NC STATE UNIVERSITY

JTATM

JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 4, Issue 3, Spring2005

Size-specific Analysis of Body Scan Data to Improve Apparel Fit

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ABSTRACT

This paper describes how size-specific analyses of body scan data of an apparel company's target market can provide information that can be used to adjust ready-to-wear sizing to improve apparel fit. We describe a variety of size-based statistical and visual analysis methods that can be applied to target market body scan data. These analyses begin to describe and address the variety of body shapes and measurements that exist within a sizing system and identify potential design adjustments that could be made in order to increase the percent of acceptable fit within each size category for a target market.

Keywords: apparel, body scan, fit, sizing system

Introduction

Apparel sizing and fit are difficult concepts to research and analyze as the relationship between the body and clothing is complex and often ambiguous. Current methods of creating sizes and analyzing garment fit are 1) based on measurements of one "ideal" customer embodied in a single fit model, 2) adjusted for additional sizes by using grade rules to define proportional increases and decreases from the base pattern, and 3) evaluated on the fit model visually and in two dimensions by comparing linear garment measurements to linear body measurements (Keiser & Garner, 2003). Although these methods are useful for evaluating simple garment fit issues, they are not adequate to investigate the complexities of the multifaceted relationship between the body and clothing for a large number of customers with a variety of body types within each size. It is not surprising that a Kurt Salmon Associates study reported that 50 percent of women claim they cannot find apparel that fits; other studies have indicated that fit problems are the reason for 50 percent of catalog returns (DesMarteau, 2000; Goldsberry, Shim, & Reich, 1996).

By definition, ready-to-wear clothing (RTW) is developed and offered for sale before potential customers select and try on styles of interest. RTW is offered in a variety of styles and stocked in a limited number of sizes, e.g., 4-16 for misses tops and bottoms or 32-44 for men's pants and suits. Most sizing systems are derived from ASTM standards (ASTM D5585-95, 1995; ASTM D6192-98, 1998; ASTM D6240-98, 1998; ASTM D4910-99, 1999; ASTM D 6458-99, 1999). However, individual firms have always interpreted the standards differently in order to distinguish their garments from their competitors' garments. In other words, size (and the resulting fit) is used as a marketing strategy. A size 10 at one firm is not the same as a size 10 at another firm, even when the style and some of the body measurements such as bust, waist, hip, etc. that the size is based on are identical. Body height and proportions of the fit model and the preferred "fit" established by the company explain the differences.

It would be easier for the RTW customers if all size 10's fit the same way. Unfortunately, it does not seem feasible for the apparel industry to shift to a standard sizing system that all firms agree to adopt as this would have the effect of decreasing consumers' fit choices. An alternative approach would be to improve each firm's unique sizing system to fit more people within the group that they consider to be their target market. The focus on a specific target market also allows the company to focus on the particular styles desired by that target market. An existing sizing system could be improved many ways. The following two seem most promising:

1. change the base size specifications to correspond more closely to the proportions of the majority of the people in the target market or
2. develop a new sizing system that may have six or eight sizes that are based on target market body and shape measurements rather than on proportional fit assumptions.

Both approaches are logistically and financially feasible using the 3D body scanner and computer-aided design (CAD) grading systems.

Applications of Body Scan Data in the Apparel Industry

The body scanner has the ability to obtain 3-dimensional data of the surface of the human body, providing valuable information to improve garment fit (Connell, Ulrich, Knox, Hutton, Trent & Bruner, 2003; DesMarteau, 2000; Simmons, Istook, & Devarajan, 2004a, 2004b). Most scanners collect over 300,000 data points as xyz coordinates and these data are now being analyzed in a variety of applications. Recent anthropometric research using body scan data has been conducted by consortiums in several countries with members across several industries (Computerized Anthropometric Research & Design Laboratory. 2004) or specifically in the apparel industry (Treleaven, 2004). The consortium members are provided with measurement information for thousands of people in age and gender categories for application by designers and manufacturers to improve the fit of garments. Body scanning technology has been applied in industry to improve garment fit by several well-known firms. For example, Brooks Brothers creates custom fit suits and dress shirts for men based on body scan measurements. Benchmark Clothiers (www.benchmarkclothiers.com) offers a business-to-business (B2B) service by deploying scanners to retailers so they can measure customers and offer made-to-measure apparel through partnership with Benchmark Clothiers.

Researchers at universities and in the armed forces are using a variety of approaches with body scan technology to analyze the complex relationship between the body and the fit of a garment. Examples include projects on scan measurement extraction and use (Pargas, Staples, & Davis, 1997), shape analysis and quantification (Connell et al., 2003; Jones, Li, Brooke-Wavell, & West, 1995), fit analysis (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004; Paquette, 1996; Whitestone & Robinette, 1997), use of scan data in a mass customization scenario (Fralix, 2001), and automated pattern making from body measurements (Kang & Kim, 2000). These are the pioneer studies of body scan data applications to improve garment fit. Generally, the objective of these studies is either

1. developing custom clothing from an individual's scan data and CAD patternmaking software and hardware
2. developing an improved sizing system that could be adopted by industry instead of the existing systems used by apparel firms

3. virtual draping on the body to create apparel patterns, either from a 2D pattern to a 3D virtual garment or *vice versa.*

Realistically, any large-scale use of body scan data to improve apparel fit will not be in custom clothing or industry-wide sizing system changes. Although Brooks Brothers' custom fit suits from scan data and Lands' End custom fit khakis and jeans from personal measurements have been great successes, the majority of apparel customers, especially women, have grown accustomed to having a broad selection of garments from which to choose based on style, color, and fit. They are accustomed to trying on a number of garments and selecting from them. Custom clothing requires imagination, prepaid commitment, and, currently, a limited number of garment type and style offerings. How could we improve fit without forfeiting the shopping model we use today? We argue that collecting body scan data from target market samples and using it to modify existing sizing systems used by individual firms will improve sizing for many consumers within the current shopping model.

The scan data used in research studies and industry applications to date are linear circumference measurements. The measurements possible with body scans are much more numerous and sophisticated than those taken with a tape measure; they are quicker, less intrusive, and can be more reliable. Body scanning technology collects approximately 300,000 data points as xyz coordinates that can be used to calculate circumferences, cross sectional slice areas, surface areas, and volumes. Combined with one dimensional measurements, a more complete set of indicators are available to quantitatively address problems of garment fit.

With 3D visualizations provided by cutting-edge computer software, we can also scan target market members in an apparel firm's actual clothing articles and virtually evaluate fit. Separating the visualizations by size and viewing them as sets—e.g., all size 10's or all size 14's together—helps us to begin to understand how many of the target market population can achieve good fit. Scans in each size can be sorted into like piles based on the fit problems identified visually or statistically. Problems that occur for many participants in one size and across sizes can be addressed with appropriate solutions to improve fit.

This paper presents size-specific research methodology and results based on one apparel firm's target market, the 34 to 55 year old woman, and a size set of pants in one style. The research question is:

How can a firm's existing sizing system be improved using size-specific visual and statistical analyses of body scan data, resulting in improved apparel fit for the desired target market?

A variety of visual and statistical analyses were conducted to consider which variables

4. contributed to differences between participants' body scans within sizes,
5. contributed to differences between body and pant scans of individual participants within sizes,
6. can be adjusted to lead to more acceptable fit ratings for the target market scans.

The Design Process: The Design of Sizing Systems

The design process was the foundation for our research. A sizing system is only as good as the method and creativity that go into the development of the system. The process of creating or modifying a sizing system (the design of the sizing system itself) can be addressed using a subset of the process used to design products.

Design methodology has been described as a process that allows for initial precise definition of the problem, stages of development using creative processes to generate ideas, and stages of development in which analysis and testing generate information to modify and choose among the ideas generated (Watkins, 1995). This is an iterative process, as each stage reveals new issues and concepts. Each iteration results in refinement and re-focus of the design based on the new information. In the case of designing or improving the design of a sizing system the design criteria are as follows: provide good fit for the greatest number of persons in the target market, use an economically feasible number of sizes in the system, and create a system that is understandable and easy to use (e.g., size selection) for the consumer.

In this paper we will discuss the middle stage of the process, the analysis and testing of the ready-to-wear (RTW) sizing system to generate information for improvements to the system. We are taking a sizing system that has already been implemented and evaluating the level of fit provided for each of the different sizes. Our plan is to analyze the results of the evaluation and ideate a new prototype sizing system based on scan measurements of the target market.

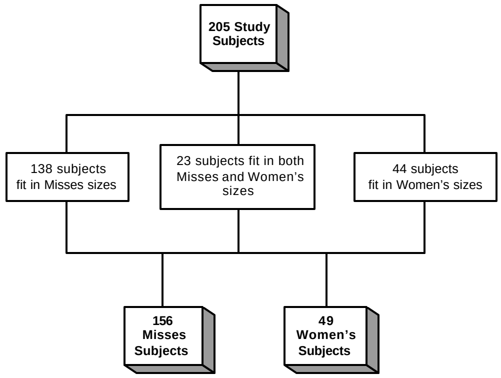
Methodology

An industry apparel firm provided test pants in two size ranges (misses 4-16 and women's 14-24), size specifications and grade rules for the pant styles, and two fit models' 3D scans and manual body measurements (the fit models were size 8 and 18). Participants were recruited using the firm's target market age range of 34 to 55 years and pant size. A questionnaire was used to collect demographic information from participants and information about participants' comfort with the body scan process and interest in scan applications (Loker, Ashdown, Cowie, & Schoenfelder, 2004; Loker, Cowie, Ashdown, & Lewis, 2004). The 205 female participants were representative of the target market with 60% married, 82% full-time workers, 66% holding a bachelor's degree or higher, and the majority with annual household incomes over $50,000. The mean age was 44.9 years and participants' ages were relatively equally divided across the four five-year age spans- 34-39 years (*n*=41), 40-44 (*n*=51), and 45-49 (*n*=65), and 50-55 (*n*=46).

Participants were scanned with a Human Solutions scanner on campus or in New York City with a rented scanner. Each participant was scanned twice, once with a Lycra scanning suit designed for this project to capture the minimally clothed body and a second time wearing test pants in the size with the "best fit" at the hip as determined by the researcher. A second pant scan was taken if it was difficult to determine the "best" fitting pant or the participant wore a size that overlapped between the misses and women's pant size ranges, i.e., 14 and 16. Participants who were scanned in multiple pants were later assigned to one "best fit" size by a panel of experts who assessed the visual fit using the 3D pant scan visualizations. Figure 1 displays the results of the size categorization, 156 in the misses and 49 in the women's pant size categories. The data analysis reported here will focus on the 156 participants who fit best into the misses sized pants.

Data Cleaning and Organizing

The Human Solutions/Tecmath VitusSmart scanner uses eight cameras and four laser light sources to record xyz coordinate data from the surface of the scanned object. Data from the eight camera views were transferred to Polyworks, a software package developed by Innovmetric, for processing, measuring, and displaying data in three dimensions. These data were merged and re-triangulated, eliminating redundant points. Any missing data (holes) in scans were then patched, as volume measures required a closed model. Polyworks software allows 3D visualization and measurement of circumference, surface area, volume, and cross sectional slice area. These measurements are similar to the Volume Index, Cross Sectional Index, and Signature Curve described in previous research on developing 3D models (Ng, Chan, Pong, & Au, 1995).



Size	Number of Misses Scans	Number of Women's Scans
04	32	
06	21	
08	20	
10	21	
12	24	
14	28	13
16	10	15
18		9
20		5
22		3
24		4

Figure 1. Sample population description.

Planes were set parallel to the floor at the abdomen, hip, crotch, and thigh, locating each plane according to specific visual landmarks. Frontal and sagittal planes were set to divide the body vertically. Tilted planes were set to capture the waistband of the pant. The following landmarks were chosen to set the planes for each participants: 1) center of the back, 2) natural waist indent in front, 3) abdomen at the greatest protrusion, anterior to the frontal plane, 4) crotch length measured from the center waist in front to the center waist in the back 5) hip at the greatest protrusion, posterior to the frontal plane and 6) thigh at 25mm below the crotch plane. The planes for each participant were visually set using the 3D visualizations of the pant and minimally clothed scans. The same plane set was used for both scans, ensuring that measurements from the two scans would be taken at the same level. Figure 2 illustrates this process of setting horizontal planes on a scan at the waist, abdomen, and hip as well as frontal and sagittal planes.

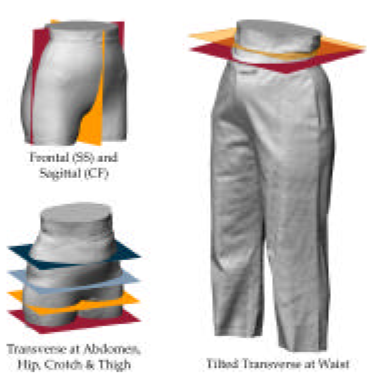


Figure 2. Landmarks defined by planes.

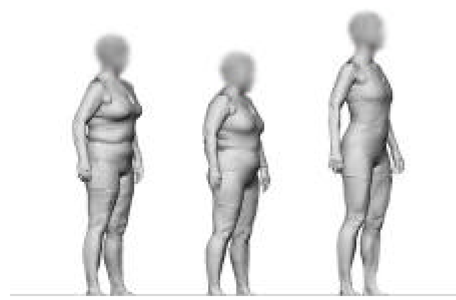


Figure 3. Three size 10 participants.

Data Analysis

Data analyses were conducted using both visual and statistical analysis approaches. Visual analysis was used to compare the minimally clothed scan with the pant scan in a fit evaluation process similar to traditional methods with a single fit model (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004). The objective was to identify visual clues concerning the level of fit or misfit within participants wearing the same "best" size pant. Fit ratings of acceptable, marginal and unacceptable were assigned both for specific areas of the pants and an overall fit rating based on stress folds and other visual indications of misfit.

Statistical analyses compared the measurements of the 1) minimally clothed participants to evaluate how well the existing size systems categorized like bodies, and 2) minimally clothed and pant scans of participants within each size to determine the ease values related to acceptable, marginal, and unacceptable fit.

Visual Analysis

Innovmetric's Polyworks software suite was used for measurements and scan visualizations. Most body scanners come with software that is designed to output specific measurements, usually one dimensional circumference measures. Polyworks provides more sophisticated 3D visualizations including data point, triangulated wireframe, and smoothed surface views. The smoothed surface visualization of the 3D data set was used in the visual analysis to assess fit or misfit and easily compare the minimally clothed and pant scans.

In 3D, the body surface data can be rotated to any angle or orientation in addition to the usual front, back, and side views. In addition, it is possible to zoom in for closer evaluation of the 3D surfaces. While we anticipated interesting visuals, we were surprised how different some of the body types were that fell within a single size. Figure 3 shows a snapshot of the minimally clothed body scans for three participants, all of whom were assigned to the size 10 "best" fit category. When apparel sizing systems are developed using only linear data and proportional grading, one can see how difficult it is to provide acceptable fit for all variations of women's' bodies.

Figure 4 shows the back view of two scans for one person: the minimally clothed and pant scans. The concurrent visual representation of the two scans makes a visual assessment of fit easier. The stress folds and corresponding body curves and bulges viewed without pants inform the analysis of pant fit. Additionally, wrinkles that indicate misfit in the pants can be analyzed using knowledge of the underlying body shape shown in the minimally clothed scan. For example, sometimes we found that body bulges were not a result of a tight pant waistband but, rather, were caused by poorly fitting underwear.

Figure 4. Visual comparison of minimally clothed and pant scans.

Fit Ratings

One of the unique approaches to analyzing body scan data in this research is using the scan visualizations to analyze fit and misfit. Using computer visualization tools, three experts in apparel fit analyzed the pant scans of all participants visually on a computer screen and rated the front and back overall fit of the pants (Ashdown et al., 2004). During the process of reviewing pant fit, two subjects of the original 205 were removed from the fit analysis because of extreme body asymmetry, one participant fitting in the misses size category and one fitting into the women's size category. Due to the small participant count in the larger women's size category, the analysis focused on the measurements and visual fit ratings for the misses size category.

Two approaches were explored using these ratings to investigate the relationship between body and pants, or misfit, in order to find predictive strategies that could be used to identify acceptable fit: 1) analysis of fit ratings by size and 2) analysis of fit ratings based on ease values. This paper only presents the fit ratings by size.

Fit Ratings by Size

To analyze the fit ratings by size, the percentage of acceptable, marginal, and unacceptable ratings within each size was calculated. Figure 5 displays some of the results. In general, most of the sizes did not fit the participants well, with almost half of the overall ratings in the marginal or unacceptable categories. The marginal fit in sizes 12, 14, and 16 was especially notable. The greatest number of acceptable ratings existed in sizes 6, 8, and 10 as might be expected as the size specifications were based on a size 8 fit model. We found a number of participants too small for size 4, the smallest size of pant, explaining the relatively high number of participants with unacceptable fit in that size.

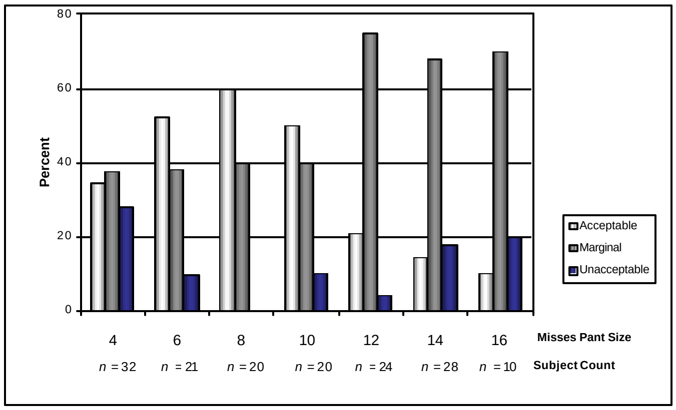


Figure 5. Percent overall fit ratings within size (*N* =155).

Cross-tabulations of the fit ratings by size were run for the critical fit locations standard in pant pattern making: waist, waist location, abdomen, hip, crotch length, and thigh circumferences. Significant differences across sizes were calculated using the chi-square statistic in order to identify problem fit areas by size. The crotch and below buttocks ratings were mostly unacceptable for all sizes indicating a fault in the basic pant pattern at the crotch. The smaller sizes were rated with relatively high acceptable fit across all critical fit locations except the crotch and below buttocks ratings. These ratings indicate that the smaller sizes were closer in proportion to the fit model than the larger sizes and, perhaps, that smaller sizes are easier to fit with flatter body curves.

Significant differences across the waist and abdomen pointed to fit problems in sizes 12 and 14 with many more marginal and unacceptable ratings than the smaller sizes. Figure 6 illustrates the ratings across sizes for these critical fit locations. The hip fit also had significantly more marginal ratings for size 14. These results indicate the potential for transforming marginal fit to acceptable fit with some minor pattern making or grading adjustments.

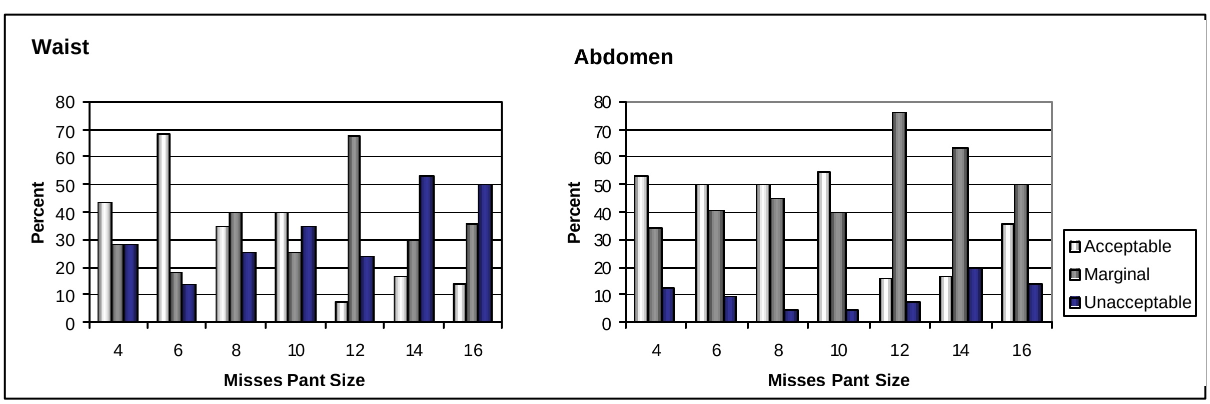


Figure 6. Percent fit rating within size at waist and abdomen (*N* = 155).

The process of fit rating based on visual evaluation and size categorization identified problems within some sizes and not others. The results point out problems with proportional grading assumptions that underlie most pattern development systems. Additional 3D measurements and statistical analyses may lead to specific adjustment of size specifications within each size that will provide acceptable fit for more people in the target market.

Statistical Analyses with 2D and 3D Measurements

The IMEdit module of the Polyworks software suite was used to set landmark planes at critical fit locations in order to collect measurements from the scan data in addition to visually assessing the pant fit. Figure 7 illustrates the visual representation of the measurements taken for each scan. The circumference measurements reflected traditional tape measure values, taken in millimeters. The cross sectional slice area and surface area measurements described the variations in shape between body and pants using area in squared millimeters. The volume measurements were calculated in millimeters cubed. Statistical normalization techniques were used to control for the multi-dimensional nature of the measurements.

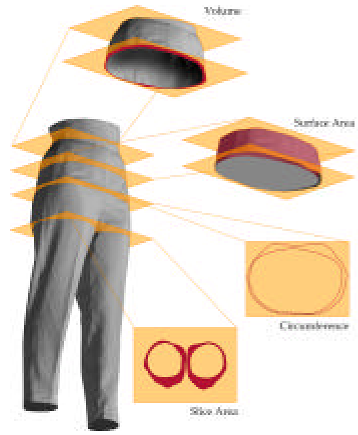


Figure 7. Circumference, surface area, slice area and volume measurements.

Cluster Analysis

The objective of our statistical analysis was to group study participants based on their body measurements and then compare those groupings to the actual pant size worn. Twenty measurements were calculated and used in order to group the subjects. A K-Means cluster analysis was run in SPSS in order to group participants according to similarities of measurements. Eight separate cluster analyses were run, generating participant cluster membership when given from two to nine grouping categories. Each K-Means cluster result was evaluated to determine the ideal number of grouping categories. We found that five seemed to be the most ideal and that the difference between the four and five cluster runs was most interesting.

Table 1

Cluster Analysis of Body Measurements for Participants Wearing Misses Pant Sizes (N=156)

			Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5	
			Mean	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
z-scores	Circumference	Natural Waist	0.25	0.37 [a]	-1.09	0.44 [b]	1.73	0.46 [c]	-0.34	0.37 [d]	1.08	0.35 [e]
		Top of Waistband	0.31	0.36 [a]	-1.11	0.45 [b]	1.76	0.43 [c]	-0.34	0.35 [d]	1.03	0.38 [e]
		Bottom of Waistband	0.40	0.38 [a]	-1.17	0.44 [b]	1.72	0.29 [c]	-0.30	0.30 [d]	0.98	0.44 [e]
		Abdomen	0.40	0.40 [a]	-1.15	0.43 [b]	1.67	0.57 [c]	-0.27	0.48 [d]	0.91	0.36 [e]
		Hip	0.83	0.26 [a]	-1.25	0.44 [b]	1.62	0.41 [c]	-0.22	0.33 [d]	0.58	0.42 [a]
		Thigh	0.87	0.45 [a]	-1.17	0.55 [b]	1.44	0.63 [c]	-0.21	0.44 [d]	0.49	0.55 [a]
	Slice Area	Natural Waist	0.21	0.35 [a]	-1.06	0.39 [b]	1.79	0.53 [c]	-0.37	0.36 [d]	1.08	0.40 [e]
		Top of Waistband	0.27	0.33 [a]	-1.07	-0.38 [b]	1.85	0.51 [c]	-0.37	0.32 [d]	1.02	0.41 [e]
		Bottom of Waistband	0.36	0.37 [a]	-1.14	0.38 [b]	1.80	0.33 [c]	-0.33	0.28 [d]	0.98	0.47 [e]
		Abdomen	0.34	0.42 [a]	-1.10	0.37 [b]	1.76	0.64 [c]	-0.31	0.45 [d]	0.92	0.40 [e]
		Hip	0.75	0.27 [a]	-1.22	0.39 [b]	1.73	0.45 [c]	-0.27	0.33 [d]	0.63	0.43 [a]
		Thigh	0.87	0.49 [a]	-1.15	0.50 [b]	1.48	0.69 [c]	-0.24	0.43 [d]	0.48	0.57 [e]
	Surface Area	Top of Waistband to Bottom of Waistband	0.31	0.33 [a]	-1.12	0.37 [b]	1.85	0.33 [c]	-0.35	0.28 [d]	1.01	0.40 [e]
		Top of Waistband to Abdomen	0.20	0.51 [a]	-0.97	0.44 [b]	1.65	0.99 [c]	-0.31	0.55 [d]	0.92	0.48 [e]
		Abdomen to Hip	0.94	0.51 [a]	-1.11	0.58 [b]	1.25	1.07 [a]	-0.15	0.45 [c]	0.33	0.57 [d]
		Hip to Thigh	0.66	0.39 [a]	-1.15	0.47 [b]	1.70	0.62 [c]	-0.27	0.37 [d]	0.63	0.54 [a]
	Volume	Top of Waistband to Bottom of Waistband	0.33	0.36 [a]	-1.11	0.38 [b]	1.82	0.42 [c]	-0.35	0.31 [d]	0.99	0.40 [e]
		Top of Waistband to Abdomen	0.08	0.66 [a]	-0.78	0.47 [b]	1.45	1.38 [c]	-0.27	0.63 [a]	0.80	0.73 [d]
		Abdomen to Hip	0.90	0.73 [a]	-0.65	0.65 [b]	0.35	1.88 [acd]	0.01	0.60 [c]	-0.13	0.83 [bcd]
		Hip to Thigh	0.57	0.46 [a]	-1.07	0.48 [b]	1.72	0.81 [c]	-0.29	0.42 [d]	0.62	0.61 [a]
		Ordinal Pant Size	12.74	1.13 [a]	4.44	0.84 [b]	15.33	0.98 [c]	8.13	1.53 [d]	12.54	1.56 [a]
	Subject Count	Size 4 *n* = 32	-		32		-		-		-	
		Size 6 *n* = 21	-		9		-		12		-	
		Size 8 *n* = 20	-		-		-		20		-	
		Size 10 *n* = 21	1		-		-		15		5	
		Size 12 *n* = 39	15		-		-		-		24	
		Size 14 *n* = 28	11		-		5		-		12	
		Size 16 *n* = 10	-		-		10		-		-	
		N = 156	27		41		15		47		26	

Note. Superscripts unique to one cluster indicate a significant difference between that cluster and all others at $p<0.05$. A set of common superscripts indicates that the cluster is not significantly different from those clusters with any of the common superscripts.

The four cluster solution had one very large cluster with a large range of values. The five cluster solution essentially broke that single cluster into two (Cluster 1 and 5 in Table 1) and provided five clusters with better count distribution and smaller standard deviations within each cluster. ANOVA results from the five cluster solution are reported in Table 1 using *z*-scores of the measurements in order to eliminate unit issues among the multi-dimensional dataset. Using the *z*-scores, we then compared how the pant sizes distributed among the cluster groups.

Table 1 displays statistically significant differences using superscripts unique along rows (across clusters). For example, when all values in a row have a unique superscript (i.e., a, b, c, d, and e), there are statistically significant differences among the means across all clusters for that measurement. When there are common superscripts within a row, there are no statistically significant differences for the clusters that share the same superscript. For example, for hip circumference, Cluster 1 and 5 both have the superscript *a* indicating that there is no significant difference in the mean hip circumference between these two clusters. Most *z*-scores increased in the following order based on cluster mean values: from Cluster 2, with the lowest negative values of sample mean ($z = 0$) for most variables, to Cluster 4, Cluster 1, Cluster 5, to Cluster 3 with the highest positive values of sample mean. Compared to the pant size data at the bottom of the table, this ordering roughly equates to the ascending pant size.

We were interested to see how the clustering membership related to pant size. We found that all size 4 participants and some size 6 participants were categorized in Cluster 2, with the smallest measurements. The cluster with the next largest measurement values, Cluster 4, included participants with size 6, 8, and 10 "best fit" pants. Clusters 1 and 5 both included participants wearing primarily size 12 and 14 "best fit" pants. All participants wearing size 16 pants and some wearing size 14 were categorized into Cluster 3.

The additional two and three dimensional measurements included in our analysis essentially point to sizes that may have significantly different body types which were currently unaccounted for in the original sizing system. In other words, the additional measurements grouped participants together differently. Instead of all participants from one size being grouped into the same cluster, we found that five clusters seemed better than seven clusters, the number of groupings in the original sizing system. In addition, we found several instances of two or three sizes being grouped in a single cluster. An analysis of the differences across clusters for participants of the same size can give us clues about the variation within an existing size group.

Clusters 1 and 5 both included participants with "best size" pants of 10, 12, and 14. Looking at the significant differences between these two cluster variables, it appears that Cluster 5 has significantly larger waist and abdomen *z*-scores than Cluster 1 for almost every measurement. The hip and thigh measurements, however, were not significantly different. These results suggest that the cluster analysis might be describing body type variations. Cluster 1 might include more study participants with hourglass figures and while straighter figures where grouped into Cluster 5. It also seems that the height between the abdomen protrusion and the buttocks protrusion influenced some of the statistical differences in volume for the two clusters.

Cluster 4 had three different sizes of participants grouped together, sizes 6, 8, and 10 with the most even distribution of sizes within the cluster. In addition, Cluster 4 had the highest subject count of all clusters. Two possible explanations for these results are that

7. these sizes are the closest grade to the fit model and thus would have less variability and

8. the body types in these sizes are similar to the body type of the fit model.

All Cluster 4 measurements were significantly different to all other clusters except the abdomen to hip volume and top of waistband to abdomen volume measurements.

We turned to visual analysis to further investigate these interesting divisions that appeared from the volume measurements. Figure 8 shows a sample of size 12 participants in Cluster 1 and Cluster 5 and illustrates the impact of landmark definitions as an indicator of body shape now possible with 3D datasets. The highlighted bands show how the vertical spread between the abdomen to hip planes can significantly affect the volume measurement. The two landmark planes are set as horizontal planes at the point of greatest protrusion on the lower torso, anterior to the frontal plane (the abdomen) and posterior to the frontal plane (the hip). These differences in body shape revealed through this analysis may be one reason for significant fit variations within a single size.

These results have led us to consider including the vertical distance between planes as a measurement in future analyses. Recent new software capabilities have also allowed us to begin automating the landmark identification process which will ensure better repeatability, accuracy, and measurement validity.

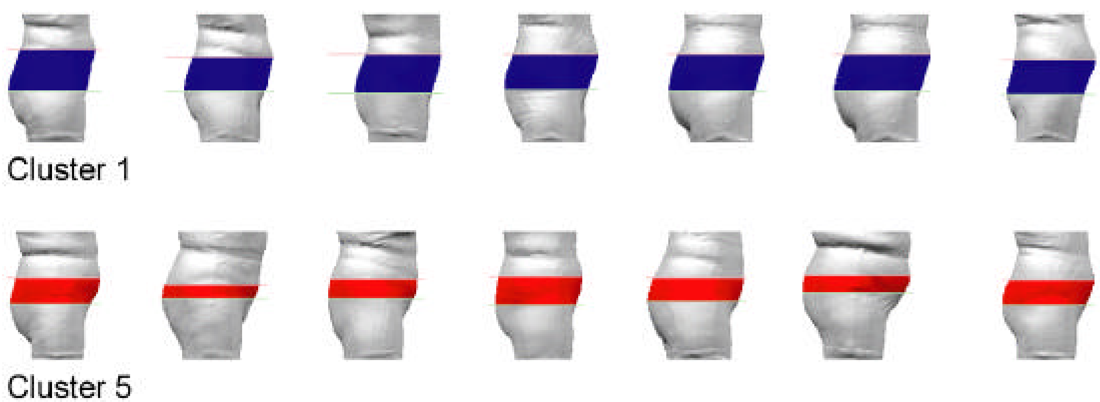


Figure 8. Abdomen to hip volume of misses size 12 participants in Cluster 1 and 5.

Visualizations of the cross sectional slice areas also show interesting trends in body shape among participants of different sizes at the waist, abdomen, and hip landmarks. Figure 9 shows the variation of waist cross section shapes for the different size groups within each size category (abdomen points towards the bottom of each image—imagine you are looking down at a body from above and you can see their belt).

In addition to general shape trends across sizes, it can also be informative to see the cross sectional slices for a specific body area superimposed with participants of different sizes. Figure 10 shows the superimpositions of the waist, abdomen, and hip slices for four participants who wore pant sizes 4, 12, 16, and 20W. Notice the variation in shape across the sizes, from a flat elliptical shape to more heart shaped in the larger sizes. Interestingly, it seems the shape is relatively similar across all three areas within a size, just changing in dimension. With additional shape information, we have been able to obtain visual clues helping to guide our statistical analyses which have the potential for significantly improving fit for a substantial portion of a target market within each size.

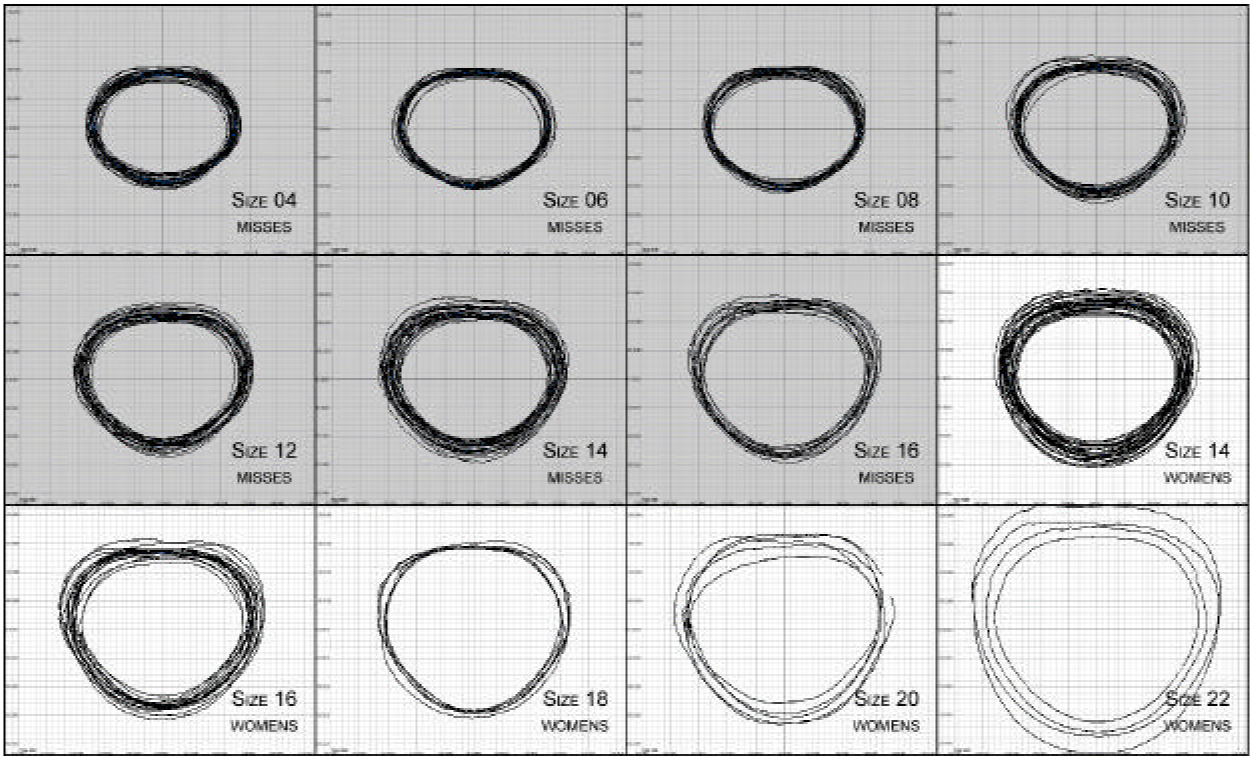


Figure 9. Shape variation in waist slices across misses and women's sizes.

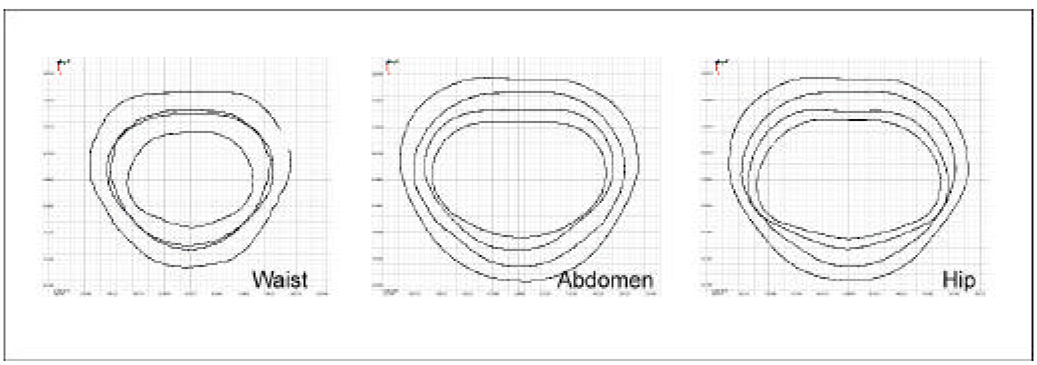


Figure 10. Shape variation across sizes 4, 12, 16, and 20W at waist, abdomen, and hip.

We can conclude from these results that it is very possible that significant fit improvements can be possible without adding additional sizes. The two and three dimensional measurements now possible with 3D body scan technology may prove essential in improving existing RTW sizing systems by enabling more intelligent groupings of the target market without increasing the number of sizes. In addition, the measurements from 3D body scans have the potential to be used to develop entirely new sizing systems based on quantitative measurements and body variations specific to a particular target market.

Conclusions and Implications

Using body scan technology, we have investigated the pant fit of 156 participants with the "best fit" pant in the misses size category. In this target market, 34 to 55 year old women, current sizing systems offer an acceptable fit to about only about half of the 156 participants based on fit ratings by three experts. Our visual and statistical analyses have helped us identify the most problematic fit areas of the waist and abdomen. In addition, it seemed clear that there were fit issues specific to particular sizes. We will continue to identify critical adjustments for existing patterns based on new 2D and 3D measurements available from body scan data. We expect the most benefit to come from applying specific adjustments to individual pant sizes resulting in an improvement to the existing RTW sizing system.

Visual analysis ratings are relatively easy to conduct using body scan data. Fit ratings were assigned by experts using a database form and 3D smooth surface visualizations of the minimal clothing and pant scans, following a process similar to those currently used in fit analysis sessions with a single fit model. Comparing the minimally clothed scan side-by-side to the pant scan clearly seemed to aid in the fit assessment process. Visual analysis offered a qualitative assessment of fit, typical of fit sessions, except with a much larger range. Fit assessments were performed for 156 participants in seven different size categories, essentially evaluating the pant fit on 156 fit models instead of one. Visual analysis using 3D scan data also aids in validating the accuracy of the fit ratings by being able to average independent expert fit evaluations. The participant's fit ratings in each size cell can also be averaged instead of relying on the assessment of fit based on a single fit model. Statistical analyses can be conducted on these data when the number of participants in each size cell is about 20. Chi-square and percent analyses pointed to the waist and abdomen as the critical fit areas with the most problems in achieving acceptable fit for the test pants.

Cluster analysis offered an alternative categorization of the target market participants based on 2D and 3D body measurement data in addition to one dimensional circumference measurements. We determined an ideal five clusters based on 20 measurements and compared the cluster membership to size groupings. We found that with the additional measurements available with body scan data, the participants were separated into five instead of the original seven size categories and two or three original size groups were represented in each cluster. Again, the waist and abdomen measurements seemed important in defining the cluster categories. The cluster analysis results explained some of the reasons that the existing sizing system for our industry partner only fit about half of our research participants. The traditional sizing systems based on proportional size grades from the size specifications of a single fit model do not reflect the measurements of a target market. By analyzing scan data for an existing size, we can recommend adjustments specific to each existing size or propose a new approach to developing an improved sizing system for our industry partner.

Potential applications of these findings require several shifts in the way industry approaches apparel sizing. Body scan technology and analysis of its data are required, and the application of the iterative design process to the refinement of sizing systems provides the method for using these new data. Greater knowledge of the company's own target market's body measurements can be applied to adjust existing sizing systems at each firm to provide more of its customers acceptable fit. Once the improved or new sizes are on the market, firms will need to develop consumer education and marketing strategies to guide consumer product selection.

Body scan technology and the visual and statistical analyses proposed here require numerous participants as representative members of an apparel firm's target market and two scans of each participant (minimally clothed and clothed in the firm's clothing in the size of best fit) to evaluate fit. The basic strategy is to adjust existing sizing systems based on actual fit data of the company's own target market. This requires about 20 participants for each expected size category, that is, at least 140 for a misses size range from 4-16. The increased availability of portable body scanners such as the scanner recently developed by TC^2 will facilitate this type of analysis by the industry (www.tc2.com). Manufacturers and retailers can rent or purchase a scanner to rotate around several of their flagship stores. Consumers who are shopping and trying on their brand can be recruited for scanning. Scanning can be made an exciting event by emphasizing its high-tech nature, offering a cash stipend or discount coupon, or promoting its contribution toward better-fitting clothing. Alternatively, large manufacturers and retailers could scan employees, categorizing them by target market and size and essentially using them as size-specific fit models.

The size-focused data analysis could be conducted in-house or by consulting businesses that specialize in sizing and fit research. SizeUSA members already have access to body scan measurement data of the target market of their choice from the SizeUSA database of 12,000 scans of men and women. Although the actual 3D scans to conduct the proposed visual analysis are not available, the proposed and other statistical analyses could be conducted and applied to a firm's existing sizing system.

Consumer education and marketing strategies will be needed to describe the sizing changes and guide customer selection in order to fulfill the objective of creating a system that is understandable to and easy to use by the consumer. Good fit will become the mantra for progressive apparel firms similar to the historic marketing campaign for Calvin Klein Jeans and the current sizing success of Chico's. The high tech nature of the development will attract fashion innovators and young consumers. The potential for better fit will interest women who have struggled to find clothing that fits.

Firms considering an investment in the application of body scan data for improved fit should consider their apparel styles and target market as well as financial and human resource requirements. Apparel that is either very closely fit or very loosely fit may not benefit from this research as much as styles that are of moderate fit. Target markets of young people may be less concerned about what experts consider acceptable fit and more concerned with the fit based on current fashion and cultural norms. Target markets of middle age and older women may be very willing to participate in scanning for the expressed purpose of achieving acceptable fit. Target markets of men desiring custom clothing may be interested in scanning, though the majority of men may be uninterested as men have traditionally expressed fewer problems finding good fit in apparel. Promotions that explain the new sizing to consumers and retail sales associates will be vital to the success of this new orientation to sizing development. As size is a very personal and somewhat sensitive product characteristic, marketing campaigns should focus on advantages of acceptable fit and how to find the right size.

It is clear that body scanning technology can help us to improve apparel fit. Applications for it in the industrial setting are still unfolding. We expect progressive firms to be able to use scan data to add value to their RTW product and we have proposed some approaches that may help them in their journey.

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