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FEMALE FIGURE IDENTIFICATION TECHNIQUE (FFIT) FOR APPAREL PART I: DESCRIBING FEMALE SHAPES

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Abstract

Sizing standards used in the United States that identify the body measurements used in the design and development of clothing were established from identified "best practices" of the apparel industry. However, the industry as a whole has not adopted a single system of clothing sizing. We know that manufacturers and retailers use their own sizing systems as a marketing tool, convinced that this is a differential advantage of their product for their market. Regardless of the sizing systems used, however, almost all are based on the myth that humans have mathematically proportional bodies and that they grow in proportional ways. In addition, the shapes and proportions of today's American population differ greatly from the shapes of the generations before. So a variety of issues impact our inability to 'fit' the American customer of today. These fit issues continue to be a growing concern.

This article, as Part One of two, describes the historical process involved in describing the body shapes of humans. In addition, it lays the theoretical framework for the development of an expert shape sorting system using 3D body scan data.

Keywords: FFIT for Apparel, shape sorting, sizing standards, mass customization, fit, female figure types

FEMALE FIGURE IDENTIFICATION TECHNIQUE (FFIT) FOR APPAREL
PART I: DESCRIBING FEMALE SHAPES

Introduction

Currently, clothing sizes are based on a biased study that is over 6 decades old. This method of sizing does not conform to the diversity of human shapes that currently exist in the United States. Attempts to classify body shapes into analogous types, in order to establish size standards, have resulted in the formation of several size groupings.

Additionally, the shapes and proportions of today's American population differ greatly from the shapes of the generations before. Because the clothing sizing system is based on a study from the 1940s, many fit problems are occurring with consumers. These fit issues continue to be a growing concern (Cotton Inc., 2002a, 200b, 1998, 1997). Regardless of how one defines fit exactly, it must always start from basic human proportional truths. The fact that our current sizing systems strays so far from this fact is a significant problem for retailers and manufacturers, alike.

New and improved technologies are now available that allow realistic images of human bodies to be classified into categories that will better reflect the differential proportions of the true American population. Mega-computing power, three-dimensional body scanning, dimensional design programs, and computer-aided-design software are allowing advances in the product development process that will lead to a seamless technology of customized clothing and ready-to-wear garments that can provide fit, as they have been designed to do. Some attempts have been made to chart the body in two dimensions but they do not yield a satisfactory illustration of true body shape.

Research Purpose and Methodology

The research of this study focused on two basic objectives: 1) to determine if the current sizing systems actually meet the needs of today's female population and 2) to develop preliminary subgroups for the female population that might aid in the description of their various shapes. The first part of the research methodology involved the development of software that would allow for comparison of 3D body scan data of female subjects to recognized standards for body measurements. The second part of the research methodology was to find out how female shapes are currently described and to identify ways that they might be more appropriately described when using 3D body scanned data.

Literature Review

<u>Fit and Sizing Issues</u>

The purpose of a sizing system for apparel should be to make clothing available in a range of sizes that fits as many people as possible (Ashdown, 1998; LaBat, 1987). Apparel design and production experts believe that the fit of a garment is one of the most important factors in producing garments that flatter the individual (Minott, 1978). Fit has been defined as:

- "A correspondence in three-dimensional form and in placement of detail between the figure and its covering to suit the purpose of the garment, to provide for activity, and to fulfill the intended style (Berry, 1963)."
- 'Simply a matter of length and width in each part of the pattern being correct for your figure (Minott, 1978)."

Much research has been conducted over the years on the topic of fit of apparel (AAMA, 1975; Croney, 1977; O'Brien & Shelton, 1941). In general, consumers have been dissatisfied with fit for some time. Some of this dissatisfaction could be associated with the fact that the current sizing system for the manufacturing of garments is based on body measurements that are more that 60 years old (Salusso-Deonier, 1982). Dissatisfaction with fit can also be attributed to several factors that have changed the average body types: diets (Meek, 1994; Tamburrino, 1992a), physical exercise and activities (LaBat, 1987; Tamburrino, 1992b), increased immigration (Meek, 1994), disproportionate growth rates in minority groups (Meek, 1994), sedentary lifestyles (CNN, 2001), and changes in ideals of masculinity and femininity (Meek, 1994).

The United States population distribution has gone through dramatic physiological and demographic transformations since the 1940s when the O'Brien and Sheldon study (upon which our current sizing system is based) was undertaken. For many years, the United States population has been a mixture of ethnic origins. But over time, the configuration of this mixture has changed. Minority groups have become larger and new groups of immigrants have been added to the mixture (LePechoux, 1998; US Census, 2000). With consumer trends and products becoming universal, free trade is opening an increasing number of foreign markets to U.S. commerce. Worldwide interaction and travel are heading toward increased interracial mixes. Projections for the number of multiracial Americans will be released in a report in 2005 (FOXNews, 2004). These progressions have had direct impact on body measurements of the international consumer. Many studies have been conducted around the idea that body proportions differ according to their racial origin (Abesekera & Shahnavaz, 1989; Al-Haboubi, 1992; Hertzberg, 1972; Hutchingson, 1981; Miller, 1993; NASA, 1978). The racial mixture in the United States is definitely different than in the 1940s when the body measurements used to develop the current standard were taken.

History of Figure Typing/Somatotyping

In the pre-Christian era, the Greeks dominated the scientific and philosophical studies of the time. As early as 400 BC, the founder of modern medicine, Hippocrates, had proposed that certain physical types were susceptible to certain diseases (Wells, 1983). In the fourth century BC, Aristotle attempted to additionally elaborate and develop Hippocrates' ideas (Tsang, Chan, & Taylor, 1940). Around the seventeenth century, anthropometry started to be used in combination with morphology. At the University of Padua, Elsholtz documented a method for taking body measurements. It would be two hundred years later before Quetlet would be a pioneer in studying the measurements of man statistically (Carter & Heath, 1990).

The twentieth century had the most significant contributions of any time period before that concerning the figure typing and classifications of the human body. In the early 1920s, a German psychiatrist, Ernst Kretschmer, grouped the human body-build in four basic categories. His bodily characteristics were, like those of most early physicians, associated with particular disease susceptibilities.

The most significant contribution to the existence of body type classifications began in the 1930s by American psychologist William Sheldon. In 1940, Sheldon, with Stevens and Tucker, introduced the concept of "somatotype" in their book The Varieties of Human Physique. "The patterning of the morphological components as expressed by three numerals is called the somatotype" of the individual (Sheldon et al, 1940, p3). Sheldon and his colleagues had worked out a system to measure these components and express them numerically (Inner Explorations, 1999). These components were called endomorphy, mesomorphy, and ectomorphy. Carter and Heath (1990) maintained that "the procedure (of somatotyping) was laborious and obviously not feasible for general use" (p. 31). Tanner (1964) said "this system does not work, and has never, in fact, been used" (p. 37).

In the 1960s, the research team of Lindsay Carter and Barbara Heath collaborated on continuing the modification of Sheldon's somatype methodology (Heath, 1963). The validation of the modifications and the presentation of the Heath-Carter modified somatotype method were products of this joint effort (Heath & Carter, 1967).

Also influenced by Sheldon, another researcher became interested in somatometry with respects to the clothing industry. Dr. Helen Douty, a clothing specialist in the School of Home Economics at Auburn University, believed a greater understanding of the body and of the principles of aesthetics could allow students to become more successful at solving problems and creating illusions in relation to the fit of clothing. Realizing the difficulty of measuring the body visually in three dimensions, Dr. Douty believed that a silhouette projected onto a graph simplified the entire process. It showed the body mass and shape in graph form, where the characteristics were clearly visible and could be analyzed objectively and classified into figure types (Douty, 1968).

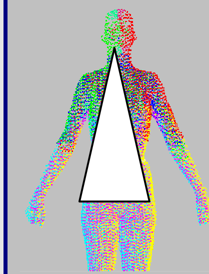
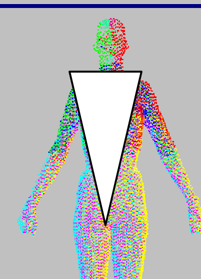
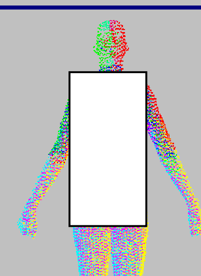
An Italian company called CAD Modeling believes that body-scanning technology is very useful in its output of data, but all data should be relative to the mathematical model of the volume of the naked body, the 3D volume. They also think that within a population, only a few consumers have a body type, which exactly fits the standard forms. CAD Modeling has proposed the idea that it is possible to individualize all possible human physical structures with a few parameters that correspond to the most important and irregular body features with respect to clothing needs (Quattrocolo & Holzer, 1992). Those parameters include the physical base, height, and size.

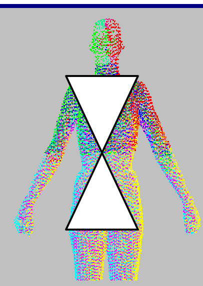
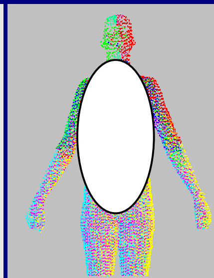
When descriptions of different body or figure types are being discussed, the terms “endomorph, mesomorph, and ectomorph” are not usually the most common. Most often, terms are divided into two separate groups of “apple, pear, triangle, oval” or “Missy, Junior, Women’s, Half-Size”. All of these terms can be very confusing. Some appear misleading because they seem to indicate the age of the person. Others just seem to be saying the same thing (isn’t the shape of a pear the same as a triangle, being proportionately larger on the bottom than the top?).

All of these terms are associated with the pattern industry. Unlike ready-to-wear apparel manufacturers, American pattern companies agreed on the body measurements that were used for each size, even though, they changed the standard measurements four times before 1972 (Palmer & Alto, 1998). The pattern industry then devised its own standard set of figure types and sizes. Many pattern making and sewing books (Armstrong, 2000; Liechty, Pottberg, & Rasband, 1995) reference these figure types as having differences in height and contour according to its designation.

The other grouping of terminology for figure types is categorized by names of shapes, letters/numbers, and fruits/vegetables. Apple and pear are identifiers in the fruits/vegetables category. Oval, circle, round, hourglass, diamond, rectangle, straight, ruler, triangle, inverted triangle, spoon, Christmas tree, and cone belong to the shapes category. In the letters/ numbers category, “O”, “X”, “H”, “A”, and figure 8 are included. These lists are not exhaustive as other terms may apply. Table 1 characterizes these figure types.

Table 1. Common Shape Groupings.

Figure Type	Traits	Illustration
Triangle[c, h, I, j, n, o, p] “A” Frame[l, m,] Pear[a, b, d, e] Spoon[g, k] Christmas Tree[f]	Shoulders narrower than hip. Bottom heavy with weight mainly in buttocks, low hips and thighs. Bust is small to medium. Upper body smaller than lower body.	
Inverted Triangle [c, p, h, I, j, o, n] Cone[g, k] “V” Frame[d, m]	Heaviest part of body is on top. Shoulders wider than hips. Weigh gain in upper body and stomach. Usually large chest. Very narrow hips.	
Rectangle[c, p, h, I, j, o, n] Ruler[g, k] “H” Frame[m, l]	No definition at the waistline. Shoulders and hip about the same width. Equal body proportions .	

Hourglass[c, g, h, I, j, k, n, o, p] Figure 8[m] "X" Frame[l]	Equally broad on top and hips. Thin at the waist, usually 10 or more inches smaller than chest and hips.	
Oval[c, h, I, j] Circle/Rounded[o] Apple[a, e] Diamond[p, o] "O" Frame[l]	Top and bottom are narrow. Chest and belly are where weight is found. Skinny legs.	

Note: (a) Self, 2000 (b) iVillage.com, 2001 (c) la.assortment.com, 2001 (d) teraformahealth.com, 2001 (e) tinajuanfitness.com, 1999 (f) Farro, 1996 (g) Jackowski, 1995 (h)betterhalf.com, 2001 (i) carlamathis.com, 2001(j) Beauty Is, 2001 (k) exude.com, 2001 (l) Duffy, 1987 (m) Your Total Image, 2001 (n) Palmer & Alto, 1998 (o) Rasband, 1994 (p) eswimmers.com, 2001

Three-Dimensional Body Scanning

During the 1960s, research began on technology that would revolutionize the study of human measurement. It wasn't until the early 1990s, however, that three-dimensional (3D) body scanning technology would make significant contributions to the apparel industry.

As the current, most advanced user of this technology, the apparel industry has noteworthy potential for its use while the concept is still in its early stages of development. There are some retailers and manufacturers who have adopted 3D body scanning with open arms. Levi Strauss premiered a body scanning program for custom jeans called Levi's Original Spin (Lajoie, 1999). In 2000, Lands' End sponsored the "My Virtual Model Tour 2000" as the world's first body scanning truck. Individuals were scanned with a (TC)^2 scanner and a realistic, size accurate virtual model was created with the scan measurements and could be used to try on clothes, create outfits, and determine what size to buy through the Lands' End catalog and website (Lands' End, 2001).

Large, well-organized groups are using 3D body scanning technology to gather anthropometric data. One project was the Civilian American and European Anthropometry Resource (CEASAR) project. This effort attempted to gather data relating to the various shapes and sizes of the Western world's 18- to 65-year-old population using a Cyberware WB-4 whole body scanner (Ponticel, 1999).

In the Fall of 2001, *Size UK*, a comprehensive national sizing survey of the United Kingdom (UK), was completed utilizing the 3D body scanning technology by (TC)^2 . This was the first national sizing survey in over 50 years, and the first time that shape data will have been collected of the UK population ([TC]^2, 2001). *SizeUSA,* a collection of 3D body measurement data of over 10,000 men and women in the US, was completed in the Fall of 2003 and findings reported in the Winter of 2004 ([TC]^2, 2004). *SizeMexico* is planned in for late 2004 and *SizeCanada* is in the developmental stage. The combination of these surveys provides significant opportunities for the evaluation and development of sizing systems on a more international basis.

Several studies have been completed concerning 3D body scanning. A 2000 study by McKinnon investigated the effect of respiration and foot stance in a whole body scanner on critical measurements of the body. An analysis of differing types of scanners and scanner manufacturers was revealed in a study by Simmons and Istook (2001). A comparative analysis of the Textile/Clothing Technology Corporation (TC)^2 scanner models 2T4 and 3T6 was also conducted (McKinnon & Istook, 2001).

From a 2001 study comparing the body measurement techniques of three different scanners, it was found that the $(TC)^2$ scanner was the most appropriate for the use of measurement extraction in the manufacturing of clothing (Simmons & Istook, 2002).

Full body scanning has the potential to provide the data needed to identify and characterize the segments of the population not being served well with current sizing systems. Development of models that use three-dimensional body scan data to identify different body types can provide the industry with tools to identify and design for these market segments that are not being provided with well-fitting clothing.

Theoretical Framework

Data lives in our lives and on our desks as isolated elements. Only when we assemble this data into a significant configuration do we have information. When this information is converted into a valid foundation for action, it becomes knowledge. Knowledge is "taken to be an attitude towards a proposition which is true (Dienes & Perner, 1999). Knowledge management is a strategy that turns an organization's intellectual assets (both recorded information and the talents of its members) into greater productivity, new value, and increased competitiveness (Murray, 2002).

This recorded information, which is obvious knowledge found in manuals, documentation, files, and other accessible sources, is known as explicit knowledge (bestbooks.com, 2002). Explicit knowledge is information and skills that are easily communicated and conveyed to others. It is shared, stored, and distributed (hyltonassociates.com, 2002).

However, the greater level of knowledge in an organization is tacit-unarticulated knowledge (Saint-Onge, 1996) and may be the real key to getting things done (Murray, 2002). The definition of tacit knowledge has been identified in several ways:

- Knowing more than we can tell (Polanyi, 1966).
- Found in the heads of an organization's employees being far more difficult to access and use for obvious reasons (bestbooks.biz, 2002).
- The personal knowledge in people's heads, which has not been written down or documented. It is largely gained through experience and is influenced by beliefs, perspectives, and values. Tacit knowledge usually requires joint, shared activities in order to transmit it. Personal (tacit) skills such as expertise, gut feel, subjective insights, and intuitions are not easily communicated and documented (hyltonassociates.com, 2002).
- Knowledge that is used as a tool to handle or improve what is in focus (Svelby, 1997).
- An aspect of practically intelligent behavior that is acquired through experience and is unrelated to general cognitive ability (Wagner, 1985).

Tacit knowledge allows a person to engage in an activity and have little or no conscious experience of what it is causing it. Wagner states that it is not simply the amount of experience that matters but also how well one is able to learn from and apply knowledge gained through experience (Wagner, 1985 & 1987).

Many industries have begun to understand and use tacit knowledge to enhance their future performance: law enforcement (Kerr, 1995), social work (Holland, 1985; Imre, 1985), anthropology (Heath, 1984), survey research methods and sampling (Maynard, Houtkoop-Steenstra, Schaeffer, Van Der Zouwen, 2002), systems engineering (Tatalias & Kelly, 2001), gemology (Collins, 2001), laser-building (Collins, 1992), nuclear weapons (MacKenzie & Spinardi, 1995), biology (Jordan & Lynch, 1992), and vetinerinary science (Pin., Collins, & Carbone, 1996).

This research was an effort to use both explicit and tacit knowledge to aid in the development of clothing that should be better able to meet the needs of the female consumer of today. Capturing and applying tacit knowledge was an important first step in what is likely to be a long developmental process.

Methodology

The first step in achieving the objective of this research was to develop a database of three-dimensional body scan data, from a variety of consumer markets, which included measurement data, 3D point cloud data, and demographic data. This initial step provided an established catalog of subjects for all research pertaining to 3-dimensional body scanning.

The second step was to develop a "Best Fit" software, using Microsoft Access, to compare the 3D measurement data of a selected group of subjects to the sizing systems that have been developed in the US since the 1941 study by O'Brien and Sheldon. The final step in this study was to review the ways in which female shapes are currently described and to develop a description that could be used that would encompass the 3 dimensional shapes of women, rather than only their silhouette.

Database Development

A convenience sample of women was solicited primarily from the Triangle area of North Carolina (Raleigh, Durham, and Cary). Each subject was informed of the scanning procedure, possible risks, confidentiality, and contacts in accordance with the rules of a Human Subject Review Board at the university. Demographic information was also collected for each subject.

Subjects wore close fitting athletic gear to be scanned. Extracted measurements, 3D point cloud data, and reduced body data were stored and maintained entirely by the subject identification number given to each subject. No potential subject was excluded on the basis of race, size or shape. Women ages 18 and older, who had complete demographic data, good 3D body scans, and complete extracted measurement data were used for the sizing system evaluation in this study.

Best Fit Evaluation

Two tables were created in Microsoft Access, one for storing the sizing standards (called Projections) and the other for storing the subject measurements. Current ASTM sizing standards, as well as past standards, were chosen for the evaluation because, with each revision, groupings of body types were added and/or taken away. See Table 2 for a complete listing of all standards used in the study.

Table 2. Standards included in the Best Fit © Database

Standard	Size	Standard	Size
ASTM 5585	2-20	CS215-58 Missy (S,F)	8-12
ASTM 5586 (55+) Junior	3-17	CS215-58 Women's (R,A)	30-42
ASTM 5586 (55+) Junior Petite	3-15	CS215-58 Women's (T,A)	32-40
ASTM 5586 (55+) Misses Petite	8-18	CS215-58 Women's (R,S)	32-42
ASTM 5586 (55+) Missy	6-22	CS215-58 Women's (R,F)	28-38
ASTM 5586 (55+) Misses Tall	10-22	CS215-58 Women's (T,F)	30-36
ASTM 5586 (55+) Half Sizes	12.5-26.5	CS215-58 Half Sizes (S,A)	10.5-24.5
ASTM 5586 (55+) Women's	34-52	CS215-58 Half Sizes (S,S)	12.5-22.5
CS215-58 Missy (R,A)	8-22	CS215-58 Half Sizes (S,F)	8.5-20.5
CS215-58 Missy (T,A)	10-20	PS42-70 Junior	3-17
CS215-58 Missy (S,A)	8-18	PS42-70 Junior Petite	
CS215-58 Missy (R,S)	10-22	PS42-70 Missy Petite	
CS215-58 Missy (T,S)	12-18	PS42-70 Missy Tall	
CS215-58 Missy (S,S)	12-18	PS42-70 Women's	
CS215-58 Missy (R,F)	8-16	PS42-70 Half Sizes	
CS215-58 Missy (R,T)	10-14		

There were 21 subject measurements compared with those found in the various standards. These measurements were selected from the many available from body scan data, because they were common among all of the standards and met the measurement definitions within the standards. A 'Form' designed in the Access software compared 21 of each subject's measurements with the same measures for each of the size standards. It then calculated and displayed the best fitting standard that was closest to the subject's body size. The comparison was completed in three different ways – Percentage Difference, Tolerance Difference and Weighted Tolerance Difference.

Percentage Difference

The Percent Difference formula calculated the closest size based on the percentage difference between the subject's measurement and the standard measure that was determined to provide the "Best Fit". For every 5% difference between the standard and the subject's measurement, the 'Difference' was calculated as one. The number of measures that were 5% or more different from the Best Fit standard is displayed as 'Distance'. A positive number indicated that the scan data was larger than the Best Fit standard. A negative number indicated that the Best Fit standard was larger than the scan data. The standard that had the lowest 'Distance' value was determined to be the standard that would provide the "Best Fit" for the subject.

Tolerance Difference

For the Tolerance Difference formula, each measurement was given a tolerance limit. If the difference between the subject's measurement and the standard measurement fell within this value, the difference was counted as zero. If the measurement fell outside the tolerance value, the difference was counted as one. The tolerances were taken from the *Apparel Design and Production Handbook* (Fashiondex, 1998), which includes a list of tolerances customarily used by the apparel manufacturing industry. This was proposed as a logical way to evaluate fit, since production of clothing generally is allowed to fall within the specified tolerance, so too might bodies. The standard corresponding to the least value of 'Distance' was taken as the closest standard size to provide the "Best Fit" for the individual.

Weighted Tolerance

A Weighted Tolerance formula was developed to calculate the degree to which a measurement was out of tolerance with the standard. This formula was proposed to allow researchers the opportunity to "value" the degree to which a standard might depart from providing good fit. The value of 'Difference' was increased from zero to three based on the tolerance level. For example, if the difference between the subject's measurement and the standard measurement was within tolerance, the value of Difference was zero; if it was within twice the tolerance value, it was one, if it was within three times the tolerance level, it became two or else, the value of Difference was three. The 'Difference' values of all the 21 measurements were added up to get the final "Distance". As before, the standard size having the lowest 'Distance' value was determined to be the standard size that would provide the "Best Fit" for the individual.

"Best Fit" Results

Percentage Difference Results

Using the Percentage Difference method, the standard that provided the 'Best Fit' for the largest number of subjects (over 44%) was the CS215-58 database. Regardless, more than 93% of the subjects' measurements were greater than 5% larger than the standard that gave them the best fit.

Tolerance Level Results

When using the Tolerance Difference method, the standard that provided the 'Best Fit' for the largest number of subjects (over 35%) was the 55+ASTM 5586-95 standard. The average number of measurements that were out of tolerance within this "Best Fit" standard was 10 out of the 21 measurements. That is, for every subject, at least 48% of the measurements were not within the tolerance limits for their "Best Fit" standard size.

Among the 254 subjects in the database, the number of people whose measurement fell out of tolerance for each measurement category was determined. The results are shown in the Figure 1. Among 254 subjects, 253 people fell out of tolerance from their standard in the bust measurement. Likewise, more than 100 subjects fell out of tolerance in all of the twenty-one measurements. Overall, at least 74% of the subjects fell out of tolerance from their standard size in their body measurements.

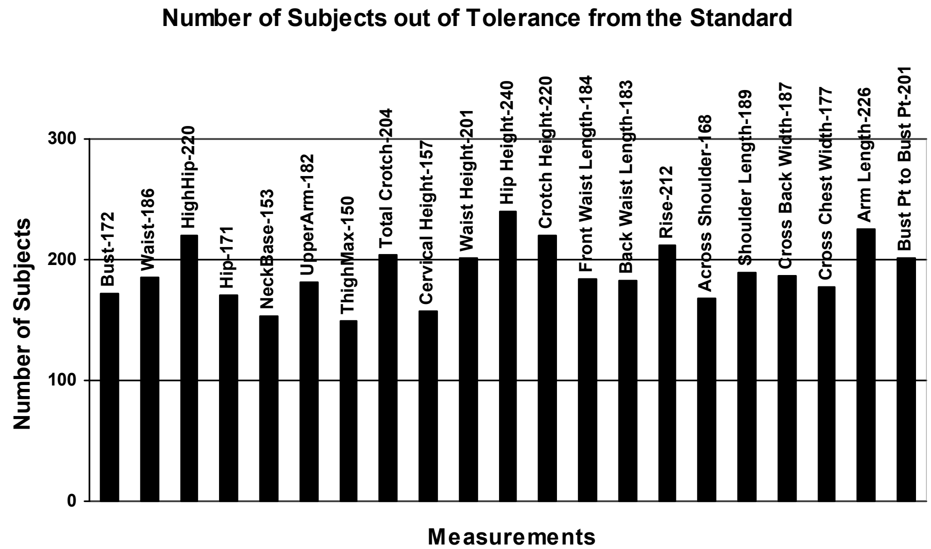


Figure 1. Tolerance difference for each measurement.

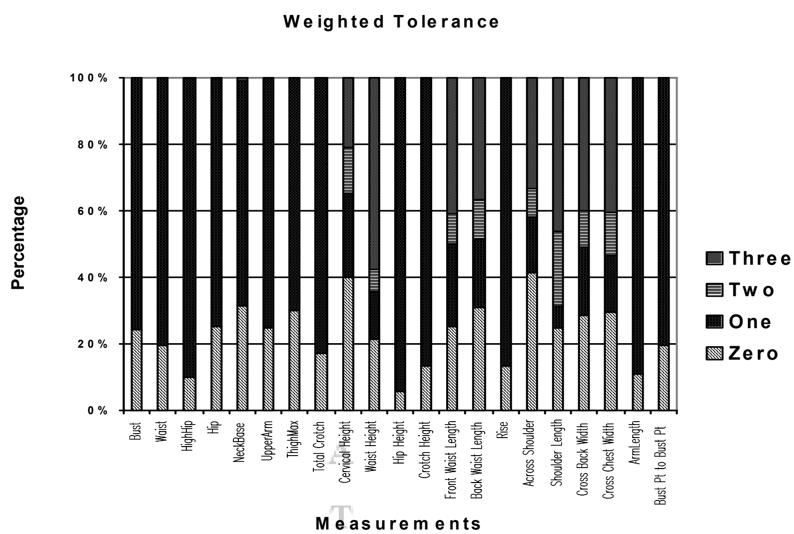


Figure 2. Weighted tolerance differences for each measurement.

Weighted Tolerance Results

When using the Tolerance Difference method, the standard that provided the 'Best Fit' for the largest number of subjects (over 50%) was the 55+ASTM 5586-95 standard. Figure 2 demonstrates that most of the subjects' measurements fell out of the tolerance limit by one level. This means that the subject's measurement values differed from the standard measurement values by less than twice the tolerance value. On an average, 23% of the measurement values fell within tolerance, 57% of the measurement values fell under the tolerance level of one, 5% of the subjects' measurement values fell under a tolerance level of two and 15% of the measurements fell above the tolerance level of two.

Based on these results, past and current sizing standards were determined to be significantly insufficient at describing the body shapes/sizes of most of the subjects compared in this study. Inconsistencies existed in more than 50% of the measurements compared within the one size that was determined to provide the "best fit" for each subject, regardless of the evaluation method used. These finding suggest that researchers could significantly impact consumer satisfaction with the fit of apparel by working to redevelop the sizing systems to more accurately reflect the shapes of today's consumers.

Shape Group Identification

The final objective of this research was to develop preliminary subgroups for the female population that would aid in the development of better fitting clothing. A comprehensive literature search was conducted to examine the elements or qualifiers for all of the pre-existing body shape classifications. The majority of methods used a simple visual process of classification with a vague list of descriptors to define the bodies that fell in each category. None of the methods used mathematical formulas, ratios, or expressions to aid in the determination of body shapes. The elements for shape classification determined from the literature search were used as a starting point for the shape descriptions. Once the basic shape categories were identified from literature, the relative visual and descriptive information was evaluated to help determine a mathematical logic that could successfully identify shapes. Using mathematical criteria and the tacit knowledge of experts in apparel design, development, and fit, a preliminary set of shapes with was defined with mathematical descriptors.

Initially, five shape categories were identified, "hourglass", "oval", "triangle", "inverted triangle", and "rectangle". Each category was given ranges of numerical values that corresponded to the body measurements that were significant for that shape. The "bust", "waist", "hip", "stomach", and "abdomen" circumferences were used in combination to describe each shape. After consideration of all of the available measurements that would describe the body, the basic ratios were essential circumferential measurements that were determined to be elemental for shape and for well fitting clothing.

A control data set of 31 females was obtained from $[TC]^2$ with unknown height, weight, and age information. This data was not part of the subject sample group. The mathematical shape definitions were initially tested on this group and yielded a subject in every shape group, indicating that the initial definitions worked.

When the 222 subject measurements from the developed database were tested using the shape definitions for the first time, many subjects did not fall into any category. This indicated that more categories were needed. As a result, four new categories were created that resembled shapes of a "spoon", "diamond", "bottom hourglass", and "top hourglass". Numerical values that corresponded to the body measurements that were significant to these new shapes were then developed. With the addition of these four new groups, now a total of nine groups, every subject fell into a shape category. In order to verify that all of the categories were correctly identified and the numerical values associated with each were accurate, the control data set was tested using the mathematical shape definitions with all shape categories being given an identifying shape. A visual check was made of each subject shape by our "expert panel" for verification that the shape identified by the mathematical definitions was theoretically correct.

Individual Shape Category Information

Hourglass shape. The Hourglass category was the basis from which many of the other categories were created. The body measurements used to define the Hourglass category were the bust, waist, and hips. The underlying criteria of the Hourglass shape says that if a subject has a very small difference in the comparison of the circumferences of the bust and hips AND if the ratios of bust-to-waist and hips-to-waist are about equal and significant, then the shape will be defined as Hourglass. The person with an Hourglass shape has the appearance of being proportional in the bust and hips with a defined waistline.

Bottom Hourglass. This shape category is a subset of the Hourglass category. The shape was determined by utilizing the same body measurements of the bust, waist, and hips, as in the Hourglass. However, there is a slight difference in the two categories. The Bottom Hourglass shape category utilizes the underlying criteria that if a subject has a larger hip circumference than bust circumference AND if the ratios of the bust-to-waist and hips-to-waist are significant enough to produce a definite waistline, then the shape will be defined as Bottom Hourglass.

Top Hourglass. This shape category is also a subset of the Hourglass category. The underlying criteria for the Top Hourglass shape category says that if a subject has a larger bust circumference than hips circumference AND if the ratios of their bust-to-waist and hips-to-waist measures are significant enough to produce a definite waistline, then the shape will be defined as Top Hourglass. The person with a Top Hourglass shape has the appearance of being heavy in the bust as compared to the hips but still has a defined waistline.

Spoon. The shape category of Spoon was determined by utilizing the body measurements of the bust, waist, hips and high hip. The Spoon shape category utilizes the underlying criteria that if a subject has a larger circumferential difference in their hips and bust AND if their bust-to-waist ratio is lower than the Hourglass shape AND the high hip-to-waist ratio is great, then that shape will be defined as a Spoon. The person with a Spoon shape is characterized by having a "shelf" at their hips. The waist tapers from the bust yielding a defined waistline but, starting at the waist going down, the high hip and hip project straight out to the side unlike other shapes that gradually taper from the waist to the hip area.

Rectangle. The Rectangle category was determined by utilizing the bust, waist, and hips circumference measures. The underlying premise for this category is that if the bust and hip measure are fairly equal AND bust-to-waist and hip-to-waist ratios are low, then the shape will be defined as Rectangle. The person with a Rectangle shape is characterized by not having a clearly discernible waistline. Therefore, the bust, waist, and hips are more inline with each other.

Diamond. The shape category of Diamond was determined by utilizing the body measurements of the bust, waist, hips, stomach, and abdomen. This category utilizes the underlying condition that if the average of the subject's stomach, waist, and abdomen measures is more than the bust measure, then the shape will be defined as a Diamond. The person with a Diamond shape is characterized by having several large rolls of flesh in the midsection of the body that protrude away from the body at the waist area. They appear to have a very large midsection in comparison to the rest of their body, almost having a tube-like apparatus wrapped around their waist.

Oval. This shape category was determined by utilizing the body measurements of the bust, waist, hips, stomach, and abdomen, just as in the Diamond shape. The person with an Oval shape is characterized by having several rolls of flesh in the midsection of the body and appears to have a large midsection in comparison to the rest of their body. The shape from the front view can be different for each subject but the side view is where the true characteristics of the Oval shape are seen. The Oval shape category utilizes the underlying criteria that, if the average of the subject's stomach, waist, and abdomen measures is less than the bust measure, then the shape category would be an Oval.

Triangle. The shape category of Triangle was determined by utilizing the body measurements of the bust, waist, and hips. The Triangle shape category utilizes the underlying criteria that if a subject has a larger hip circumference than their bust AND if the ratio of their hips-to-waist is small, then the subject can be identified as having a Triangle shape. The person with a Triangle shape has the appearance of being larger in the hips than the bust without having a defined waistline. This shape differs from the Bottom Hourglass because the Triangle does not consider the bust-to-waist ratio where the Bottom Hourglass does.

Inverted Triangle. The shape category of Inverted Triangle was determined by utilizing the same body measurements of the bust, waist, and hips as in the Triangle. The Inverted Triangle shape category utilizes the underlying criteria that if a subject has a larger bust circumference than their hips AND if the ratio of their bust-to-waist is small, then it will fall into the shape category of Inverted Triangle. The person with an Inverted Triangle shape has the appearance of being heavy in the bust as compared to the hips but not having a defined waistline. This shape differs from the Top Hourglass because the Inverted Triangle does not consider the hips-to-waist ratio where the Top Hourglass does.

Discussion

In this study, we have proven that the basic sizing systems are not adequate. Mass customization methodologies appear to provide a "solution" by allowing customized fit of apparel. A significant underlying problem exists, however, when attempting to alter a garment for fit based on one standard shaped garment product. "Extreme" alterations seldom provide the desired fit in the final garment. This discovery has led us to understand that optimal customization can only occur if customization starts from the most correctly shaped garment for each customer's "figure type". Thus a system was developed to identify female figure types using 3D body scan data. Such categorization of body types will allow a more appropriate reorganization of sizing systems with more successful attempts at customization and mass customization. This information will allow researchers to analyze body scan data relative to target market sizing, develop new shape categories not possible with 2-dimensional systems, and characterize body types for today's market. This process will allow us to use the most "correctly shaped" garment for the customization procedure that will better ensure satisfactory fit of the final garment.

The development of the shape categories required a stringent evaluation of all the variables that could potentially impact a person's shape and thus impact the fit of a garment. Combinations of variables were studied to determine their value in the development of new sizing systems or in the customization of clothing. We determined that the most benefit would be achieved by defining body shapes at the most elemental level.

Based on the premise that mass customization efforts will only be successful if customization starts from the most correctly shaped garment patterns, determining elemental, basic body shapes was vital. Any additional alterations that might be needed (based on other fit variables such as torso length, posture, bust development, knee skewedness, and others) could be fairly easily achieved using customization methods available in pattern development software. Inclusion of these additional variables in the definition of body shapes would have increased the number of body shapes exponentially and decreased the value of this research to the apparel industry and, ultimately, the consumer. The complication of the process would decrease its likelihood of adoption.

While this study was limited with the use of 1-dimensional measures extracted from 3-dimensional body scans, it was an essential beginning to the shape identification process. Since existing sizing systems and apparel design processes all use 1-dimensional measures, this limitation was considered reasonable. However, a significant advantage of 3-dimensional body scans is the wealth of data available in 3-dimensional form that could describe the human shape. To this point, the industry is unable to make efficient use of 3-dimensional data, which makes this study more immediately valuable to the industry. Future developments should certainly explore the powerful variety of data available from 3-D body scanning, in addition to developing means for its use.

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