental demands.

The need to compete at a global level has pressed businesses to enhance their operations and business practices, breaking down physical barriers and 'going virtual' (Marchetta *et al.*, 2011). This situation has raised the significance of product information capture, management, communication and maintenance among businesses and in internal departments. The concept of Product Data Management (PDM) was the first step towards satisfying these needs by including more information about the product than just the geometric data. However, PDM only considered the product development stages, namely information modelling. Therefore, PDM has evolved towards Product Lifecycle Management (PLM), which includes information about resources, performance, risk management, and all the stages along the product lifecycle. PLM has come to be considered a key concept to achieve efficiency and maintain consistency along a product's lifecycle, from early stages of the development process to product disposal (Gunpinar and Han, 2008). PLM involves the management of product information and the integration of business processes (Marchetta *et al.*, 2011). In the fashion industry, the Lectra Fashion PLM solution combines management tools such as flexible workflow and sourcing functions, tailored to the needs of the fashion sector, with applications and features specific to the processes found in the fashion industry, such as textile and fashion design and pattern-making. Siemens PLM computer software specializes in 3D and 2D product lifecycle management processes (Siemens, 2009) and provides an inclusive system of digital management which allows a company to track all necessary work in the product development cycle from the original concept to the end customer. This free exchange of product data concerning each item produced allows for faster, more efficient, less expensive, easier and more accurate communication between the various individuals involved in the product development process, often requiring less labour than previously, while increasing productivity.

As shown in Fig. 11.1, the consumer is always considered the principal agent, that is, they can participate directly and/or indirectly in the development of successful new products. They can play a critical role in any stage of product development. Figure 11.1 has been developed based on Kunz's (2010) basic product development process, which includes idea generation, line development, line presentation, garment production, and Gam *et al.*'s (2009) 'cradle to cradle' C2CAD apparel design model.

In this sustainable product development process model, sustainability must be considered at every stage. In addition to the conservation of material usage and sustainable design flows, production, marketing, and distribution can all utilize or integrate the concept of sustainable practices. Technological solutions have been created for this purpose as well. Apparel companies use software packages to facilitate design, sourcing and production (Gam *et al.*, 2009). Key features of industry-standard software packages in this regard include not only CAD design systems, 3D body scanning technology, and virtual simulation system, but also support for selecting and ordering materials, assigning inventories, sourcing, estimating costs, and producing products through product lifecycle management systems (Gam *et al.*, 2009; Stark, 2011).

Designers can use interactive design functionality to enhance their designs. For example, a designer can modify a design while other designers observe; designers



11.1 Computer technology integration into sustainable product development process.

can invite others to participate in the design process, who can add comments and observations (Hu *et al.*, 2008). Virtual human/garment simulation systems are incorporated into CAD to offer maximum visualization effects. These functionalities are integrated by an application integration unit, depending on the distributed communication infrastructure (Hu *et al.*, 2008). As CAD systems have developed, the user interface has become very significant, and the integrated user interface is required. Therefore, the CAD system must support integration with product lifecycle databases, new menu items, and direct accessing to runtime data (Hu *et al.*, 2008).

Regulations related to health, environment, and safety are also significant for sustainable product development. If products do not meet the regulations defined by governments and international authorities, product development or sales of the finished product can run into difficulties (Stark, 2011). The opportunities for sales and profits presented by globalization, however, are massive. Market research is crucial, which necessitates improving innovation, being able to accommodate specific customers' needs, reducing time-to-market for new products, and providing new services for existing products. Product-related material and energy costs are usually fixed early in the product development process, and computer technologies can provide the tools and knowledge to minimize these costs. The technology can also help cut recall, warranty and recycling costs that come later in the product's life (Stark, 2011).

In a global market, various other emerging technologies such as social media and infrastructure systems can be important assets in the product development process. Social media include web-based and mobile technologies used to change one-way information conveyance into interactive communication. Social media have substantially changed the way organizations, communities, and individuals communicate because of their accessibility and ubiquity (Kietzmann *et al.*, 2011). Infrastructure is a significant factor that should be considered when developing a product, in terms of applying technology to increase efficiency and functionality. Because of the importance of fundamental facilities such as transport, power supplies, and communication, the product development process is profoundly linked to the infrastructure of a country, society, or organization (Kusar *et al.*, 2004).

Market pressures for fast fashion and extremely short product development cycles are forcing companies to implement quick and efficient processes in design and product development. Simultaneously, they are further pushed to execute sustainable product design and development under the auspices of 'corporate social responsibility'. Companies need to establish enterprise-wide standards and common metrics to measure performance while advancing their ability to latch onto fashion industry trends, maintaining product quality and responses to customer needs in a flexible environment.

To conclude, advancements in computer technology have brought about radical changes not only in how apparel manufacturers approach product development and production, but also in consumers' expectations for their products. The emerging era of mass customization, the merging of technology with mass production techniques to offer customized apparel according to individuals' fit and style preferences, promises to fulfil consumers' need for unique personalized apparel while preserving the manufacturers' profit margins. Emerging technologies facilitating this movement include: computer-aided-design (CAD), digital virtual simulation, 3D body scanning, 3D apparel design and drafting, and product lifecycle management (PLM) systems. Each of these new technologies requires advanced skills and trained workers to maximize their potential.

11.7 Sources of further information and advice

11.7.1 Websites

Alvanon: http://www.alvanon.com
A clothing size and fit consulting firm in Manhattan providing full-service integrated fit solutions for the apparel industry, including fit consulting and the creation and implementation of customized fit mannequins and tools.

Archetype Solutions, Inc.: http://www.archetype-solutions.com
A technology solution firm offering mass customization technology solutions and custom fit apparel solutions.

ASTM International: http://www.astm.org
Develops international standards for materials, products, systems and services used in construction, manufacturing and transportation.

Beyondclothing: http://www.beyondclothing.com
A customized clothing firm in Seattle, WA.

Browzwear Solutions Pte Ltd.: http://www.browzwear.com
A provider of three-dimensional development tools to the apparel industry.

Bodymetrics Ltd.: http://www.bodymetrics.com
A UK firm offering body mapping technology for the perfect clothing fit.

Calvin Klein, Inc.: http://www.calvinkleinjeans.com
Calvin Klein Jeans offer a denim guide for both women and men to help customers choose their fit preference.

Cornell University: http://www.bodyscan.human.cornell.edu
The work of the Cornell Body Scan Research Group.

Cornell University: http://fit.cit.cornell.edu/textiles
Teaching support for apparel patternmaking/draping.

Cornell University: http://www.sizingsystems.human.cornell.edu
Reference list of publications on sizing and fit of apparel.

Gerber Technology: http://www.gerbertechnology.com
A provider of software and manufacturing systems for the apparel, technical textiles, aerospace and composites markets.

Insurance Services Office, Inc.: http://www.iso.com
Offers information, products, and services related to property and liability risk.

Lands' End, Inc.: http://www.landsend.com
A firm whose website allows customers to create a model, customize its looks to match their appearance and have it try on clothes.

Lashowroom: http://www.lashowroom.com
Online apparel firm using virtual showrooms to present their apparel to businesses.

Lectra: http://www.lectra.com
A France-based company offering technology solutions for industries using textiles.

Levi Strauss & Co.: http://www.levis.com
Offering curve ID fit service for jeans to 'find your own curve',

Lori Coulter LLC: http://www.loricoulter.com
Made-to-order swimwear company using a 3D body scanner.

Me-Ality: http://www.me-ality.com
A free service whereby it takes less than 10 minutes from Scan to Shopping Guide, making it easy for individual customers to find the best-fitting clothes for them.

MIT Media Lab: http://www.media.mit.edu
MIT's Media Lab providing a broad range of human-machine research.

My Virtual Model: http://www.mvm.com
A Canadian company that has led technology development and retailer-based business strategy.

Ned Graphics: http://www.nedgraphics.com/
Offering Computer Aided Design and Manufacturing (CAD/CAM) software solutions for the fashion and textile industry.

Nike, Inc.: http://www.nikeid.com
Offering custom shoes and clothing co-designed by customers.

National Public Radio: http://www.npr.org
National Public Radio: Delivers breaking national and world news from business, politics, health, science, technology, music, arts and culture.

OptiTex International Pty Ltd.: http://www.optitex.com
A developer of computer-aided design and computer-aided manufacturing software for the apparel industry.

Styku, LLC: http://www.styku.com
Offering online fitting room technology, providing online 3D virtual try-on solutions.

Shape Analysis Ltd.: http://www.shapeanalysis.com
A company focusing on research in clothing and textiles, specializing in body measurement using whole body scanning systems; also an agent for scanner and software sales in the UK.

[TC]^2: http://www.tc2.com

A company providing 3D body scanning equipment, software for measurement extraction, avatar creation, and virtual fashion, specializing in technology development and supply chain improvement.

TPC(HK) Ltd.: http://www.tpc-intl.com

A company offering garment technology specializing in fashion house and garment manufacturer solutions, particularly in the pattern creation process.

Tukatech, Inc.: http://www.tukatech.com

A company offering pattern making, grading and marker making CAD software, 3D apparel prototyping systems and manufacturing equipment

Fits.me: http://www.fits.me

Virtual fitting room for online clothing retailers.

11.7.2 Major newspapers that report on fashion

Apparel magazine: http://apparel.edgl.com

Financial Times: http://www.ft.com

International Herald Tribune: http://global.nytimes.com

New York Times: http://www.nytimes.com

The Economist: http://www.economist.com

Washington Post: http://www.washingtonpost.com

Women's Wear Daily: http://www.wwd.com

11.7.3 Publications

AATCC Review: Published by Association of Textile Chemists and Colorists

Offering articles on new developments in textiles.

'Clothing appearance and fit: science and technology', by F. J. Yu and W. L. Hunter, published in 2004.

Offering a critical appreciation of the technological developments and scientific understanding related to clothing appearance and fit.

'Sizing in clothing: developing effective sizing systems for ready-to-wear clothing' edited by S. P. Ashdown, published in 2007.

Offering a critical look at key technological and scientific developments in sizing, and their application.

Textile Progress

Has been published on behalf of the Textile Institute by Taylor and Francis since 1969.

Offering critical examinations of the origins and application of developments in the international fibre, textile and apparel industry, and its products.

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12
Wearing comfort using body motion analysis

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Abstract: Wearing comfort is one of the key features that should be taken into account in clothing design. This chapter provides an overview of the ease allowance adopted to provide comfort during body motion. It begins with a discussion of the key terms and role of the ease allowance. After this introduction, the interaction between body motion and clothing as a shell is explained. The chapter then discusses the fit and allowance for comfort and wearability, and also includes a detailed overview of various kinds of ease allowance requirements for different articles of clothing.

Key words: clothing, body shape, fit, ease allowance, wearing comfort.

12.1 Introduction

Clothing quality which meets the demands and expectations of customers depends in part on the aesthetic appearance and the quality of the material used. However, it also depends on the properties of the end product. These properties of clothing are reflected in comfort and clothing behaviour during wearing, i.e., adaptation to body motion and clothing resistance against acting dynamic loading (Geršak, 1997).

It must also be noted that wearing comfort can only be realistically planned on the basis of the role and function of the clothing, which can affect the extent of body motion and the resulting changes on the surface of the body. These changes play a role in determining the requirements for ease allowances and also affect the loads that act on clothing during wearing.

12.2 Variation in body shape during motion

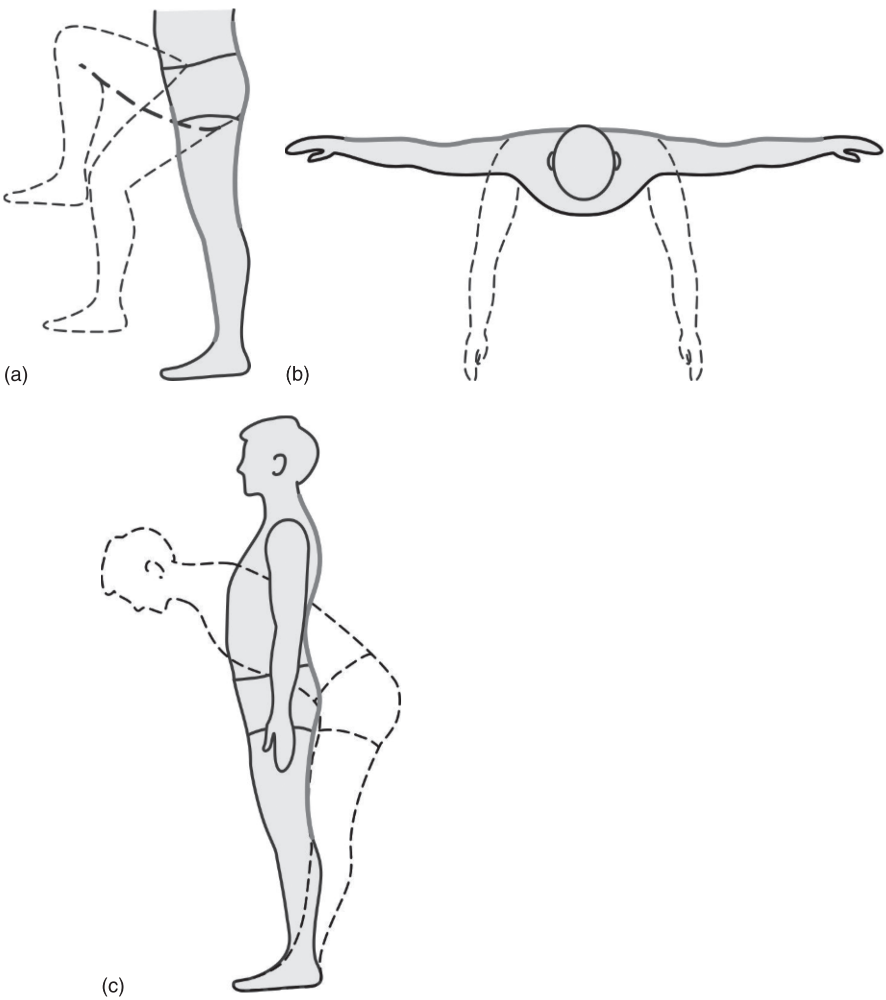
The human body is in a constant motion: during this motion, the parts of the body undergo dynamic change, meaning that the ability to move is determined and limited by more than just the static dimensions of the body. Data drawn from static anthropometry (the science of measuring the size, weight and proportions of the human body) therefore differ considerably from those drawn from dynamic anthropometry, with the latter being of significantly greater interest. Namely, the dimensions of static anthropometrics variables are obtained by measurements of the body in static position, in the meantime the dimensions of dynamic anthropometrics variables are obtained by measurements of the body movement. Dynamic anthropometrics variables, which refer to the different working postures, are important information about movement amplitude in the joints, reach field of the hand, as well as about muscular strength. When the human body is bent by different working postures the body tissue is stretched. Body tissue is stretched the more so the further the distance to the axis of the bending.

Changes in body shape during motion and/or work and the behaviour of individual parts are determined by the type of activity being undertaken. Some typical positions used to assess mobility are shown in Fig. 12.1.

Several authors have investigated the influence of the individual movements of the body to change the body dimensions (Schmid and Mecheels, 1981; Adams and Keyserling, 1993; Motsuo et al., 1995; Huck *et al.*, 1997; Tözeren, 1999; Ng *et al.*, 2007a, b). A variety of experimental investigations have been used to measure and assess mobility restriction by clothing (Huck, 1991; Adams *et al.*, 1993; Ng, 2007a). Huck (1991) studies the technique for evaluating restriction of wearer mobility. Adams *et al.* (1993) compare three methods (a universal goniometer, a Leighton Flexometer, and an electrogoniometer) for measuring

12.1 Positions used to check motion limitation.

range-of-motion of subjects wearing protective clothing, as well as studying whether measurement was affected by garment characteristics. The investigation of the movement of the human body reveals that different body parts vary in length when certain movements are performed. These changes, which can be expressed as a percentage difference between dimensions during individual movements, are relatively significant. During walking or running, for example (Fig. 12.2a), the measurement from the lower leg to the waist undergoes a 10% to 22% change; when stretching the arms forwards (Fig. 12.2b), the measurement from the upper arm over the spine to the lower arm undergoes an approximately 31% change; and if the body is bent over (Fig. 12.2c), the measurement from



12.2 Changes in body dimensions during characteristic movements: (a) walking or running, (b) stretching the arms forwards and (c) bending the body.

the cervical vertebra to the lower leg changes by 21% (Schmid and Mecheels, 1981).

Relatively few studies have dealt with dynamic loading acting on clothing during wearing. Stresses in clothing according to the seam strength were investigated by Crow and Dewar (1986), which developed a method to determine where maximum stresses occur in clothing, the locations of these stresses in wear, and the stances that cause these stresses. Dynamic stress distribution on clothing was also studied by Ng and coworkers (Ng *et al.*, 2007a), whose report was based on an experimental study of dynamic anthropometry and necessary movements of the human body (based on the extreme position), that the clothing is during the performance of extreme postures (they correspond to jumping, climbing, ducking, reaching and bending) under intensive stretch by the wearer. Clothing should be designed to be able to adapt to this type of change. However, basic mobility is not the only important factor: the ability to move while performing specific activities also plays a key role. A key criterion of wearability can therefore be defined as the ability to move in the clothing without effort, or clothing must take account of the activities of the human body, and not interfere with movements such as walking, sitting, standing, bending, stretching. In addition it must also permit the body to perform normal physiological activity: this means the blood must circulate, the body must sweat and breathe. This freedom of motion of a clothed person is dependent on both the fabric used and the construction of the clothing. Clothing must able to stretch to the same degree as skin; if clothing is not in direct contact with the skin it must allow greater extension. Contemporary technologies allowing 3D scanning of the surface of the human body play an important role in the field of clothing design and construction, and are used to evaluate the freedom of motion permitted by new clothing shapes. Motion causes changes on the surface of the body and directly impacts the wearing behaviour of the clothing. Folds develop in clothing as a result of dimensional changes in the body; these folds are also influenced by the fabric yield.

12.3 The interaction between body motion and clothing as a shell

Determining the extent of dynamic loading acting on clothing during wearing is a complex problem, and requires an understanding of the interactions between changes in body posture, body surface measurements during motion, and the deformation of clothing. Clothing is designed on the basis of anthropometric requirements, produced using two-dimensional textiles, and then joined in a 3D shape. In the relationship between clothing and body motion, this 3D shape can be said to cover the body as a shell. The adaptability of clothing as a shell to the movement of the body and resulting changes in body dimensions is dependent on the type and quality of the material used, the clothing style, and ease allowances for movement or comfort, which should be considered during the development stage.

12.3.1 Definition of dynamic loading in clothing

Clothing loading during wearing can be defined by investigating the elastic behaviour, or extent of deformation, of the fabric used. Fabric as clothing material does not generally have a clearly defined structure: it varies according to material type, weave, density, and finishing, which is directly reflected in its mechanical properties. In addition materials demonstrate viscoelastic behaviour and friction slippage even under very low strain, and the relationships during different strains are very complex. Studying the behaviour of clothing as a shell that adapts to changes in body surface dimensions is thus somewhat challenging and involves an understanding of the rheological properties of fabrics: elasticity, plasticity, slippage, Young's modulus, dynamic shear modulus, Poisson's ratio, and strain-hardening phenomenon. The following section presents the results of an investigation into the dynamic loading of clothing, based on direct measurements of clothing deformations during wearing.

12.3.2 Dynamic loading acting on clothing during wearing

One of the ways to precisely identify the stress of fabric at a particular area is to look at the elongation of clothing placed over a body. For this purpose Ng (2007a) developed a so-called Vicon motion capturing system and special type of net garment, which holds the light reflecting balls that provide the stress information. The motion capturing system can record these distance changes and hence the dynamic stress distribution can be found.

The research presented here into clothing loading during wearing and the resultant clothing deformations is based also on a study of the relationship between clothing and the human body in motion, but it is based on direct measurement of the deformation. The loading of a man's jacket during defined movements was measured using a device known as a Ω bridge, developed specifically for this purpose, and the effect of different postures (i.e. body movements) on the main areas of strain was analysed. A schematic view of a system for the direct measurement of clothing loading during use is given in Fig. 12.3 (Geršak and Gotlih, 1996; Geršak, 1997). The results obtained showed that changes in body surface dimensions caused by movement directly affected the loaded parts of the clothing. The loading resulted in clothing deformation or fabric extension. The deformation as specific extension ε can be expressed as follows:

$$\varepsilon = \frac{\Delta L}{L} \qquad [12.1]$$

while the dynamic loading, which is expressed by stress of the loaded part of the clothing, can be expressed as:

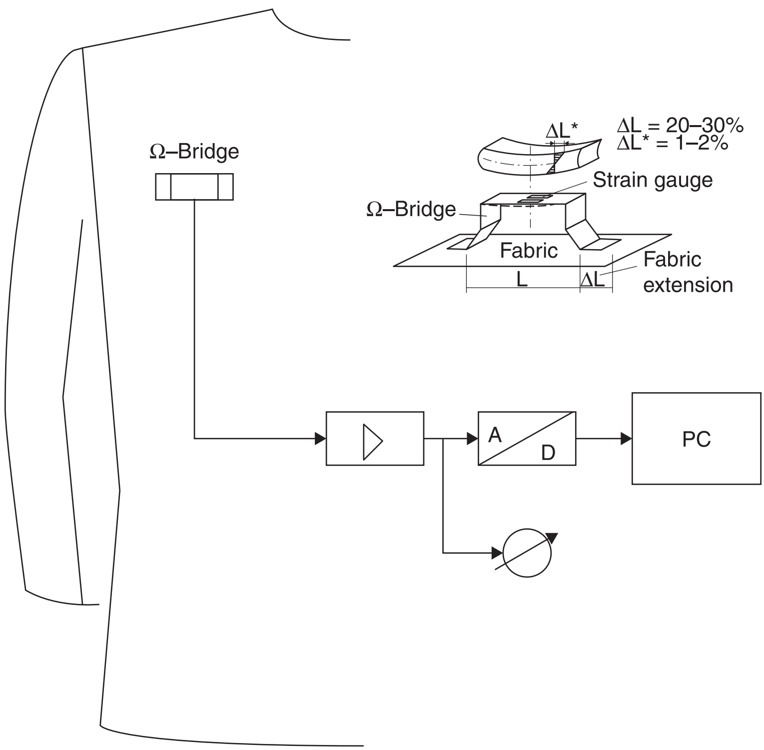
$$\sigma = \frac{F}{A} \qquad [12.2]$$

where:

F is stretch force,
A is surface area of loaded part of the clothing,
L is segment length,
ΔL is change of the segment length.

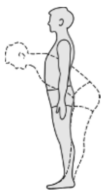
Table 12.1 presents the average values of dynamic loading for different body postures and measuring positions, while Fig. 12.4 shows the course of deformations during cyclically repeating body movements.

The investigation showed the direct interaction between loading of clothing during wearing and changes in body surface dimensions in body motion. The largest jacket loading and resultant deformations were observed in the middle of the back during the posture referred to as 'contracted arm on the shoulder' (Table 12.1). The loading intensity, and hence the extent of deformation, decreased towards the shoulder blade area, with a loading level 16% lower than in the back region (Geršak, 1997). Although changes in body surface dimensions directly

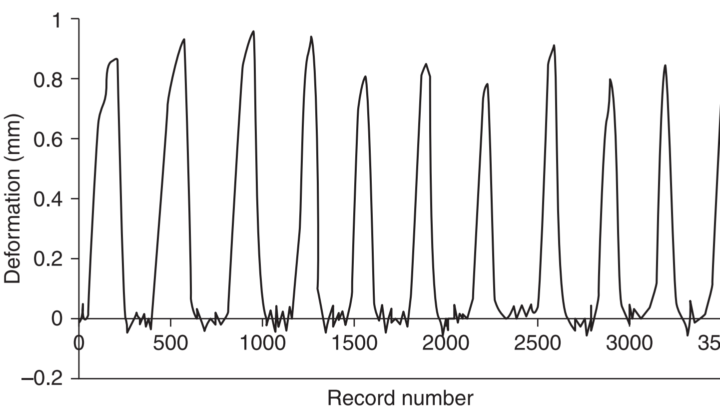


12.3 Schematic view of a measuring system for direct measurement of loading acting on clothing during use.

Table 12.1 The average values of measurement of stretching force F and deformation – specific extension ε for a jacket under different body movements

Body posture	Measuring position	Stretch force $\bar{F}$ (N)	Specific extension $\bar{\varepsilon}$ (%)
 Contracted arms on shoulder	On sleeve On shoulder blade In the middle of the back	38.0 52.5 62.5	2.24 2.92 3.42
 Bending	On sleeve In the middle of the back	48.5 25.5	2.72 1.65

influenced the clothing in this area, lower strain was perceived because of the interaction between the clothing, acting as a shell, and the movement of the body. Elastic deformations were assumed to have taken place. Stretching forces, a result of dimensional changes in body surface, caused a minor slippage of clothing along the body. This occurred as the clothing adapted to the movement in the shoulder blade area of the back part of the jacket, towards the sleeve. A lesser degree of deformation was observed after multiple cyclic repetitions of a particular continuous movement, showing that clothing slippage along the surface of the body allows clothing to adapt to some degree to the changing dimensions. In summary, clothing deformations are dependent on body posture at the time of



12.4 The course of jacket deformations for body posture 'contracted arms on the shoulder'.

movement, the resulting dimensional changes in body surface, the number of cyclic repetitions of a specific movement, and the properties of the fabric. The intensity of the loading forces acting on the clothing is dependent on the individual body constitution and the style of the clothing. The results obtained in studies such as this are extremely important in the design of clothing and the assessment of ease allowance for fit, comfort and wearability.

12.4 Fit and allowance for comfort and wearability

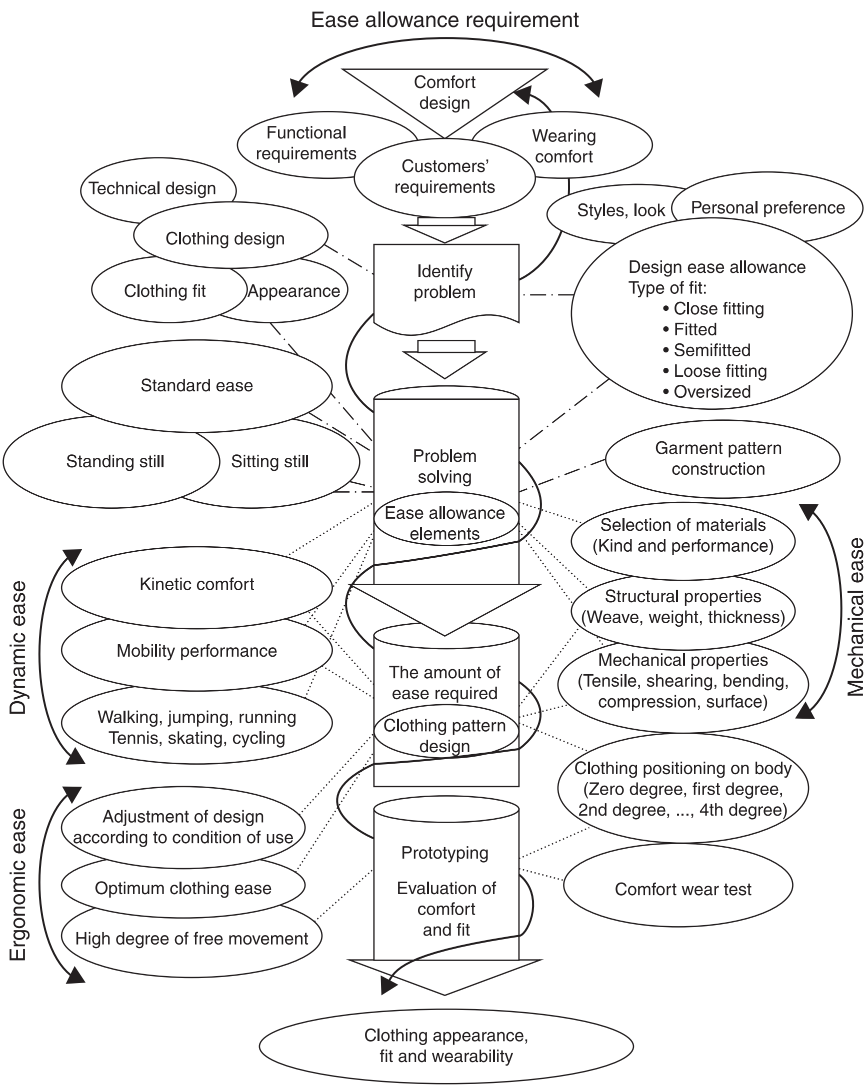
Different types of clothing adapt to changes in the dimensions of the body surface in very different ways. Knitwear, for example, is able to adapt very well to dimensional changes of body surface, thanks to its elastic structure: under loading conditions, the force is transferred from the clothing to the knitted fabric. In contrast, clothing produced from ordinary woven fabric does not adapt so easily to these changes, making ease allowances for movement or comfort necessary.

Fabric used for clothing must be able to cope with the difference between the changing dimensions of the surface of the body and the dimensions of the clothing as a shell. This can be achieved through appropriate ease allowances, allowing clothing to slide over the surface of the body when dimensional changes occur. This means that clothing is able to adapt to new dimensions and should fit the body smoothly with enough space to move easily, i.e. it provides the wearer with the required level of comfort and mobility. Fit is an important factor that needs to be taken into account in the design of comfortable and functional clothes. Clothing fit is a complex property, determined by a combination of ease, line, grain and balance (Erwin and Kinchen, 1969; Yu, 2004). It is also influenced by fashion and style, clothing size variations, and by the perception of the individual.

12.4.1 Allowance for comfort

Wearing comfort is a key property of any garment, and depends on body measurements, the construction of the clothing, the mechanical and structural properties of the selected fabric and, importantly, on the allowance for comfort (also known as the ease allowance). This is defined as the difference in space between the measurement of the clothing in a given area and the measurement of the body, and can be taken into account in the pattern by increasing the outline area. The amount of ease allowance required depends on the clothing type, design, fabric, body type, and function of clothing as well as on personal preference (Cooklin, 1997).

Ease allowance is very important for clothing design. There are two main types of ease allowance, with distinct functions: one aims to achieve improved comfort and wearability, while the other is added by the designer to create a particular style. The first type is employed to enable the wearer to move, bend, breathe, sit, raise the arms and walk without the clothing being over pulled, pinched, bent, stretched, or strained beyond a natural relaxed position (Myers-McDevitt, 2004). Design ease allowance, on the other hand, is based on aesthetic considerations and personal preferences of the designer, and represents ease allowance added by creating different styles or look according to fashion trends and personal preference. A schematic representation of ease allowance within the clothing design process can be seen in Fig. 12.5.



12.5 Ease allowance within the clothing design process.

Ease allowance for comfort and wearability can be divided into four types (Myers-McDevitt, 2004; Chen *et al.*, 2008; Ng *et al.*, 2007a; Geršak, 2001; Geršak and Marčič, 2013):

- standard ease allowance;
- dynamic ease allowance;
- mechanical ease, called also fabric ease allowance; and
- ergonomic ease allowance.

Standard ease allowance, based on the standard human body shape for a standing or sitting posture, is the difference between the maximal and minimal perimeter of the wearer's body (Chen *et al.*, 2008). Dynamic ease allowance, sometimes referred to as kinetic comfort, is defined as the ability to allow wearers to move (extreme movements and postures). It provides sufficient space to the wearer, so in the case of non-standard body shapes (thin, fat, big hip, etc.) as during their movement such as walking, jumping, running, and so on. Ng (2007b) defined dynamic ease allowance as the amount of spacing between the garment and the wearer that is required to allow the wearer to perform certain postures. The amount of ease allowance is related to the extreme posture required, the stress distribution, and the mechanical properties of the fabric.

Mechanical ease allowance, also called fabric ease, which refers to the mechanical comfort for wear, takes into account the influence of the mechanical properties of the fabrics used in the clothing. Mechanical comfort is expressed by a limited range of mechanical parameters of fabric tensile and shear deformation properties, such as fabric tensile strain in warp (EMT-1) and weft (EMT-2) direction measured with KES-FB standard condition (Kawabata, 1980), the relation between fabric tensile strain in the weft and warp direction α (α=EMT-2/EMT-1), linearity LT, tensile resilience RT, shear rigidity G and shear hysteresis 2HG5 (Geršak, 2001). Kawabata with coworkers defined mechanical comfort zone as a guideline for manufacturing ideal fabrics, which indicates clearly that the fabric is perfect or not for wear (Kawabata *et al.*, 1998).

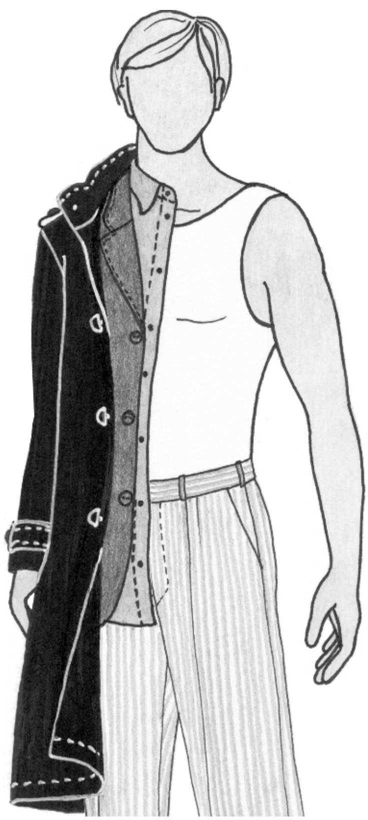
Ergonomic ease allowance is expressed by constructive solution of clothing as a lightweight clothing system that will allow unhindered movement and work, and involves the adjustment of the design, structure and construction of clothing. Clothing should be ergonomically designed, in accordance with the dynamic anthropometric conditions of use and functionality, while still allowing wearing comfort and a high degree of free movement, as well as uninterrupted and safe work activities. All possible conditions of use must be taken into account, for example carrying tools, devices, sensor and actuator systems and so on (Geršak and Marčič, 2013).

A number of studies have investigated ease allowance with the aim of understanding why it was required and establishing relevant values for it. Optimum clothing ease was agreed to be important for appearance, fit and wearability. One particularly notable study was carried out by Burgo (1998) who studied the impact of different elements on ease allowance, and concluded that the required ease allowance could be determined on the basis of three variable factors:

(a) the line of the clothing (determining the style of the pattern), which can be
   - classic – a modern practical style,
   - fitted – a style that hugs the body,
   - loose fitting – a style that requires more ease allowance and can be fitted with gathers, pleats or flaring;

(b) position of clothing with respect to proximity to the surface of the body (see below);
(c) thickness of the material (with thicker materials, the fabric in the seam allowance occupies space and reduces ease allowance).

The position of clothing with respect to the surface of the body is an important factor in the design of normal and functional clothing (Fig. 12.6).



12.6 Clothing positioning on body.

Burgo (1998) defined clothing position in terms of five different degrees for normal clothing:

- zero degree – clothing worn directly in contact with the skin, such as underwear and bathers;
- first degree – clothing worn directly on top of the underwear;
- second degree – clothing worn on top of the first degree of clothing;
- third degree – very heavy weight clothing; and
- fourth degree – clothing with lining, such as fur or quilting.

Table 12.2 suggests values for the ease allowance required for the different degrees (Burgo, 1998).

In functional clothing systems, the ease allowance is based on the onion principle, and takes into account the influence of the mechanical properties of the fabrics as well as ergonomic ease allowance. In this case, the ease allowances should be arranged such that the multiple thinner layers worn on top of one another capture and retain body heat through the formation of small pockets of air that act as additional insulation and heat storage.

Table 12.2 Ease allowance according to the clothing positioning on the body (Burgo, 1998)

Control dimension	Ease allowance (cm)				
	Zero degree	First degree	Second degree	Third degree	Fourth degree
Chest girth	from –4 to 0	from 2 to 6	from 6 to 12	from 12 to 16	from 16 to 24
Bust girth	from –4 to 0	from 2 to 6	from 6 to 12	from 12 to 16	from 16 to 24
Waist girth	from –4 to 0	from 2 to 6	from 6 to 12	from 12 to 16	from 16 to 24
Hip girth	from –4 to 0	from 2 to 6	from 6 to 12	from 12 to 16	from 16 to 24
Shoulder width	from –4 to 0	from 1 to 3	from 1 to 3	from 4 to 6	from 4 to 6
Breast distance	from –0.5 to 0	from 0.25 to 0.75	from 0.75 to 1.5	from 1.5 to 2	from 2 to 3
Lowering arm hole	from –1 to 0	from 0.25 to 1.5	from 1.5 to 3	from 3 to 4	from 4 to 8
Neck-opening	from –0.25 to 0	from 0.25 to 0.75	from 0.75 to 1	from 1 to 2	from 2 to 3

12.5 Conclusion and future trends

This chapter has provided an overview of the body shape variation caused by motion, the interaction between body motion and clothing, and the role and different types of ease allowance, which is a key factor in wearing comfort. Fashion considerations can affect the accepted degree of wearing ease; however, regardless of the design, a finely balanced ease allowance is essential for correct fit and to provide the required comfort and mobility for the wearer.

Comprehensive investigations have been carried out in the field of anthropometry and in garment construction and design, and extensive results obtained, permitting the development of efficient methods for determining the required additions for suitable comfort levels. However, advanced 3D computerised technologies and rapid developments in virtual simulation in the garment industry (where not only the 3D shape of the garment is presented but also the mechanics of fabric behaviour), combined with an increase in the production of made-to-measure garments, require still more precise methods of determination. New methods will have to be developed that can offer precisely defined values for comfort additions such as ease allowances. These methods will have to be sufficiently flexible and able to adapt to human body morphology, which has undergone considerable changes in the course of the last century, while also meeting the requirements of the contemporary clothing market. Many possibilities for the accurate modelling of ease allowances remain open, along with many methods of estimating ease allowance to allow personalisation of clothing design.

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